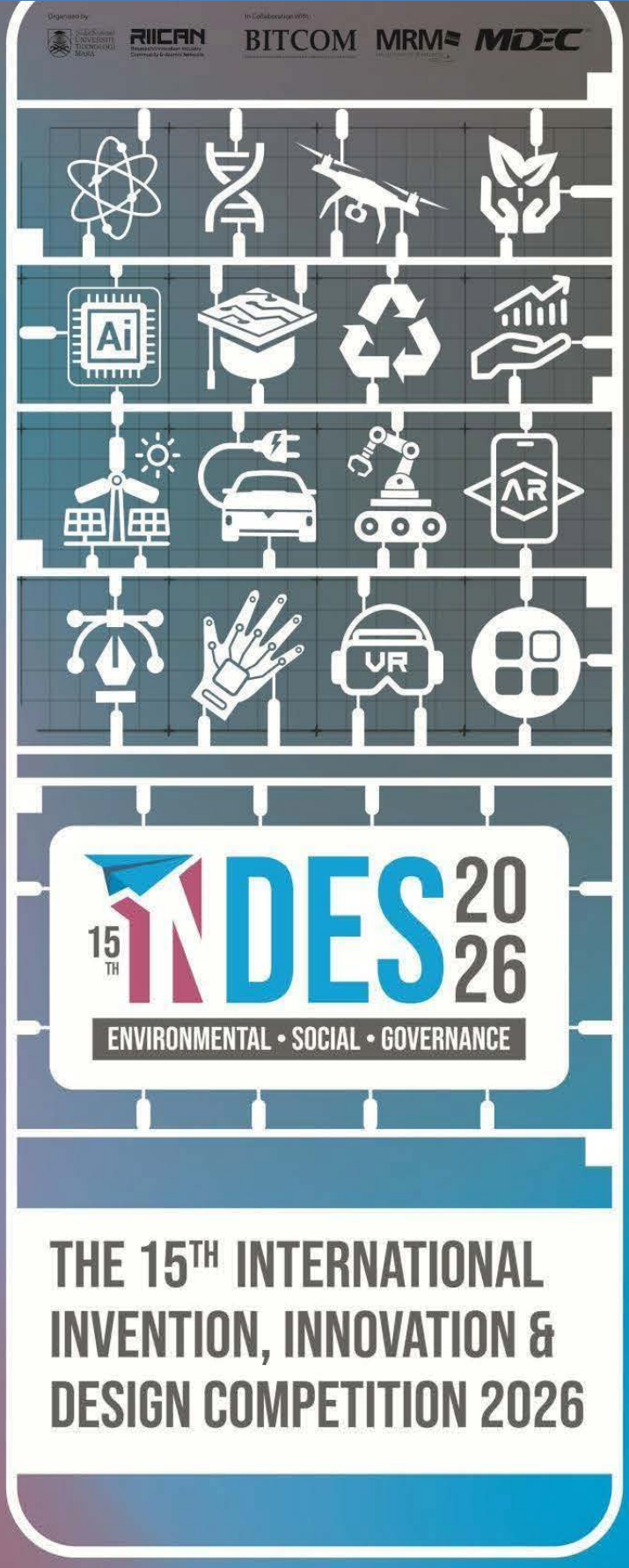


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THE 15th INTERNATIONAL
INVENTION, INNOVATION &
DESIGN COMPETITION 2026

Organized by:
Office of Research, Industry,
Community & Alumni Network
UiTM Perak Branch

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Unit Penerbitan UiTM Perak,
Universiti Teknologi MARA,
Perak Branch, 32610
Seri Iskandar Perak, Malaysia.

