Using the machine learning models to optimize time management in logistics and supply chain management systems

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Abstract

In today's world, where market competition is prevalent, industrial companies must be competitive by producing and selling high-quality products while providing excellent service. Establishing logistics systems helps solve specific problems related to optimizing production activities and maximizing the efficiency of managing processes that create value for consumers. In this research we explained how to optimize and manage the time of delivering company's orders in the best method using machine learning models like Linear regression and data visualization tools these provide a good result to minimize the time and the cost of logistics services. This optimization process achieves the organization's goals and magnitudes the business benefits in the logistics sector.

Keywords

Machine learning, optimize logistics process, supply chain optimization, time management, data analytics, ML Algorithms

1. Introduction

In today's competitive environment, the revolution in information technology, economic globalization, and increasingly high customer expectations have led to significant changes in company supply chain management (SCM). It has become evident that the competition is not between individual companies but between supply chains as a whole [1], [2]. SCM involves actively integrating supply chain activities, from initial suppliers to end users, to deliver services, products, and information that maximize customer value and provide sustainable competitive advantage. In the age of big data, large volumes of interactive data are constantly being created, collected, and stored in various manufacturing industries [3]. This data is crucial for operations, management, and process design. Using this data judiciously and extracting information and knowledge from it has the potential for significant gains. The immense volume of data across various components of SCM has compelled companies to develop and implement new technologies that can quickly and intelligently process large amounts of data [4]. Traditional decision support systems need to be improved for handling big data, necessitating the exploration of new, more effective technologies. As a result, supply chain professionals are seeking to harness big data to create intelligent supply chains in the era of big data.

Artificial intelligence (AI) methods are best suited for addressing significant data challenges. Machine learning (ML) methods, a popular discipline within AI, automatically identify and extract patterns from large datasets [5]. Machine learning algorithms can uncover hidden patterns, provide new insights, and guide researchers in various fields such as manufacturing, operations, healthcare, and housing [6].

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Additionally, machine learning plays a vital role in managing different aspects of the supply chain. Recent interest in machine learning algorithms has emerged in supply chain management applications due to the limitations of traditional methods in analyzing big data. Machine learning methods have high capabilities in analyzing and interpreting large datasets, addressing non-linear problems common in genuine supply chains, and working with extensive, unstructured data from various supply chain areas. Therefore, a compelling case exists for replacing traditional and machine learning methods.

On the other hand, machine learning techniques have been created to handle large amounts of unstructured data. Machine learning methods are also significantly more effective than traditional statistical approaches in identifying and predicting the most impactful supply chain performance factors. Therefore, machine learning is crucial for companies to analyze large datasets in their supply chain management SCM.The supply chain optimization problem has prompted many proposed techniques and applications.

Still, they often need to be more specific or knowledge-intensive to be implemented as an inexpensive, user-friendly computer system. Implementing an optimization system for a new problem instance requires significant effort and expert personnel involvement, with low levels of automation. This project aims to develop strategies to increase automation in creating a new optimization system by focusing on multi-objective optimization, optimization algorithm usability, and optimization model design [7].

However, machine learning (ML) is strictly based on pattern recognition research in the 1980s. The field stagnated for quite a long time due to technical limitations. Just a few years ago, ML underwent a breakthrough caused by developing much more powerful processors. The new technical standard enabled software engineers to work with complex algorithms. Furthermore, companies are already recognizing the value of ML when it comes to optimizing their business or saving costs. Algorithms can process more data than humans, more quickly derive patterns and models from them, and make more accurate calculations and forecasts. The emerging automation reduces routine work and frees up resources for value-adding activities and additional investments [8].

2. Literature review

There is a strong need in the literature to explore the various applications of ML techniques in different parts of the supply chain and logistics services, as most of the work has dealt with one, two, or limited areas of the supply chain. For example, Wenzel et al., they applied machine learning techniques to develop an automated supply chain management (SCM) structure [9]. Also, Lin et al., introduced the application of artificial intelligence in Supply chain management [10].

