

Dynamic Load Management and Route Optimization in Logistics Using Predictive Analytics



Final Year Project Proposal Session 2022-2026

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Abstract

The logistics industry faces significant inefficiencies due to static routing, underutilized vehicle capacity, and reactive decision-making. This project proposes an intelligent system that integrates predictive analytics and optimization algorithms to enhance logistics operations. The system will forecast daily delivery demand using machine learning models such as XGBoost and Prophet. Based on these predictions, it will optimize vehicle loading using bin-packing algorithms to maximize capacity utilization. Furthermore, it will generate dynamic delivery routes by solving the Capacitated Vehicle Routing Problem (CVRP) using Google OR-Tools, minimizing travel distance and fuel consumption. A web-based dashboard developed with Streamlit will visualize forecasts, load distributions, and optimized routes. Expected outcomes include a measurable reduction in operational costs, trip frequency, and fuel usage, while improving delivery timelines. This project applies core Artificial Intelligence concepts—machine learning and constraint optimization—to a real-world logistics challenge, demonstrating the practical value of AI in industrial automation and supply chain intelligence.

1 Introduction

The rapid expansion of e-commerce has intensified pressure on logistics networks to operate more efficiently and responsively. Traditional logistics systems rely on fixed schedules and manual planning, which fail to adapt to dynamic daily fluctuations in demand. This results in vehicles often operating below capacity, increased fuel costs, delayed deliveries, and overall resource wastage. This project, titled *Dynamic Load Management and Route Optimization in Logistics Using Predictive Analytics*, aims to address these inefficiencies by developing a unified, data-driven decision support system.

The project will bridge the gap between predictive forecasting and operational optimization. The background of this work lies in the convergence of Time-Series Forecasting, Combinatorial Optimization, and Geospatial Analysis. The main sub-tasks include: 1) building and validating a demand forecasting model, 2) developing a load allocation module to maximize vehicle utilization, 3) implementing a dynamic route planning engine, and 4) integrating these components into a user-friendly monitoring dashboard. Algorithms such as Gradient Boosting Machines (XGBoost/LightGBM), the 0/1 Knapsack algorithm, and metaheuristics for Vehicle Routing Problems (VRP) will be adopted.

The success of this project will be measured against verifiable criteria: a high-accuracy forecasting model (e.g., $\text{MAPE} < 15\%$), demonstrable improvement in vehicle load utilization (targeting $> 85\%$ average capacity), and a quantifiable reduction in total route distance compared to baseline static routes. Evidence of these achievements will be presented in the final dissertation through comparative analysis, performance metrics, and system validation on historical and simulated logistics datasets.

2 Success Criterion

For this project to be deemed a success, it must satisfy the following specific, verifiable criteria:

1. **Forecasting Accuracy:** The developed predictive model must achieve a Mean Absolute Percentage Error (MAPE) of less than 15% when tested on a held-out validation dataset of historical delivery information.

2. **Load Optimization:** The load allocation module must demonstrate, through simulation, an increase in average vehicle capacity utilization to a target of 85% or higher, compared to a documented baseline utilization rate from a traditional system.
3. **Route Optimization:** The dynamic routing module must generate routes that result in a minimum 10% reduction in total kilometers traveled compared to traditional static routes for the same set of deliveries, as validated through simulation using tools like Google OR-Tools.
4. **Integrated System Delivery:** A fully functional, integrated system comprising the three core modules (forecasting, load optimization, routing) must be developed and accessible via a web-based dashboard.
5. **Supervisor Acceptance:** The final system, its documentation, and demonstrated results must receive formal acceptance from the project supervisor, confirming that all stated objectives have been met or exceeded.

Satisfying these criteria will constitute a successful project, while exceeding them—for example, achieving higher accuracy or greater cost savings—will demonstrate exceptional performance.

3 Related work

The application of Artificial Intelligence in logistics and supply chain management is a well-researched domain. Early works focused on classical operational research techniques for solving static Vehicle Routing Problems (VRPs) [1]. Recent advancements integrate machine learning for demand prediction to inform dynamic routing decisions.

In the area of demand forecasting, research by [2] demonstrated the superiority of ensemble methods like XGBoost over traditional statistical models (e.g., ARIMA) for retail sales prediction, a finding applicable to logistics demand. For load optimization, the Bin Packing Problem (BPP) and its variants are standard formulations. [3] provides a comprehensive survey of heuristic and metaheuristic approaches to BPP, highlighting methods suitable for real-time logistics constraints.

The core of dynamic routing lies in solving the Capacitated VRP (CVRP) and its dynamic variants (DVRP). Google's OR-Tools library has become a benchmark for implementing efficient VRP solvers using constraint programming and local search metaheuristics [4]. The integration of predictive models with optimization was explored by [5], who proposed a two-stage framework where forecasts directly parameterize a subsequent VRP model, showing significant cost reductions.

