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AI-Powered Route Optimization System in Supply Chain Operations

Rudrendu Kumar Paul[1], Bidyut Sarkar[2]

[1]Boston University, Boston, MA, USA, 02215

[2]IBM, NY 10504

Abstract: ***Addressing the considerable challenge of last-mile delivery optimization in e-commerce and supply chain enterprises, this paper presents a data-centric strategy intended to boost the efficacy of both B2C (business-to-consumer) and B2B (business-to-business) deliveries. The proposed approach utilizes demand pattern analysis, data integration, and customizable constraints to generate delivery routes that minimize costs and enhance customer satisfaction. The method's versatility allows for adjustments based on market characteristics and specific timeframes, offering a solution adaptable to varying supply chain scenarios. The proposed approach enables businesses to tailor the optimization process to their unique requirements, enhancing operational efficiency, maximizing cost savings, and improving customer service. The novel method delineated in this paper signifies a remarkable advancement in efficient last-mile delivery management, offering a wealth of key insights that hold relevance for both academic researchers and industry practitioners.***

Keywords: Artificial Intelligence, Data Science, Last-mile Delivery Optimization, Supply Chain Management, Route planning, Demand pattern analysis, e-commerce, logistics

1. Introduction

In supply chain operations, the last-mile delivery segment signifies the transportation of products from distribution centers to their terminal points, such as residences for B2C or business establishments for B2B shipments. This phase frequently accumulates substantial expenses and duration due to the intricacy and variability of delivery points, traffic, and meteorological conditions (wind, temperature, snow), among other elements. With the ongoing growth of e-commerce and the rising consumer anticipation for on-time and trustworthy deliveries, the optimization of last-mile delivery routes has become a pivotal concern for supply chain and e-commerce businesses.

This paper intends to formulate a data-driven technique to refine last-mile delivery routes, specifically focusing on independent courier services that have pre-negotiated rates with supply chain and e-commerce companies. Through the application of data science methodologies and adjustable constraints, the suggested method aims to maximize the effectiveness of last-mile delivery, paving the way for cost reduction and improved customer service for both B2C and B2B shipments.

In subsequent sections, the paper delves into the procedure of identifying demand patterns, assimilating data from diverse sources, and delineating constraints and aims for improving the delivery route statistics. It further details the creation of the optimization algorithm and introduces a modifiable analysis adaptable to varying markets and durations. The paper concludes by providing a visual flowchart illustrating the sequential optimization process and delineating steps to develop the proposed strategy in a practical environment.

2. Identifying Demand Patterns

Understanding demand patterns is a crucial step in optimizing last-mile delivery routes, as it enables companies to allocate resources effectively and make informed decisions on route planning. This section describes the process of discerning demand patterns across varied markets in the US, the formation of area clusters, and the visualization of these patterns employing heat maps.

2.1 Distribution and last-mile delivery patterns of the US market

Several factors, such as population density, regional preferences, weather, and seasonal variations, influence the supply chain distribution and delivery patterns in the US market. To gain insights into these patterns, we collected historical data on delivery volumes, frequency, and destinations.

2.2 Analyzing data from the past two years to identify demand trends

Delivery data spanning the last two years served as the basis for the analysis of demand trends. This time frame ensured the capture of both short-term fluctuations and long-term seasonal patterns in a region's demand. The derived data enabled the identification of high-demand regions, delivery frequency, and any potential trends that could impact route optimization.

2.3 Aggregating Zip Codes to Form Area Clusters

To streamline the analysis and elevate the efficiency of route planning, zip codes were aggregated into area clusters based on geographical proximity and delivery demand patterns. This step made it possible to group nearby areas with similar demand characteristics, facilitating more effective route optimization.

2.4 Visualizing Demand Patterns with Heat Maps

Heat maps were utilized to visualize the identified demand patterns, providing an intuitive way to comprehend the distribution of delivery demand across various markets. These heat maps helped identify high-demand zones, regional variations, and potential bottlenecks in the delivery network. This visualization technique also served as a valuable tool for communicating the findings to stakeholders and decision-makers involved in the route optimization process.

By discerning demand patterns, the groundwork is established for the data-driven optimization of last-mile delivery routes. These demand patterns help guide the development of the routing plan and enable the adjustment of constraints and business objectives, resulting in more efficient and cost-effective last-mile delivery routes.

3. Data Collection

The effectiveness of route optimization is contingent on the accessibility and precision of pertinent data. In this section, the paper discusses the procedure for gathering route delivery metrics, consolidating multiple data sources, and segmenting the data to enable route optimization.

3.1. Procuring Last-mile Route Delivery Statistics from Third-party Carrier's Internal Database

Third-party data sources from third-party carriers who were responsible for the last-mile deliveries for the supply chain or e-commerce company were utilized to gather route delivery statistics such as delivery times, distances, and the number of stops made by drivers. This data provided valuable information on the existing delivery routes and enabled the identification of areas for improvement.