Flores-García et al., presented a comprehensive assessment of literature that analyzes the technological capabilities of smart production logistics (SPL) when using machine learning (ML) to increase logistics skills in dynamic contexts [11]. Pasupuleti et al., they leveraged the advanced machine learning (ML) techniques to enhance logistics and inventory management [12]. Odimarha et al., they applied the machine learning models to the companies in the oil and gas sector to improve operational efficiency [13]. Youn et al., they used Data Analytics and Machine Learning the improve the logistics services [14]. Hudnurkar et al., calculated the Delays for Truck Delivery Logistics using machine learning models [15].

However, there needs to be more focus on conducting a comprehensive study to look at the applications of ML in various related aspects of the supply chain, which may impact the understanding of how these valuable techniques can be effectively used in managing various aspects of SCM [16]. Therefore, this article develops a framework in which the most commonly used ML algorithms for managing different areas of the supply chain will be discussed. The main contributions of the article are summarized as follows:

(i) By comparing the effectiveness of traditional and AI methods when dealing with big data.

(ii) By reviewing, summarizing, and classifying the most commonly used artificial intelligence techniques in SCM.

(iii) Providing a detailed framework to explain the results of applying ML methods in supplier selection and segmentation, supply chain risk forecasting and demand and sales assessment, production, inventory management, transportation and distribution, sustainability (SD), and circular economy (CE).

3. Research methodology

The field of machine learning (ML) and supply chain management (SCM) has seen many applications of research, but there is still a need for more research on applying ML algorithms in supply chain and logistics management. There is also a need for more communication between researchers and practitioners in this field, possibly due to practitioners requiring more knowledge about the benefits of ML algorithms in solving SCM problems. This section will provide an overview of applying popular ML algorithms to address supply chain challenges such as sourcing, supplier segmentation, supply chain risk prediction, demand and sales estimation, manufacturing, inventory management, and transportation.

Machine learning involves using statistical modeling to solve problems without explicitly programming rules and instructions. This approach differs from traditional programming, where preset rules are applied to existing data to obtain the desired result. In machine learning, the data is known in advance, and the goal is to discover previously unknown rules to achieve the desired outcome. This modern problem-solving approach can be precious in general business, especially supply chain management. The complexity of a supply chain, with its numerous hidden and variable factors, can make it very challenging or even impossible to model using traditional methods.

Machine learning involves five main steps at a high level:

1. Data collection (feature selection)
2. Data preparation (function development)
3. Model selection and training
4. Model evaluation
5. Forecasting

Analytics and predictive modeling can be utilized at nearly every stage of the supply chain to facilitate efficient and precise sales, operations, and inventory planning. Here are the details:

- Procurement: Predictive modeling can be employed to determine the equilibrium between supply and demand and identify cost drivers.
- Production: Quality control and optimized planning based on inventory and production stage opportunities.
- Warehousing: Workload optimization, stock relocation.
- Transportation: Route optimization and planning.
- Consumer: Credit scoring, recommendation systems, fraud detection.

Furthermore, Linear regression is a machine learning technique to predict a continuous numeric target variable, This method is straightforward, yet it effectively captures the linear or near-linear relationships between the features utilized in the model. Understanding linear regression is essential as it is the foundation for more advanced methods.

Also, classification is one of the most common tasks in machine learning. It involves building models that assign the object of interest to one of several known classes. Hundreds of classification methods are available to predict the value of a response with two or more classes. The question arises whether this set of methods adequately meets the needs of solved problems.

Learning and Prediction:

Once the data is split into training and test sets, the final step is to train the decision tree algorithm and make predictions. Scikit-Learn contains a tree library with built-in classes/methods for various decision tree algorithms. Since we are performing a classification task, we will use the Decision Tree Classifier class in this example. The fit method of this class is called to train the algorithm on the training data.

In summary, in this research machine learning (ML) is an application that enables IT systems to identify patterns and characteristics of existing data using self-learning algorithms. These algorithms are based on statistical models and allow for predictions, classifications, and exploration of underlying patterns. In simple terms, these algorithms help automate complex calculations to facilitate better decision-making.

In this research we utilized two datasets "NYC Taxi Trip Duration", and " Amazon Delivery analysis" from Kaggle.

