Delivery Route Optimization in Supply Chain Management

1st Vadadoriya Nitin
Information Technology
Indian Institute of Information Technology Allahabad
vadadoriyanitin55@gmail.com

2nd Savaliya Kaushal
Information Technology
Indian Institute of Information Technology Allahabad
savaliyakaushal0412@gmail.com

***Abstract*—An efficient supply chain management system is crucial for companies seeking to increase dealings with customers while concurrently reducing costs. The study explores optimizing delivery routes to enhance delivery times and minimize resource usage within an organization's large-scale supply chain. Under this background, the research investigates the influences of delivery performance determinants and proposes a two-pronged solution, namely, an analytical model to understand the risks of late delivery and a TSP-based method for optimal delivery paths across cities and states within India.**

The analysis is done on actual data in terms of delivery type, estimated, and actual delivery times with resultant risks of late delivery. Graphical insights reveal some salient trends, in this case, how longer shipping times appear to correlate with higher risks for the potential failure of delivery. Orders shipped within two days show little risk of delivered, whilst shipments taking over five days seem to show significantly higher risk. The graph illustrates estimated delivery times by delivery type-for example, Express or Regular-and, on average, same-day and next-day deliveries have shorter estimated times and greater variability.

This research, apart from understanding the above pattern, uses TSP-based algorithms to find out the best way in terms of delivery from various destinations to reduce the time as well as costs. The algorithm finds the shortest possible route for delivery and estimates the total time for delivery to all involved points and provides a suggested sequence for improving the delivery efficiency.

For instance, predictive analytics and route optimization in logistics and supply chains are used to answer questions put forward for the research conducted to help in the streamlining of operations among logistics and supply chain managers. The research's findings include actionable insights that help with the reduction of late delivery risks, delivering sooner or more quickly, and optimizing resource allocation-all of which contribute toward the achievement of wider sustainability goals such as cost-effective supply chains.

I. Introduction

Supply Chain management emerged as a tool for survival in the current high-speed world; hence, it forms a very important part of running any business successfully while addressing the expectations of customers that constantly evolve without losing control of the costs emerging from operations. The rise of e-commerce and globalization of supply chains intensified the requirement for logistics optimization and delivery strategies, particularly as companies strive to offer faster and more reliable services. Customers today want to see such products they order reach them within very short time frames, sometimes even the same day or next day. That is not only the problem of speed; it is about planning, routing, and managing risk. Supply chain optimization addresses not only these two biggest challenges for deliveries: reducing delivery times and minimizing the risk of delayed shipments. One key reason deliveries will be late is that it will leave the customer unhappy, increase the expense and lost reputation. In summary, the variables in determining the delivery delays have to do with the type of delivery. For example, if this is classified as an Express or Regular delivery, then estimated shipping times would be a variable. Understandably, a company will then be able to predict and mitigate the eventualities of a late delivery better.

In addition to managing delivery risks, the other critical element that represents supply chain optimization is route planning, especially for deliveries across a large geographic area. One of these is the classic Traveling Salesman Problem (TSP), which can be used to calculate the shortest possible route through a set of locations. Applying TSP-based solutions to delivery route planning in India, where vast geographic diversity prevails, has the potential to reduce both delivery time and cost. Optimally routed companies will, therefore, make efficient use of resources such as fuel and labor towards achieving timely delivery to customers.

This research intends to address these challenges by combining data analysis on delivery factors with TSP-based route optimization. This section of the research will focus on an examination of historical delivery data regarding significant variables influencing delivery performance such as delivery method and shipping time. Visualizations will thus enable exploration into patterns such as the following: longer shipping times correlate with a greater risk of delay. For example, an assessment indicates that shipments that need to be delivered within two days are less risky for being delivered on time compared to shipments that should be delivered in five days or more, which are much more at risk of delay.

This part of the research applies the TSP algorithm to delivery points across several cities in India to determine an optimal delivery path that would minimize travel time, fuel consumption, and resource allocation. The model will benefit from faster deliveries and significantly reduced costs. With the application of both predictive analytics and optimization techniques, this study tries to establish a holistic approach in dealing with the main headache experienced in supply chain logistics.

II. Problem Statement and Motivation

These days, business concern has been on the rise day by day in today's competitive markets. Consumers expect fast and reliable delivery, which has surged tremendously. Besides, the growth in e-commerce has made this challenge of delivering on time with their control of operational cost all the more difficult. The kind of delivery, Same Day, Next Day, or Express, and the estimated shipping time can have very significant effects on delivery performance, but management of these variables to avoid delay turns out to be challenging. Poorly planned routes also exacerbate the problem, especially in large countries like India, where delivery routes expand over various cities and districts.