Perpustakaan Negara Malaysia Cataloguing in Publication Data

No e- ISBN 978-967-2776-67-3

Cover Design: Asrul Nizuan Ariffin

Typesetting : Georgia

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GREENROUTE OPTIMIZER: A GREEN MIXED-INTEGER GOAL PROGRAMMING MODEL FOR SUSTAINABLE FRESH VEGETABLE ROUTING

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ABSTRACT

GreenRoute Optimizer is a sustainable decision-support model that improves fresh vegetable distribution by integrating Mixed-Integer Goal Programming (MIGP) with the Vehicle Routing Problem with Time Windows (VRPTW). Current fresh produce logistics often prioritize delivery cost and distance, while freshness preservation and carbon emissions are treated separately or qualitatively. This study develops a Green Mixed-Integer Goal Programming Vehicle Routing Problem with Time Windows (G-MIGP-VRPTW) model that simultaneously minimizes total travel distance, travel time, and CO2 emissions, while maximizing freshness score and satisfying customer delivery time windows. The freshness score is incorporated as a measurable optimization component based on weighted postharvest criteria, including mode of transportation, delivery time length, biological control, and temperature control. The proposed model is validated using fresh vegetable routing data from the Malaysian logistics setting. Priority-based optimization results show that the model maintains a near-optimal freshness score with only 0.03% deviation from the ideal benchmark, while producing feasible routes under real-world operational constraints. The innovation offers practical value for agri-food logistics operators, government agencies, and supply chain planners by balancing operational efficiency, environmental sustainability, and produce quality assurance. The model is also scalable for cold-chain, horticulture, pharmaceutical, and fast-moving consumer goods distribution systems.

Keywords: green vehicle routing; mixed-integer goal programming; time windows; carbon emission; freshness score; sustainable logistics; agri-food supply chain

1. INTRODUCTION

Fresh vegetable supply chains are highly time-sensitive because product quality deteriorates rapidly after harvest, particularly when postharvest handling, storage, transportation, and delivery activities are not properly controlled. Recent studies emphasize that cold chain logistics is essential for preserving the freshness and quality of fresh agricultural products, as delays, temperature fluctuations, and inefficient distribution processes can increase food loss, reduce customer satisfaction, and weaken supply chain performance (Ding et al., 2025; Liu et al., 2025; Zhu, 2025). In Malaysia and other agri-food logistics contexts, these challenges are further associated with higher operational costs and unnecessary carbon emissions due to inefficient routing and energy-intensive cold chain operations. Conventional Vehicle Routing Problem with Time Windows (VRPTW) models commonly focus on minimizing transportation cost, travel distance, vehicle usage, or delivery feasibility. However,

freshness deterioration is still not consistently incorporated as a quantitative decision criterion in routing optimization models (Ding et al., 2025; Wangsa et al., 2023). At the same time, green logistics and low-carbon cold chain models increasingly focus on reducing carbon emissions, but many of these models pay limited attention to the simultaneous preservation of product freshness for perishable vegetables (Liu et al., 2025; Zhang et al., 2025; Zou et al., 2024). Therefore, a methodological and practical gap remains in developing sustainable agri-food logistics models that simultaneously optimize freshness preservation, transportation cost, and carbon emissions in fresh vegetable supply chains.

GreenRoute Optimizer addresses this gap by developing a Green Mixed-Integer Goal Programming Vehicle Routing Problem with Time Windows (G-MIGP-VRPTW) model for sustainable routing of fresh vegetables. The model integrates five goals: minimizing total travel distance, minimizing travel time, minimizing CO2 emissions, satisfying customer time-window requirements, and maximizing freshness score. The novelty of this innovation lies in converting freshness into a measurable objective that can be embedded directly into mathematical routing decisions, allowing logistics operators to balance efficiency, sustainability, and product quality within a single optimization framework.

2. METHODOLOGY

2.1 Model development

The proposed G-MIGP-VRPTW model is formulated as a Mixed-Integer Goal Programming model. The decision variables determine vehicle assignment, customer sequence, route selection, and departure time. The model includes hard constraints for depot departure and return, customer service requirements, vehicle capacity, route continuity, delivery feasibility, and time-window compliance. Goal constraints are then used to represent the five optimization objectives, where deviation variables measure the distance between each achieved solution and its respective aspiration level.