4. Research results and discussions

At this section, we will explain the application of machine learning algorithms that we discussed in the research methodology section, the application of machine learning algorithms generates more finding that can facilitate the optimization of logistics services like the time management of orders' deliver and others. As shown in Fig. 1, The scatter plot depicts the actual trip durations on the x-axis and predicted trip durations on the y-axis. Most points are clustered near the origin, indicating shorter trip durations. However, some predicted values, such as negative durations, need revision, suggesting the model struggles with outliers. Many points deviate from the red line, especially for longer trips, indicating potential underprediction or overprediction. Outliers show extreme deviations, indicating issues with the model or data. Consider data cleaning, feature engineering, and algorithm tuning to improve the model's performance.

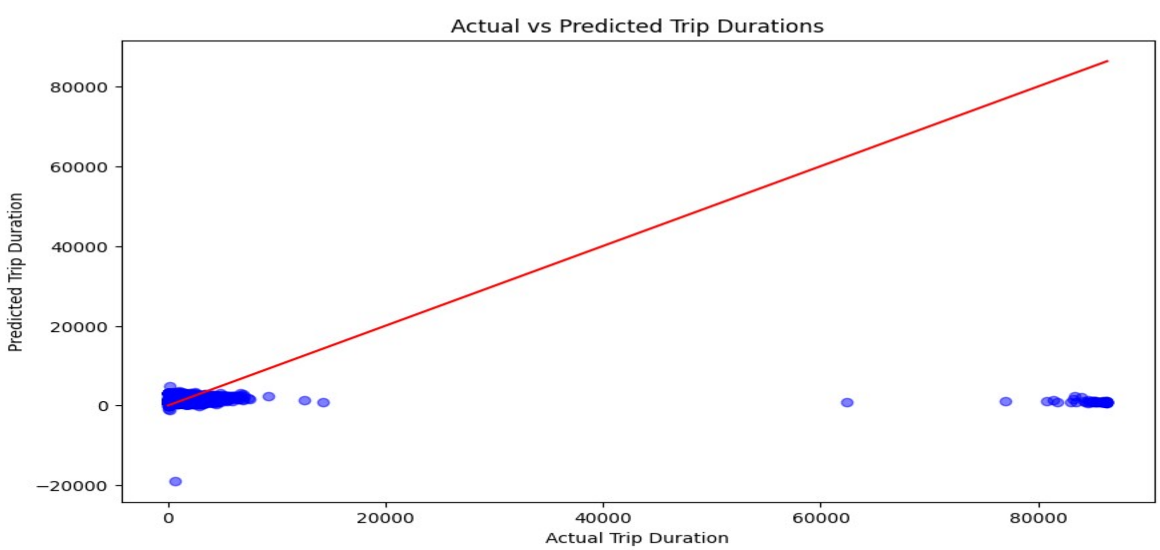

Figure 1: Visualising the Linear Regression results.

The histogram in Fig. 2 displays delivery time distribution, with most deliveries between 130-150 minutes. This suggests a right-skewed pattern, indicating occasional longer delivery times. Machine

Learning models can utilize this data to predict delivery times, detect anomalies, optimize resources, and improve estimated time of arrival accuracy. These insights can optimize logistics operations, leading to better efficiency and customer satisfaction. Lastly, interpreting delivery time distributions through the lens of ML can enhance logistics management systems, improving time management, resource allocation, and customer satisfaction within the industry.