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4 Problem Statement

Current logistics and delivery systems employed by many companies suffer from significant inefficiencies rooted in non-adaptive, manual planning processes. The specific challenge in AI and optimization that this project addresses is the disconnect between demand forecasting and real-time operational

decision-making. Existing systems often use static routes and fixed schedules that do not adapt to daily fluctuations in order volume and geographic distribution. This leads to a cascade of problems: vehicles are frequently dispatched partially full (poor load utilization), travel longer distances than necessary (inflated fuel costs and time), and require more trips overall. Manual intervention for schedule adjustments is slow and non-scalable. The lack of a proactive, data-driven system that can predict demand, optimize resource allocation based on those predictions, and dynamically plan efficient routes creates a substantial gap between current operational performance and potential efficiency. This project seeks to close this gap by developing an intelligent system that automates and optimizes these interlinked decisions.

5 Project Rationale

The motivation for this project stems from the critical need to reduce operational costs and environmental impact in the rapidly growing logistics sector. Inefficient routing and load management contribute directly to higher fuel consumption, increased vehicle wear-and-tear, and delayed deliveries, which hurt customer satisfaction. This project is relevant as it applies core AI competencies—machine learning and algorithmic optimization—to a pressing real-world economic and logistical problem. By undertaking this project, we hope to learn how to integrate disparate AI techniques into a functional pipeline, handle real-world data constraints, and measure the tangible business impact of an AI solution. It provides an excellent opportunity to move beyond theoretical models and develop a deployable system that demonstrates the practical value of Artificial Intelligence in industry automation.

5.1 Aims and Objectives

- To design and develop an intelligent logistics management system that reduces costs and improves efficiency through predictive analytics and dynamic optimization.
- To analyze historical logistics data and develop a machine learning model for accurate daily delivery demand forecasting.
- To design and implement a load optimization module that maximizes vehicle capacity utilization using combinatorial algorithms.
- To create a dynamic route planning module that generates minimal-distance delivery routes adaptable to daily demand.
- To build an integrated web dashboard for visualizing forecasts, load plans, and optimized routes.
- To quantitatively evaluate the system's performance in terms of reduced distance, trips, and improved load efficiency.

5.2 Scope of the Project

The project scope includes the development of a software-based decision support system. In-Scope: Data preprocessing and feature engineering from historical delivery logs; development and training of ML forecasting models; implementation of load optimization (Bin Packing) and route optimization (CVRP) algorithms; integration of modules into a single pipeline; development of a Streamlit/Flask web interface for visualization; system testing and validation using historical/simulated data. Out-of-Scope: Hardware integration (e.g., IoT sensors on vehicles); real-time GPS tracking and live traffic data integration; full-scale deployment and maintenance in a commercial environment; mobile application development.

5.3 Goals and Objectives

The goals align with the FYP guidelines: to solve a real-world problem (logistics inefficiency), apply knowledge (AI/ML techniques), and develop skills (system design, coding, project management). The objectives are the specific, measurable steps to achieve these goals, as listed in Section 5.1.

6 Proposed Methodology and Architecture

The methodology follows a structured, modular development lifecycle (See Fig. ?? for the system architecture).

1. Data Acquisition & Preprocessing

- Collect historical logistics data (timestamps, locations, package details).
- Clean data, handle missing values, and perform feature engineering (e.g., extracting day-of-week, holidays).

2. Predictive Modeling

- Experiment with time-series models (ARIMA, Prophet) and supervised learning models (XG-Boost, LightGBM) using historical demand as the target variable.
- Select the best-performing model based on Mean Absolute Percentage Error (MAPE).

3. Load Optimization Module

- Implement a Bin Packing algorithm.
- Inputs: predicted package volumes/weights and vehicle capacities.
- Output: An optimal allocation map assigning packages to vehicles to maximize utilization.

4. Route Optimization Module

- Formulate and solve a Capacitated Vehicle Routing Problem (CVRP) using Google OR-Tools.
- Inputs: vehicle loads (from Module 3), depot location, and delivery locations.
- Output: A sequence of delivery stops for each vehicle minimizing total distance.

5. System Integration & Dashboard Development

- Integrate the three modules into a sequential pipeline.
- Develop a web dashboard using Streamlit to allow users to trigger forecasts, view load plans, and visualize optimized routes on an interactive map (using Folium).

6. Testing & Validation

- Validate each module independently and the integrated system end-to-end using hold-out data and simulated scenarios.
- Compare key performance indicators (KPIs) against baseline methods.

