

## **CARBON EMISSION REDUCTION STRATEGIES IN LOGISTICS TRANSPORTATION: A CASE STUDY OF TRUCK FLEET ROUTE OPTIMIZATION USING THE VEHICLE ROUTING PROBLEM IN DENPASAR CITY**

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### **ABSTRACT**

Efficient logistics distribution is a key factor in strengthening business competitiveness, particularly in urban areas such as Denpasar, Bali, which face congestion and infrastructure limitations. This study aims to optimize logistics distribution routes by applying the Vehicle Routing Problem method supported by a Geographic Information System. The study evaluates strategies to reduce carbon emissions in Denpasar's logistics operations through route optimization using the Vehicle Routing Problem approach integrated with Geographic Information System tools. The data include existing routes of PT X, vehicle characteristics, fuel consumption, travel distance, and route elevation. Carbon emissions are calculated using a diesel emission factor of 2.7 kilograms of CO<sub>2</sub> per liter. The analysis uses ORS Tools in QGIS to generate optimal routes that consider distance and elevation gain. The results indicate a strong influence of topography on fuel consumption. The Ubud route shows substantial elevation gain, which increases energy demand and emissions. Route optimization reduces emissions by 11.61 percent on the Ubud to Ngurah Rai route and by 8.97 percent on the Mengwi to Ngurah Rai route. These findings highlight the importance of terrain based route modeling to improve logistics distribution efficiency and reduce carbon emissions.

Keywords: carbon emission; route optimization; VRP

### **INTRODUCTION**

Indonesia's logistics sector faces significant challenges, particularly in terms of distribution efficiency and environmental impact. The growth of motorized vehicles without a corresponding improvement in road infrastructure has led to severe congestion, particularly in densely populated cities like Denpasar, Bali. Land transportation is a major contributor to national carbon emissions, contributing approximately 27% of total greenhouse gas emissions, with nearly 90% of this coming from road traffic (Oceania & Narantaka, 2024). Denpasar has experienced a significant increase in traffic volume, resulting in decreased distribution efficiency, increased fuel consumption, and a surge in particulate emissions from vehicles, reaching 440 tons per year (Setyono et al., 2020).

In response to these challenges, the concept of green logistics has emerged as a strategic solution that prioritizes sustainable logistics practices. Green logistics aims to reduce environmental impact by minimizing carbon emissions, reducing fuel consumption, and increasing operational efficiency through route optimization and improved fleet management (Macharis et al., 2014). The Indonesian government has established a national green logistics policy as part of its efforts to reduce the environmental impact of the transportation sector, by encouraging the use of low-emission vehicles and optimizing distribution fleet operations.

The most recent development in the Vehicle Routing Problem literature is the Green Vehicle Routing Problem (GVRP), a VRP variant that explicitly incorporates environmental factors.

GVRP integrates environmental considerations with a focus on reducing the carbon footprint. Zhang et al. (2015) incorporate fuel costs and carbon emissions into the VRP objective function, producing a low carbon routing model with improved environmental performance. A related variant is the Pollution Routing Problem (PRP), which places fuel consumption as the primary parameter.

Vehicle route optimization represents a key element within green logistics strategies. This practice seeks to design distribution routes with high efficiency, reducing travel distance, travel time, and vehicle fuel consumption. Empirical studies report fuel consumption and carbon emission reductions of up to 15 to 20 percent when compared with conventional route planning methods (Lin et al., 2014; Roundtrip, 2023). A practical example appears in global logistics firms such as UPS, which achieved savings of millions of gallons of fuel and reductions of thousands of tons of CO<sub>2</sub> per year (UPS, 2016). In Denpasar, route optimization holds strong relevance due to frequent severe congestion, where optimized routing supports truck fleets in avoiding congested corridors and reducing travel time.

Geographic Information Systems technology and route optimization software such as OpenRouteService Tools within QGIS provide an effective solution for optimal distribution planning. ORS Tools offer a GIS based interface that supports detailed and real time road network analysis, generating optimal routes that account for shortest distance, fastest travel time, and current traffic conditions (GIScience Heidelberg, 2019; HeiGIT, 2019). The objectives of this study are as follows: 1) To identify the factors contributing to high carbon emissions along existing routes. 2) To develop and simulate a logistics route optimization model to reduce carbon emissions.