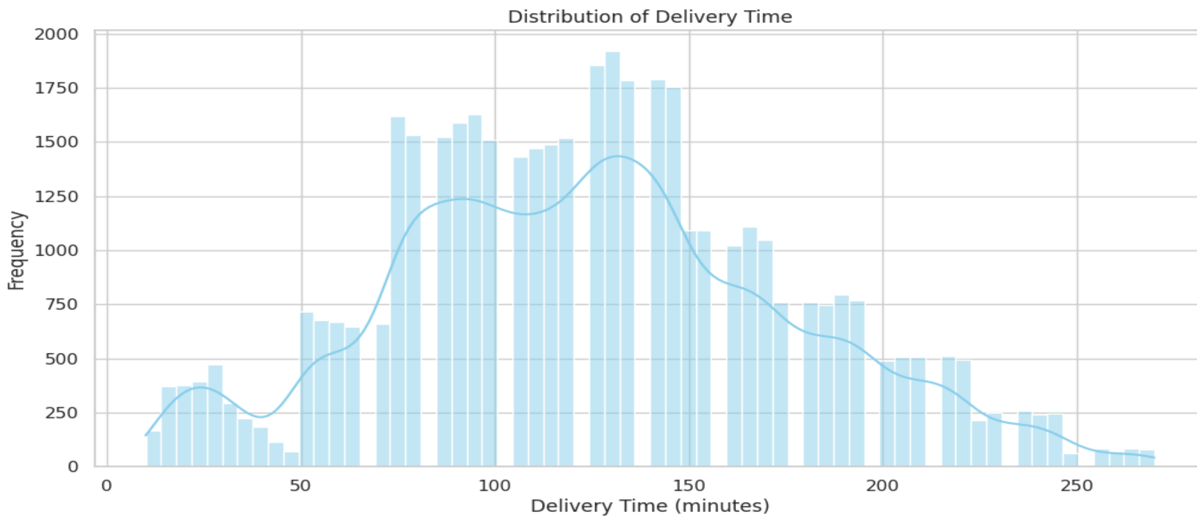

Figure 2: Visualization of the distribution of delivery times (dataset source from Kaggle).

The box plot in Fig. 3 shows that adverse weather conditions such as storms, fog, and wind lead to longer and more variable delivery times. Machine Learning (ML) models can use this data to optimize time management by predicting delivery times, allocating resources dynamically based on weather conditions, optimizing routes during bad weather, and proactively informing customers about potential delays. Weather data integration helps enhance operational efficiency, reduce delays, and improve customer satisfaction in logistics.

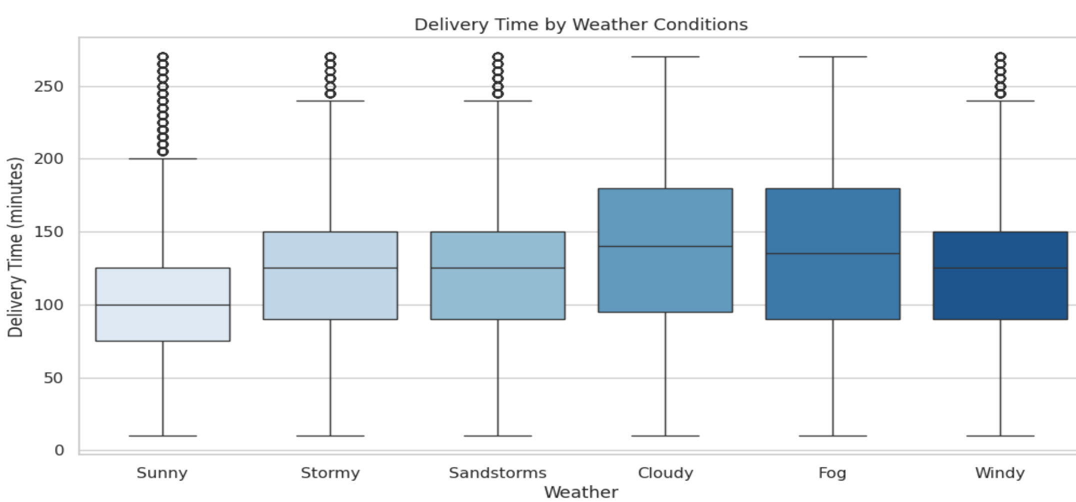

Figure 3: Analyses of the impact of weather on delivery time.

The box plot in Fig 4. shows that delivery times vary based on traffic conditions. Key insights include:

- Traffic Impact: Jams and medium traffic lead to longer and more variable delivery times, while low traffic results in shorter and consistent delivery times.
- Outliers: High and low traffic have significant outliers, indicating occasional extreme delays.
- -In the Machine Learning (ML) context for Logistics, traffic is a feature where ML models can use real-time traffic data to predict delivery times more accurately.
- Dynamic Routing: Models can optimize routes to avoid traffic and minimize delays.
- Resource Management: Understanding traffic patterns helps allocate resources effectively for timely deliveries.
- Proactive Adjustments: ML can trigger alerts and adjust ETAs when traffic conditions change. Integrating traffic data into ML models significantly enhances time management, improving the reliability and efficiency of logistics operations.