Therefore, this research is motivated to equip businesses with the ability to satisfy customer expectations by delivering speed and reliability in a cost-effective manner. The use of knowledge about the sources of delivery delay empowers logistics managers to make better judgments ahead of time in order to avoid losing their prospective benefits. Moreover, the reduction of fuel consumption, labor costs, and cutting down delivery times will all be accomplished by applying an optimization based on TSP. The conclusions from this research work will allow businesses to provide performance improvement, customer satisfaction enhancement, and appropriation of the lead with competitiveness in the e-commerce arena. This project combines predictive modeling and route optimization while facing some of the pertinent challenges related to supply chain logistics, particularly in gigantic, complex markets like India.

III. Existing Work in Delivery Route Optimization and Supply Chain Management

Delivery route optimization has been one of the most widely researched subfields within logistics and supply chain management for a long time. Among the issues of improving efficiency, cutting costs, and minimizing delay, specific methodologies have been proposed to address particularly critical problems like the Traveling Salesman Problem or Vehicle Routing Problem, generally known as VRP, and the effect of delivery time and risk.

One of the best known and researched problems is the Traveling Salesman Problem-TSP. It is formally defined as follows: Given a set of delivery points, find the shortest possible route starting from one given point, which should include a visit to each point and returns to the origin. It is quite a broadly researched problem by its combinatorial nature. A number of solutions have been presented: heuristically, and also via GA, SA, ACO-algorithms, and plenty of such practical applications in delivery route planning real-world problems. Lin and Kernighan's heuristic has been a standard algorithm used to solve TSP for a couple of decades in logistics systems. More recent research also focusses on integrating real-time data to enhance and adapt TSP solutions by developing dynamic route planning that is dependent on varied conditions of traffic, time for delivery, and in real-time availability of vehicles.

Optimization algorithms in vehicle routing were further extended to include several constraints like capacity, time windows, and road conditions in developing the Vehicle Routing Problem or VRP. One extension of the VRP worth mentioning is the Time-Window Vehicle Routing Problem (TWVRP), in which specific time windows associated with the customers are considered, for example, when to make deliveries within a specific time. For such studies on exact algorithms for solving the VRP with time windows, see Desaulniers et al. (2006). These studies have relevance in the delivery of goods during fixed hours or specific slots.

Optimizing delivery performance is also increasingly applied with the help of machine learning and predictive analytics. Researchers have used historical data involving characteristics such as order size, product type, weather conditions, and delivery status to determine probabilities for predicting late deliveries and assigning routes. For example, studies show how algorithms might predict the likelihood of a delivery delay from the experience of shipping in the past, which would lead to an optimal adjustment of both the route used and the scheduling of deliveries.

Research in late delivery risk assessment focused on the factors that might have led to the delays. The common findings of such works include shipping time and delivery type, namely same day and next day, which determine the probability of getting late on delivery. Recent approaches integrate such findings with optimization models for creation of predictive systems that may dynamically update their own delivery plan based on these types of risks.

Overall, although tremendous work is already seen in literature relating to the integration of optimization algorithms with real-time data and predictory analytics for the design of adaptive efficient delivery systems, this work has basically laid the foundation for more advanced data-driven approaches than the one proposed in this work toward improving the designing of delivery routes and controlling risks of late delivery in supply chains.

IV. Experimental and Theoretical Methods

This chapter presents the experimental and theoretical methods developed to achieve route optimization in a delivery scenario by using findings from supply chain management research. Methods: The methods use data analysis, prediction modeling, and optimization algorithms to compute optimal delivery routes that have the potential to enhance the performance of deliveries by minimizing delivery time and by achieving optimal risk reduction with respect to delivery products. Participants and Data Collection 6.1. The core source of all data used for research was drawn from a real-life management system of supply chain. The data includes delivery information, which encompasses the type of delivery, the estimated times of delivery, the actual shipping times in arriving at their destination, and the risk of delivery being delayed. This comprises information on orders delivered across various states and cities in India, routing information, delivery points, and the status of delivery, such as delivered, late, or canceled. The temporal span of the data gathered is a few months, thus the model would capture so many varied conditions of delivery performance.

The entities involved in making deliveries of the products are stakeholders for this research. Thus, the stakeholders comprise logistics firms, delivery drivers and the supply chain managers. The stakeholders are indirectly linked to the dataset since they deal with it as the orders are being fulfilled.