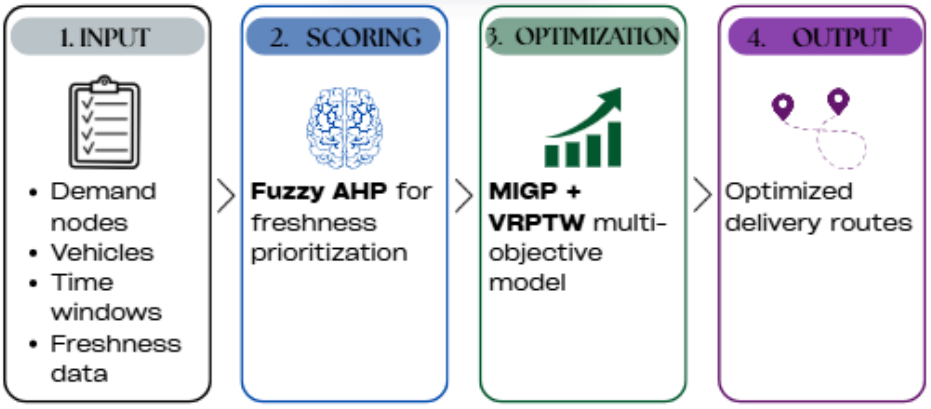


Figure 1 Methodology process for development of the G-MIGP-VRPTW model.

2.2 Freshness score and green logistics components

The freshness score is derived from weighted postharvest criteria, including mode of transportation, delivery time, biological control, and temperature control (Shuib et al., 2025). These weights are derived using the Fuzzy Analytical Hierarchy Process (Fuzzy AHP) integrated with the Lambda-Max method. Carbon emissions are estimated using a distance-based approach for conventional diesel or petrol vehicles, accounting for travel distance and vehicle-specific emission parameters. The final optimization model is solved using priority-based goal programming, where each goal is evaluated according to the assigned priority structure.

3. FINDINGS

The model produces feasible optimized delivery routes under real-world operational constraints. The priority-based results indicate that freshness preservation can be maintained at a near-optimal level while accounting for the trade-offs among distance, travel time, and carbon emissions. Table 1 summarizes the optimization performance based on the ideal benchmark and optimized feasible solution.

Table 1 Optimization Performance of GreenRoute Optimizer

Priority	Metric	Ideal Benchmark	Optimized Result	Deviation
P1	Total Distance (km)	731.51	1,207.82	+39.43%
P2	Travel Time (min)	1,241.54	1,717.80	+28.37%
P3	CO2 Emissions (kg)	605.72	980.53	+38.24%
P4	Freshness Score (kg-unit)	1,544.95	1,544.49	+0.03%

The most significant result is a deviation in freshness score of only 0.03%, indicating that product freshness can be maintained at an almost ideal level. Although distance, travel time, and emissions exhibit greater deviations from their theoretical best values, these deviations reflect practical routing trade-offs when delivery feasibility, vehicle capacity, and customer time windows are considered simultaneously.

4. CONCLUSION

GreenRoute Optimizer demonstrates the potential of mathematical optimization to support sustainable and freshness-oriented agri-food logistics. By integrating MIGP, VRPTW, carbon emission minimization, and freshness-score maximization into a single model, the innovation provides a practical tool for reducing postharvest losses, improving delivery planning, and supporting greener supply chain operations. The model is suitable for logistics operators, agri-food agencies, and supply chain planners, and it can be further enhanced through real-time Internet of Things data, GPS tracking, and AI-driven adaptive routing.

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E-BOOK OF EXTENDED ABSTRACT THE 15th INTERNATIONAL INVENTION, INNOVATION & DESIGN COMPETITION 2026

eISBN 978-967-2776-67-3

9 789672 776673

Date of Publication: 13 July 2026

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(online)