3.2. Merging Multiple Data Sources and Internal Databases

To obtain a comprehensive view of the delivery network, data from multiple sources were integrated, including third-party route statistics, internal databases housing customer information, supply chain company's distribution hub number, last-mile delivery hub numbers, delivery routes, and geographical data for zip codes. This integration enabled the establishment of a strong foundation ion for the route optimization process by providing a detailed understanding of the current delivery network and its performance.

3.2. Segmenting Data by Market Names and Associating Route IDs

To expedite the analysis and optimization of delivery routes, the compiled data was segmented by market names, representing various regions and cities in the US. Subsequently, route IDs were associated with each market, which allowed for the analysis and optimization of routes within specific markets. This method permitted a more focused analysis, taking into account the unique characteristics and demand patterns of each market.

It should be noted that the accuracy of the process is dependent on the timeliness of the inputs (recency of data) utilized in the resultant routes by gathering and integrating data from multiple sources during the optimization process. By combining various data sources and segmenting the data by market, a more detailed analysis of delivery routes is enabled, ultimately resulting in more efficient and cost-effective last-mile deliveries.

4. Constraints and Objectives

For effective optimization of last-mile delivery routes, it becomes vital to outline constraints and objectives that align with practical experiences and company-specific requisites. Customizable constraints permit the optimization process to cater to different supply chain scenarios and ensure the routes generated are both efficient and in compliance with company norms. In this section, the paper delineates the constraints and objectives employed in the proposed route optimization method.

4.1 A list of Constraints for Route Optimization is given below.

The following customizable constraints, grounded in practical experiences, were established to steer the optimization process:

Maximum delivery time per driver (8 hours): This constraint ensures that drivers do not exceed their daily working hours, preventing potential overtime costs and promoting driver safety.

Maximum number of stops per route (90): Limiting the number of stops per route helps maintain efficient delivery schedules and prevents driver fatigue.

Maximum number of boxes delivered per route (150 boxes): A restriction on the number of boxes delivered per route guarantees driver safety and deters drivers from rushing through work to meet their goals related to the delivery timeline.

Maximum route distance (250 miles): This constraint helps minimize driver fatigue and the total distance traveled, reducing fuel costs and vehicle wear.

4.2 Considerations for Overtime Pay and its Impact on Operational Costs

While the constraints aim to prevent excessive work hours, it is essential to consider the potential impact of overtime pay on operational costs. If drivers exceed the maximum delivery time constraint, the resulting overtime costs can offset the benefits of route optimization. As such, the optimization algorithm should prioritize compliance with the time constraint and local market labor laws on maximum allowable work hours to minimize operational costs.

4.3 Prime Objective: Clustered Driver Route Deliveries

The primary objective of the route optimization process is to create clustered driver route deliveries. By clustering deliveries in close proximity, the method aims to minimize travel distances and time, which ultimately yields more efficient routes and reduced operational costs.

5. Route Optimization Algorithm

The core of our proposed route optimization method is an algorithm that automates the process of finding efficient delivery routes while adhering to the defined constraints and objectives. This section will cover the development of the optimization algorithm and its main features.

5.1 Calculate the cross-product of the distance between all delivery stops.

The algorithm computes the cross-product distances between delivery stops by utilizing the latitude and longitude data of each location. This step allows the algorithm to assess the proximity of stops and identify potential clusters.

5.2 Optimize driver routes based on constraints.

The algorithm uses the calculated distances and the customizable constraints to optimize driver routes. By considering the maximum delivery time, number of stops, number of boxes, and route distance constraints, the algorithm generates routes that maximize efficiency while adhering to the established limitations.

5.3 Cluster deliveries for optimal route planning

As the primary objective is to create clustered driver route deliveries, the algorithm identifies groups of delivery stops that are close together and assigns them to individual routes. This approach minimizes the distance traversed by drivers and the total time for the deliveries on each route, resulting in more efficient and cost-effective delivery routes.

6. Customizable Analysis

The proposed route optimization method offers a tailored analysis feature that allows supply chain companies to adapt the optimization process to their specific needs. This adaptability is crucial for addressing the unique challenges and characteristics of different markets and timeframes.

6.1 Customizable constraint values

Users can adjust the constraint values, such as maximum delivery time or maximum number of boxes, to better align with their company policies and requirements. This flexibility enables the optimization process to be tailored to a wide range of supply chain scenarios.

6.2 Customizable start and end dates for analysis

The method allows users to select different start and end dates for the analysis, accommodating seasonal variations and other time-sensitive factors. By adjusting the analysis period, companies can better understand how demand patterns change throughout the year and adjust their route planning accordingly.

The algorithm's development and the tailored analysis feature enable the route optimization process to be both effective and adaptable. By considering various constraints, objectives, and user-defined parameters, the proposed method can generate efficient and cost-effective delivery routes that cater to the unique needs of e-commerce and supply chain companies.