The major tools and resources used in the process are: Python programming language: Python is used for manipulation and analysis of data and to implement algorithms. Pandas: One of the fast and clean data manipulation libraries that will be involved in cleaning, preprocessing, and possibly analysis of the dataset. Matplotlib and Seaborn: Helps to formulate insightful charts and graphs to understand the data clearly. Scikit-learn: Used for training predictive models and splitting datasets into training and testing. Tools for the geographic analysis of delivery locations are essential in running the Traveling Salesman Problem to find the best delivery route. Optimization Algorithms Several optimizations algorithms comprise the core of this paper on the use of the algorithm for the Traveling Salesman Problem in deciding on the most efficient delivery route from all delivery points.

The research also applies data preprocessing techniques that include as a characteristic of the data. These are handling missing values, converting the categorical variables into numerical variables, such as Delivery Status and Late Delivery Risk, scaling the numerical values, shipping days and sales per customer.

There is a procedure in this research that involves the following steps: Data Cleaning and Preprocessing: The missing and incorrect records of data are cleaned off from the dataset Delivery status, among others, or the possibilities of being late are converted to numerical values by a mapping method. This will serve as the input to train the machine learning model and run the algorithms for optimization. Normalization is applied on continuous variables like "Days for shipping (real)" and "Sales per customer" so values are spread within a comparable range, and outlier values don't override the model performance. Exploratory Data Analysis (EDA): In this way, using both descriptive statistics and plotting techniques, immediate trends and correlations existing in the data can come up. For instance histograms, box plots and line plots that were constructed to see how delivery time distribution varies as a function of delivery type, such as Express, Regular, and Next Day can be seen in the following figures. Such critical findings in the analysis of data are that there are trends in late delivery risk with time for delivery being a critical determinant of this. As depicted in visual analysis, risk for delay is highly reduced in orders that take two days or less and are likely to fall in the order that takes between five days or more.

Predictive Models for predicting the risk of delay of delivery on the basis of type of delivery, estimated time of delivery, and number of days to send. With historical data, predictive

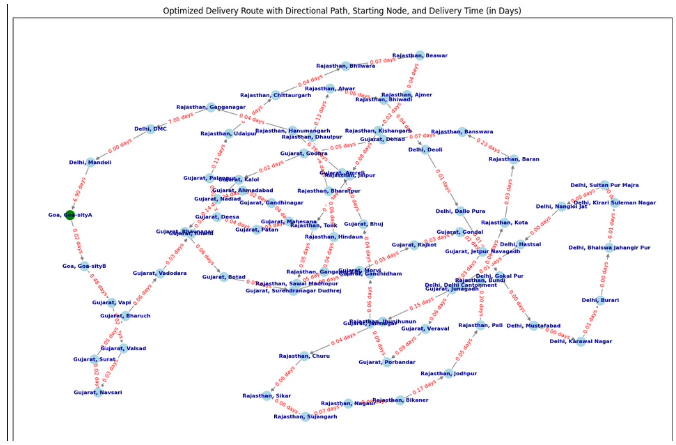

Fig. 1. Estimated Delivery Time Days

models predict the probability of delays in delivery for new orders. Accuracy, precision, recall, and F1-score measures will be used to test the models and thus evaluate their potential in correctly forecasting the risk in delivery. Optimization Algorithm - Traveling Salesman Problem (TSP): The root problem, in fact, is the Traveling Salesman Problem that tries to compute a tour of a given delivery route in the minimum travel time and cost. The TSP in graph format, the delivery points as nodes, and distance as well as approximated delivery time between points as edges have all been established. Equipped with this information of Euclidean distance or real-world traveling data, the TSP algorithm computes the most optimal path connecting all delivery points so that travel time is as short as it can possibly be. TSP has approximation algorithms like nearest neighbour, genetic algorithms and simulated annealing to solve it and get an efficient path in a reasonable time. After that, the total time taken for all deliveries is calculated to measure the efficiency of the optimized path.

V. Verification and Evaluation

The capability of models and the optimized routes is analyzed basis their probability to avoid or control the risks related to late delivery and minimizing delivery times. Validation is done through checking models and algorithms on some other dataset, (usually named hold-out validation) for generalizing the models into real-world scenarios. This includes comparison between the delivery routes and the originals with the optimized routes to point out improvements in efficiency and cost reduction as the final step.

These are the techniques applied to analysis in data collection:

This is done to ascertain if there are any associations between variables such as delivery time and the risk that happens because of late delivery. It explains how strong and in which direction the association is between the variables with the help of statistical measures such as, for instance, Pearson's correlation coefficient.

Many graphs and plots are used to visualize the distributions and patterns in data, including different types of box plots, histograms, and even kernel density plots. Visualization helps gain insights on how delivery types may impact estimated delivery time and the probability of being late.