## METHOD

This study applies ORS Tools in QGIS to solve the Vehicle Routing Problem (VRP), allowing the research to be classified as a quantitative method based on simulation and spatial modeling. Carbon emissions are measured using standards issued by the U.S. Environmental Protection Agency (EPA). Vehicle carbon emissions are estimated using the emission factor method multiplied by fuel consumption. The emission factor represents the amount of carbon dioxide (CO<sub>2</sub>) generated per liter of fuel combusted. The formula used to calculate total fuel consumption is as follows.

Total Fuel Consumption (liter) = Distance traveled (km) × Fuel Consumption per km (liter/km)

Calculate the CO<sub>2</sub> Emission:

Emission CO<sub>2</sub> (Kg) = Total Fuel Consumption (liter) × Emission factor (Kg CO<sub>2</sub>/liter)

Based on Mathers et al. (2024) and the Ministry of Natural Resources Canada (2025), the emission factor for each liter of gasoline produces approximately 2.3 kg of CO<sub>2</sub>, while each liter of diesel fuel produces approximately 2.7 kg of CO<sub>2</sub>.

Convert to Tons:

CO<sub>2</sub> Emission(ton) = (CO<sub>2</sub> Emission (kg))/1000

The use of ORS Tools in QGIS begins with plugin installation through the Plugins menu, followed by configuration of the OpenRouteService API key to connect QGIS with ORS services. After configuration, depot and customer point data are prepared as point vector layers using the UTM WGS 84 Zone 50S coordinate system. The depot serves as the starting and ending point of each trip, while customer points represent visit locations. These point datasets form the primary inputs for route optimization, with additional attributes adjusted to research

needs. Route optimization runs through the Routing feature in ORS Tools by selecting an appropriate vehicle profile and activating the Optimize Route option. The system calculates the optimal visit sequence based on the principles of the Vehicle Routing Problem or the Traveling Salesman Problem. The output appears as an optimal route layer in line format, including distance, travel time, and visit order information. This output supports distribution efficiency analysis through comparison of distance and travel time before and after optimization and visualization on maps as a basis for evaluating improvements in distribution route performance.

## RESULT AND DISCUSSION

### Agent and Warehouse of PT X Denpasar

PT X Denpasar began its business operations in Jakarta in 1981 with a primary focus on air freight services and logistics provision. Three years later, in 1984, the company expanded its network by opening a branch in Denpasar. The services offered include freight forwarding for export and import activities by air and sea, customs and excise handling, including import and export clearance processes. The company also provides warehousing facilities, domestic distribution services, and integrated land transportation support.

PT X serves not only small scale shipments but also large cargo transportation for industrial needs. The company operates an integrated fleet of land, sea, and air transportation, enabling service coverage across domestic and international destinations. With information technology support, PT X developed a tracking system that provides shipment position and status information to customers. The company also focuses on supply chain management. Services include warehouse management, cargo consolidation, and distribution across Bali and surrounding areas. The Denpasar branch holds a strategic position as a main gateway for export and import flows through Ngurah Rai International Airport and ports in Bali. This role places PT X as an important actor in supporting trade and logistics activities within the Bali Nusa Tenggara region. The Denpasar branch of PT X operates several key operational points, including the Ubud Agent in Gianyar Regency and the Seminyak Agent in Badung Regency. To support distribution activities, the company also operates a warehouse in Mengwi, Badung Regency, and a warehouse located within the Ngurah Rai Airport area.