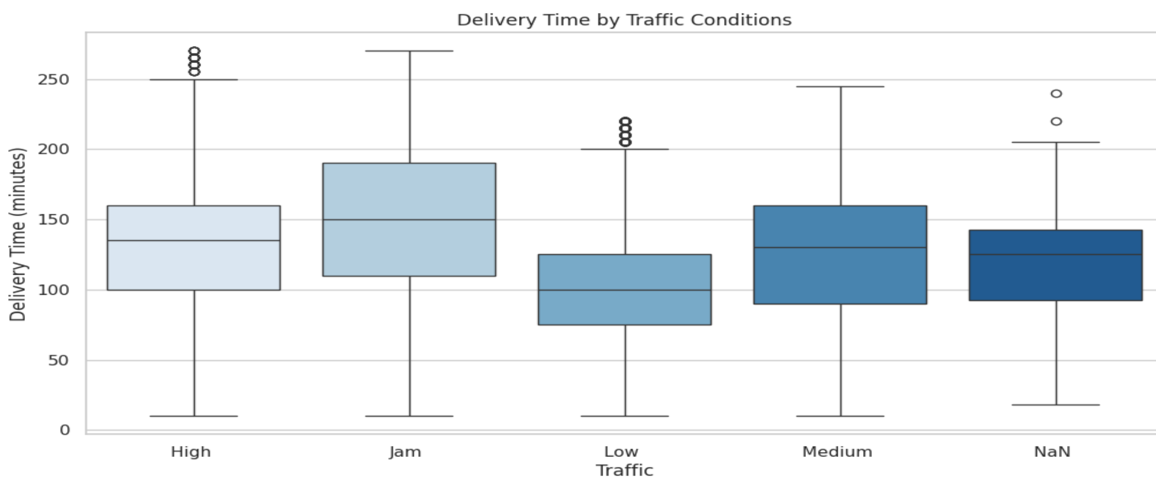

Figure 4: Analysis of the impact of traffic on delivery time.

The box plot in Fig. 5, "Delivery Time by Vehicle Type" shows the distribution of delivery times for different vehicles. Motorcycles have the lowest median delivery time and the smallest variability. Motorcycles generally have the fastest and most consistent delivery times. Keep in mind that other factors like traffic conditions and delivery distance can also affect delivery times.

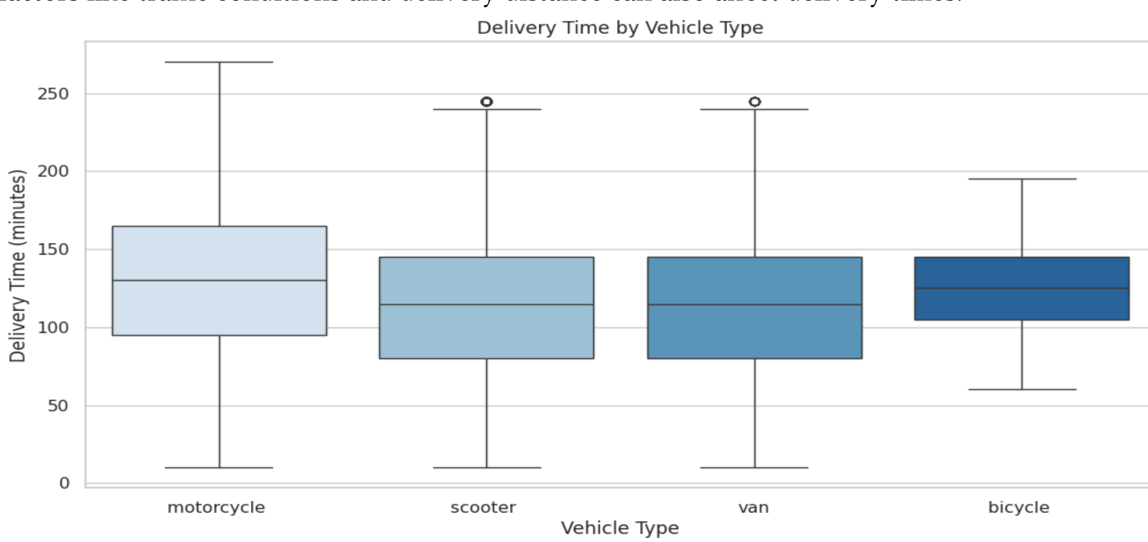

Figure 5: Analysis of the impact of vehicle type on delivery time.