Total travel time and the overall cost of the delivery optimized route was compared with the numbers for the original route. Key performance indicators such as total time saved, reduction in usage of resources and cost savings are used to measure the improvements realized by the TSP-based optimization.

These methods are used by the research to create a predictive model and optimized routes with actionable insights through efficiency in deliveries and reductions in costs in supply chain management.

VI. Key Findings of the Research

The key findings of the paper are thus aimed at optimizing delivery routes in the supply chain by analyzing delivery types and shipping times as well as the risk of delay in delivery. The second finding applies the TSP algorithms so that the optimal path for delivery could be determined which would yield minimum time and cost in the India supply chain network. It uses graphs, tables, and optimization results to support the findings.

At analysis, a strong relationship was established between the number of days to deliver via shipment and the chance of late delivery. The key observation here is that an increase in shipping time increases the chances of late deliveries. This trend shows that there needs to be faster delivery modalities such as same day or next-day deliveries which reduce the chance of delays. Below is an associated graph.

Fig. 2. Real Shipping Days to Pay Late Delivery Risk

This graph shows that orders that take 1–2 days to ship are less likely to expose themselves to delivery risks as those taking 5–6 days are much more exposed to delay. As indicated by the curve above, there is a higher rate of delayed delivery (as represented by a risk factor of 1) as regards shipping days if they exceed three.

Looking closer at the estimated number of days to delivery by type of delivery can be achieved through the following graph, which as far as different types of delivery services could confirm that different types of delivery are expected to take varying times before shipping. The analysis of estimated delivery time across categories of these goods and services shows Estimated Delivery Time Days by Type of Distribution

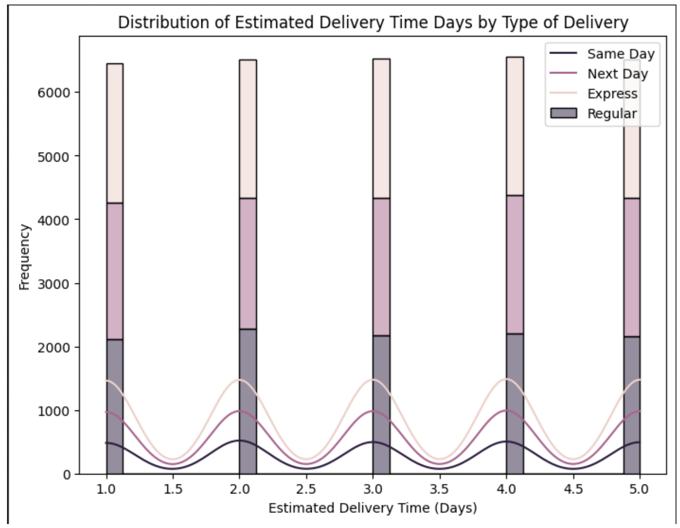

Fig. 3. Estimated Delivery Time

With the advent of the TSP, the research calculated the delivery routes to be taken for multiple delivery points across a few cities in India. The first goal was to reduce the overall travel time and cost by finding a best route for products to be delivered into several locations.

The insight obtained by the TSP algorithm is a saving of time spent in traveling and resources, hence cost savings. Optimization of the route will efficiently reduce both time and fuel consumption, which are two major cost heads of the supply chain network. It works very well in a country like India, with its varying terrain and high traffic congestion, which usually results in delays.

VII. Uncertainty Quantification

An analysis of the delivery performance in supply chains reveals an important knowledge regarding shipping time relative to the risks associated with lateness, which is very crucial in terms of improving deliveries in terms of route usage. As data indicates, a long shipping time greatly correlates with higher risks regarding the delivery lateness when shipments take five or more days. On the other hand, two-day deliveries present less risk of being late, and shipping time needs to be reduced for faster delivery in order to improve on-time performance.

As for delivery type, we find that same-day and next-day deliveries have relatively short estimated delivery times, but the relative variance in delivery time is larger, especially for same-day deliveries. This suggests that while fast delivery services promise a relatively shorter delivery time, they come with higher uncertainty; this might be related to lower customer satisfaction and delivery efficiency. However, regular and express deliveries, while more predictable, differ in their profiles and costs associated with them and thus invoke a tradeoff between speed and reliability.

A comparison of these findings with earlier studies, like those of Hopp and Spearman (2008) and Zhen et al. (2018), indicates that our findings are consistent with those in the literature that also show optimal routes often carry higher operational costs and cause higher variability in delivery times. These studies focus more on the optimality of routes to ensure that there is a guarantee of the lowest delay in times for delivery. Although, our study is more specific wherein we rely on the actual delivery data and utilize the technique of TSP while computing the optimal delivery path. The said method has been less explored in the previous researches on similar studies.