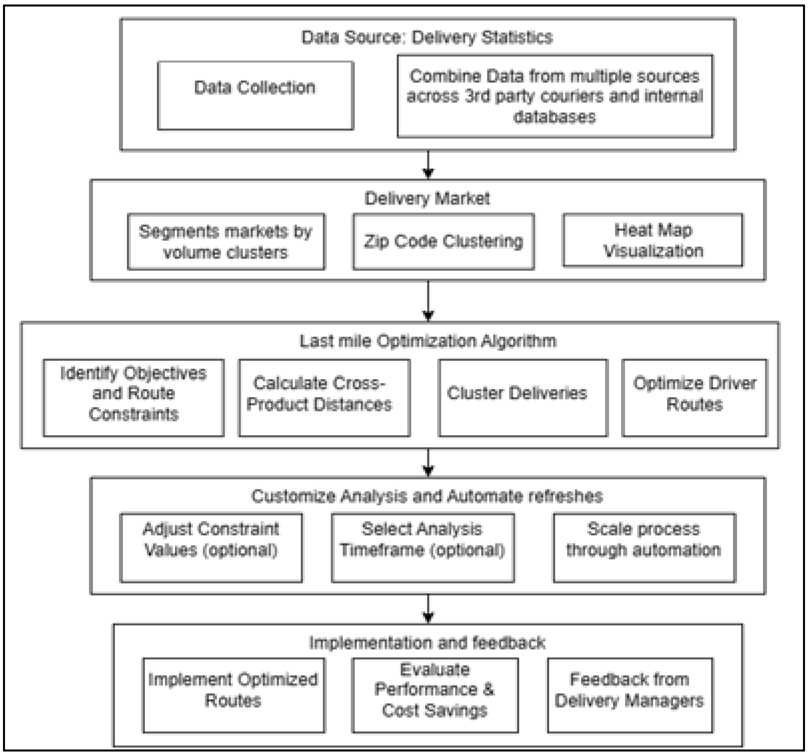

Figure 1: Flowchart illustrating the process of optimizing last-mile delivery routes for enhanced efficiency and cost savings in supply chain and e-commerce companies

7. Flowchart for the Optimization Process

Figure 1 provides a schematic representation of the route optimization process. It begins with the primary data source: delivery statistics. These statistics are then combined with data from multiple sources, encompassing both third-party couriers and internal databases in the data collection phase. The next stage in the process involves segmenting the markets by volume clusters. This includes creating clusters based on the zip codes of the delivery areas. The resulting clusters are then visualized via a heat map to allow for easier interpretation of the data and the demand patterns.

With the segmented and visualized data at hand, the next stage involves identifying objectives and route constraints, an important step in the proposed optimization algorithm. These objectives and constraints are designed to guide the route optimization process, ensuring it aligns with company policies and operational realities. The algorithm then calculates the cross-product distances between delivery stops, allowing for an assessment of the proximity of stops to each other. The optimization of driver routes occurs next, with the algorithm utilizing the previously calculated distances and constraints to generate efficient routes. Subsequently, the algorithm clusters the deliveries to optimize route planning further. Once the optimized routes have been determined, the system allows for customizable analysis and automated refreshes of the process. This could include adjusting constraint values or selecting different timeframes for analysis. This stage of customization and automation helps to scale the process and adapt it to various scenarios and time periods.

After the optimization process, the next step is implementation. The optimized routes are utilized for delivery operations, and the system collects feedback from delivery managers. This real-world testing and feedback allows for performance and cost savings evaluation, determining the effectiveness of the route optimization in actual operational conditions. Finally, the cycle can repeat, with feedback and data from the new routes feeding back into the data collection phase, allowing for continuous refinement and optimization of the delivery routes.

8. Conclusion

This paper presents a data-driven approach for optimizing last-mile delivery routes in supply chain and e-commerce companies, with a focus on both B2C and B2B deliveries. By harnessing demand patterns, integrating data from various sources, and setting customizable constraints, the proposed method generates efficient delivery routes that reduce operational costs while enhancing customer service. The versatility of this approach is highlighted by its adaptability, enabling a tailored analysis according to different markets and timeframes. This adaptability presents a versatile solution capable of addressing multiple supply chain scenarios. By allowing customization of analysis parameters, the proposed method provides businesses the freedom to align the route optimization process with their specific needs and operational constraints. The proposed approach affords substantial benefits to e-commerce and supply chain companies by fostering efficiency, reducing costs, and maintaining high levels of customer satisfaction. Ultimately, the proposed solution signifies a valuable addition to the toolkit of modern supply chain management, serving as a versatile and cost-effective means of enhancing the efficiency of last-mile deliveries. The findings of this research could serve as a launching point for future studies exploring more advanced optimization algorithms or considering other dimensions of the supply chain delivery process.

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