7 Expected Outcomes

1. Analysis and Modeling

Students will analyze and model logistics optimization problems using AI and optimization techniques.

Graduate Attributes Addressed:

- **GA1 (Engineering Knowledge):** Apply knowledge of mathematics, science, and engineering fundamentals to solve complex logistics problems.
- **Level of Attainment:** High

2. Development and Implementation

Students will develop and implement machine learning models and optimization algorithms for efficient logistics solutions.

Graduate Attributes Addressed:

- **GA2 (Problem Analysis):** Identify, formulate, and analyze complex logistics problems using AI principles.
- **GA3 (Design/Development of Solutions):** Design solutions for logistics challenges and develop AI systems.
- **Level of Attainment:** High

3. Evaluation and Assessment

Students will evaluate the performance of forecasting and optimization models for accuracy, efficiency, and cost reduction.

Graduate Attributes Addressed:

- **GA4 (Investigation):** Conduct investigations of complex logistics problems using research-based methods.
- **Level of Attainment:** Medium

4. Teamwork and Communication

Students will demonstrate teamwork, documentation, and presentation skills through collaborative project development.

Graduate Attributes Addressed:

- **GA9 (Individual and Teamwork):** Function effectively as an individual and as a member in diverse teams.
- **GA10 (Communication):** Communicate effectively on complex engineering activities.
- **Level of Attainment:** High

8 Individual Tasks

Table 1: Activity Table

Team Member	Activity	Tentative Date
Shah Fahad	Literature Review & Proposal Finalization	Dec 2025
	Data Collection & Preprocessing	Dec 2025 - Jan 2026
	Predictive Model Development (XGBoost, Prophet)	Jan 2026 - Feb 2026
	Model Evaluation & Hyperparameter Tuning	Feb 2026
	Research & Implement Load Optimization (Bin Packing)	Feb 2026 - Mar 2026
	Research & Implement Route Optimization (OR-Tools CVRP)	Mar 2026
	System Architecture Design & Planning	Mar 2026
	Streamlit Dashboard Development - UI/UX Design	Mar 2026 - Apr 2026
	Data Visualization Implementation (Plotly, Matplotlib)	Apr 2026
	Interactive Map Integration (Folium)	Apr 2026
	Module Integration & Backend Pipeline Development	Apr 2026 - May 2026
	End-to-End System Testing & Validation	May 2026
	Performance Analysis & Optimization Metrics Calculation	May 2026 - Jun 2026
	Final Documentation & Report Preparation	Jun 2026
	Project Presentation & Demonstration	Jun 2026

9 Gantt Chart

Table 2: Project Gantt Chart

Task / Phase	Dec 2025	Jan 2026	Feb 2026	Mar 2026	Apr 2026	May-Jun 2026
Literature Review & Proposal Finalization						
Data Collection & Pre-processing						
Predictive Model Development						
Load Optimization Module Dev						
Route Optimization Module Dev						
Dashboard & UI Development						
Module Integration & Testing						
Final Documentation & Submission						

10 Tools and Technologies

The following tools and technologies will be utilized for the development and implementation of this project:

- **Programming Language:** Python
- **Data Processing:** Pandas, NumPy
- **Machine Learning:** Scikit-learn, XGBoost, LightGBM, Facebook Prophet, Statsmodels (for ARIMA)
- **Optimization & Routing:** Google OR-Tools
- **Web Framework & Dashboard:** Streamlit
- **Visualization:** Plotly, Matplotlib, Seaborn, Folium (for geospatial maps)
- **Development Environment:** Jupyter Notebook, VS Code, Git/GitHub
- **Documentation:** Microsoft Word, \LaTeX (for report formatting)

11 References

1. P. Toth and D. Vigo, *The Vehicle Routing Problem*. Philadelphia, PA: SIAM Monographs on Discrete Mathematics and Applications, 2002.
2. J. Brownlee, *Deep Learning for Time Series Forecasting: Predict the Future with MLPs, CNNs and LSTMs in Python*. Machine Learning Mastery, 2018.
3. E. K. Burke, G. Kendall et al., “Hyper-heuristics: A survey of the state of the art,” *Journal of the Operational Research Society*, vol. 64, no. 12, pp. 1695–1724, Dec. 2013.
4. Google, “OR-Tools: Google’s Optimization Tools,” [Online]. Available: <https://developers.google.com/optimization>. [Accessed: Month Day, Year].
5. M. S. Alam, M. R. Khan, and A. K. M. F. Haque, “An Integrated Predictive and Optimization Model for Dynamic Vehicle Routing Problem,” in *Proc. International Conference on Computer and Information Technology (ICCIT)*, Dhaka, Bangladesh, 2020, pp. 1–6.