Although some insightful information was found, there are still limitations to this scope of research. The data used, for example, is not weather-dependent or road congestion or real-time traffic updates that would improve delivery time significantly. Also, the TSP algorithm presumes a static set of delivery points and does not become adaptive about dynamic changes in requirements for deliveries or even customer behavior. Real-time data may be integrated into future research in models on route optimization to account for uncertainties in real-world conditions. Further work may include research to improve the model using machine learning-based approaches for late delivery predictions and optimal delivery schedules. Future research could focus on incorporating real-time data into route optimization models to account for uncertainties in real-world conditions.

VIII. Key Findings

In a nutshell, this research lights up such issues in regard to delivery time and risk and route optimization in the field of supply chain management. Shipments with short delivery times, especially those which have a duration of less than two days, reflect a significantly low delivery risk, while longer delivery times of over five days are related to a higher delivery risk. A breakdown of delivery types indicates that same day and next-day deliveries have more variation in estimates of time of delivery compared to courier and normal shipments. The optimization model, based on TSP, also recognizes optimal routes between two cities for delivery which accordingly reduces the travel time and usage of resources. The key implications of these results are in optimizing the operations of logistics. It further helps in understanding the pattern of risks associated with various delivery windows and types so the companies can predict delays and take measures ahead of time against such delays. Furthermore, as the usage brings time reduction for delivering goods as well as lower operational costs, TSP raises the sustainable model to scale-up the supply chain operations. With this information, the logistics and the supply chain manager can also make data-driven decisions to bring in efficiency and improve customer satisfaction through quick and reliable deliveries.

IX. Conclusion

It is an integrated approach that works to optimize delivery routes and minimize risks associated with late deliveries in supply chain management. Data analysis showed significant relationships between delivery type, estimated shipping times, and late delivery risks. Our findings on this end tend to show that with short shipping times such as Same Day or Next Day, the risks are lower, but shipping periods tend to increase the risks of late delivery.

Further, we have applied a TSP algorithm to optimize the delivery routes across multiple cities and states of India. An algorithm designed for the Traveling Salesman Problem calculates the short route in an efficient way and thus provides an estimated total delivery time. That means, using this optimum delivery route planning, logistic teams are capable of reducing both delivery time and operational costs.

By combining predictive analysis and optimization algorithms, we have demonstrated a practical solution for improving delivery efficiency, minimizing late deliveries, and achieving cost-effective logistics, which can be directly applied to enhance supply chain operations.

X. Future Work

Future research in this area may include an extension of the proposed optimization framework to solve problems for other logistics-related issues. One such issue would be the optimal location of warehouses across states to minimize delivery time and cost. By including demand patterns and regional characteristics, a locational-allocation model can be developed for suggesting the optimal locations. It will be strategically located warehouses with smooth accessibility to every city so that transportation time and operational cost can reduce.

Another venue for future work would be to divide the delivery routes into several optimized sections, such that more than one delivery people can work concurrently. Leverage on such advanced algorithms like Vehicle Routing Problem with time windows, the delivery process will be sub-divided into smaller, narrower sections depending on geography and data patterns related to traffic movements. This will contribute towards maximized efficiency and save time while serving hence ”straining” few resources.

The third would be making the system more responsive and adaptive to unexpected delays by rerouting routes dynamically based on the momentary data of traffic or weather conditions. All of the above-mentioned strategies would lead to further cost savings, faster delivery time, and higher customer satisfaction-all of which remove all of the factors as barriers for a more resilient and responsive supply chain network.

Through predictive analysis and a combination of optimization algorithms, we have illustrated a practical approach toward efficiency in delivery, minimizing the potential of late deliveries and keeping cost-effective logistics; such improvements can be applied directly for better operation in supply chains.

XI. Algorithem

Algorithm 1: TSP Solver

Distance matrix $matrix[n][n]$ representing distances between n cities. Route $route$ representing the shortest path starting and ending at the same city.

Initialize:

  $start \leftarrow 0$ `// Starting city index`

  $route \leftarrow [start]$ `// Initialize the route with the starting city`

  $unvisited \leftarrow \{1, 2, \ldots, n-1\}$ `// Set of unvisited cities`

while $unvisited$ *is not empty* **do**

  $last \leftarrow route[-1]$ `// Get the last city in the route`

  $next\_city \leftarrow \arg\min_{x \in unvisited} matrix[last][x]$ `// Find the closest unvisited city`

  Append $next\_city$ to $route$;

  Remove $next\_city$ from $unvisited$;

Append $start$ to $route$ `// Return to the starting city`

return $route$ `// Final route covering all cities`

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