The box plot chart in Fig 6. illustrates delivery time distribution across four geographical areas: urban, Metropolitan, Semi-Urban, and Other. Key findings show that urban areas have the shortest and most consistent delivery times, while Other areas have the slowest. Factors like traffic conditions and delivery distance can also impact delivery times, as can be seen. With the future advent of Drones in delivery, it is most likely that these challenges will be highly mitigated soon.

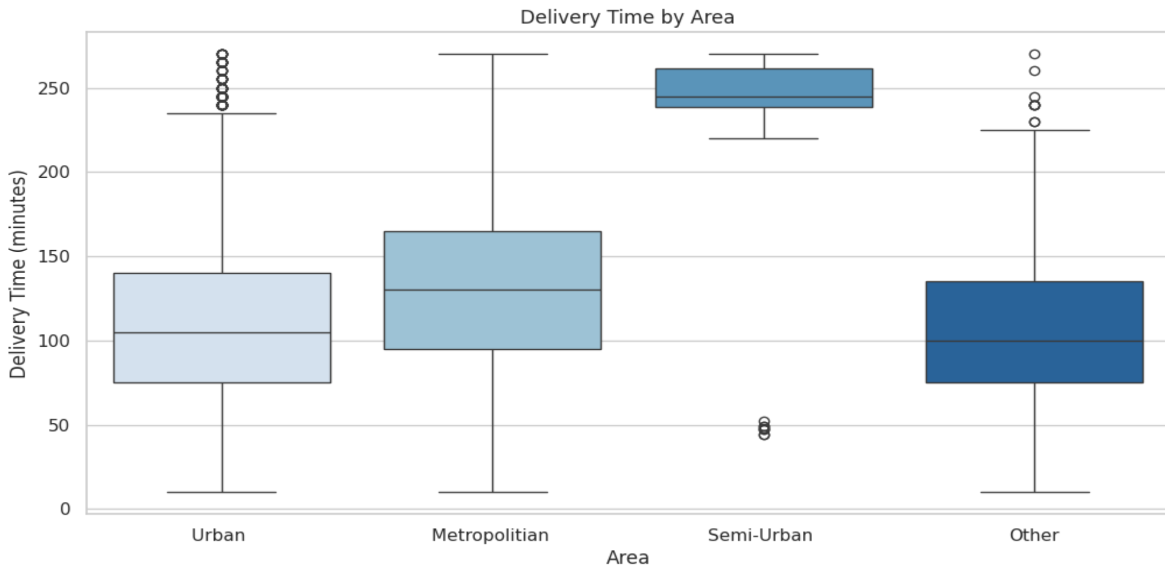

Figure 6: Analyses of the impact of an area on delivery time.

The scatter plot in Fig. 7, shows the relationship between delivery time and the distance between the store and the drop-off location. Key Observations include the following:

- No Strong Correlation: There is no clear linear relationship between delivery time and store-drop distance.
- Delivery Time Variation: Delivery times vary significantly even for similar distances.
- Outliers: Some data points with high delivery times, even for shorter distances, might represent exceptional circumstances or errors. The chart indicates that factors beyond store-drop distance are needed to predict delivery time accurately. Other factors like traffic conditions, delivery mode, or order complexity likely play a more significant role. Additional Considerations such as: - Data Distribution: Analyzing the distribution of delivery times for different distance ranges could provide deeper insights. - Other Factors: Including additional variables like time of day, day of the week, and order type could help uncover hidden patterns and improve the understanding of delivery time factors.

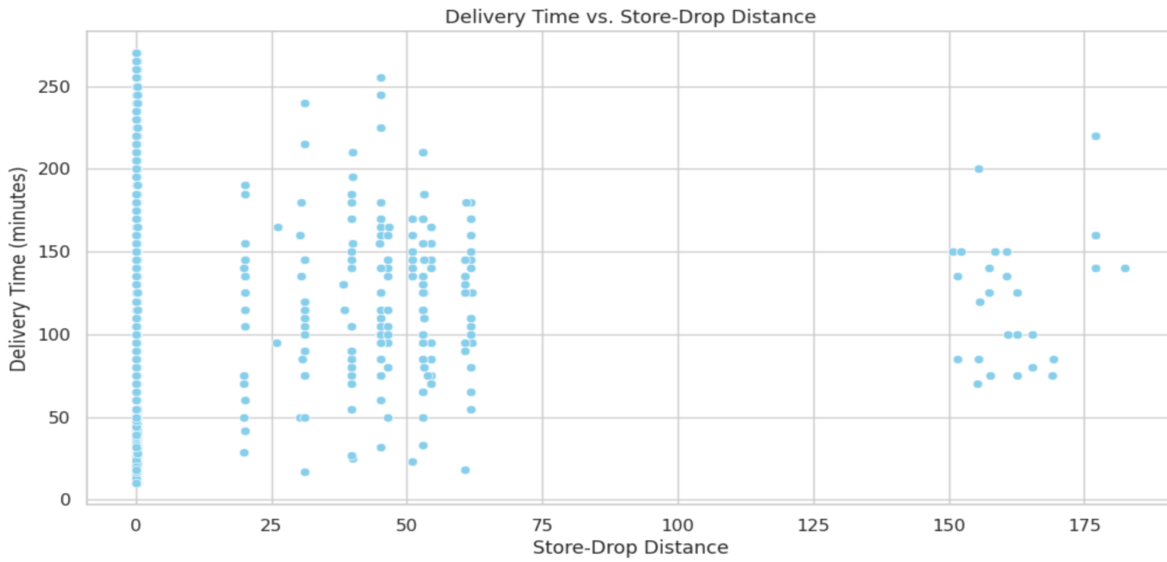

Figure 7: Visualization of the relationship between store distance and delivery time.

Future Directions

With the possibility of future advancement in AI and ML, as can be noticeably viewed in the present trends in cutting-edge development, the actualization of self-autonomous vehicles and drones that could further enhance time management in LMS is almost in sight. Also, the integration of IoTs and Big Data Analytics will provide ML models with even more granular insights to optimize time management in LMS.

5. Research conclusion

Applying machine learning (ML) models in logistics management systems (LMS) represents a pivotal shift in logistics operations, offering a beacon of hope in the face of increasing pressure to deliver faster, more efficiently, and with greater precision. ML integration into LMS optimizes time management and presents a powerful solution to these challenges, inspiring optimism for the industry's future and human life transformation. Throughout this article, we have explored the potential of some ML models, including supervised learning models like linear regression and data visualization. These models empower logistics companies to make informed decisions, improve operational efficiency, and optimize critical areas like route planning, demand forecasting, inventory management, and dynamic scheduling, instilling a sense of confidence in their capabilities in LMS.

However, the journey toward fully optimized Logistics Management Systems through ML has challenges. Issues related to data quality and availability, integration with existing systems, and ethical and privacy concerns must be carefully addressed. High-quality data is essential for accurate ML predictions, while seamless integration with legacy systems ensures that ML solutions can be effectively implemented. Moreover, logistics companies must navigate the ethical implications of data usage, ensuring compliance with privacy regulations and avoiding biases in ML models. The integrity of its sources, which is directly proportional to its value, demands the utmost attention.

Looking ahead, the future of logistics management systems will be shaped by continuous advances in AI and ML, as well as the growing influence of the Internet of Things (IoTs) and big data. These technologies will not just enable the creation of intelligent logistics networks but also revolutionize the industry, making it capable of real-time decision-making, autonomous operations, and hyper-personalization. As AI becomes more sophisticated and IoT devices generate ever-larger datasets, logistics companies can optimize their operations with unprecedented precision and agility, sparking excitement for the future.

In conclusion, machine learning holds the key to unlocking new levels of efficiency and effectiveness in logistics management systems. By embracing ML, logistics companies can significantly improve their time management and gain a competitive edge in an increasingly complex and demanding market. The path forward involves leveraging ML's power and addressing the challenges and considerations that come with it. As the logistics industry continues to evolve, those who successfully integrate ML into their operations will be well-positioned to lead the way into the future of logistics, instilling a sense of optimism and excitement for what's to come.

Declaration on Generative AI

The authors have not employed any Generative AI tools.

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