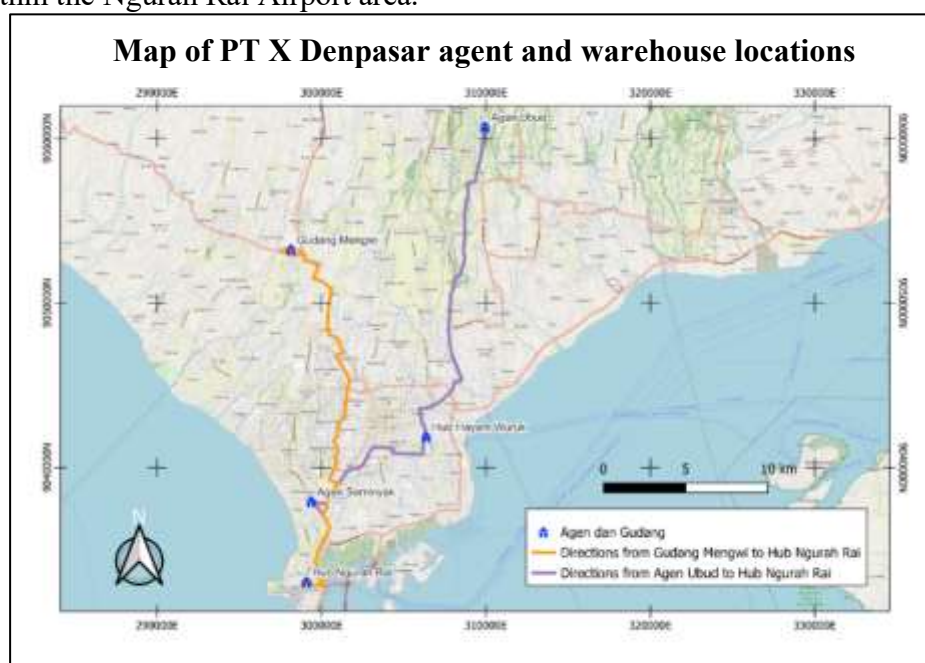


Figure 1. Location Map and Route of PT X Denpasar Agents and Warehouses

The Denpasar branch of PT X operates two main agents, namely the Ubud Agent in Gianyar Regency and the Seminyak Agent in Badung Regency. In addition, the company manages a warehouse in the Mengwi area of Badung Regency and a central warehouse located within the Ngurah Rai Airport area. All distribution activities are centralized at the Ngurah Rai Airport warehouse, which functions as the main hub for export, import, and domestic distribution operations.

### Existing Route Description

In this study, only one vehicle sample from the PT X fleet is selected, namely the Mitsubishi Canter FE71. The Mitsubishi Canter FE71 is equipped with a 4D34-2AT5 four cylinder engine with a displacement of 3908 cc, producing 125 to 130 PS at 2900 rpm and a torque of 32 kg·m at 1600 rpm. The vehicle has a permitted gross vehicle weight of 7500 kg and a payload capacity of approximately 4500 kg. This configuration makes the FE71 suitable for urban distribution and medium load routes.

Table 1.  
Existing Route Taking Elevation into Account

No	Segment	Elevation Change ( $\Delta h$ )	Positive Increase ( $\Delta h_{pos}$ )	Driving Distance (m)	Elevation Cost (m)	Adjusted Cost (m)
<b>A Ubud – Ngurah Rai Route</b>						
1	Ubud → Hayam Wuruk	-237 m	0	26964	0	26964
2	Hayam Wuruk → Ngurah Rai	-13 m	0	1930	0	19390
3	Ngurah Rai → Hayam Wuruk	+13 m	12	19044	600	19644
4	Hayam Wuruk → Ubud	+237 m	237	27891	11850	39741
<b>B Mengwi – Ngurah Rai Route</b>						
1	Mengwi → Seminyak	-111 m	0	22175	0	22175
2	Seminyak → Ngurah Rai	+5 m	5	7380	250	7630
3	Ngurah Rai → Seminyak	-5 m	0	7008	0	7008
4	Seminyak → Mengwi (Depot)	+111 m	111	21392	5550	26942

A study by Peng et al. (2023) reports that on uphill segments with gradients above 3–4%, truck fuel consumption increases sharply when compared with passenger vehicles due to a high weight to power ratio. Table 1 explains the adjusted cost as an additional distance of 50 meters for each 1 meter increase in elevation. As a result, the round trip Ubud to Ngurah Rai route has an actual distance of 93.289 meters, which increases to 105.739 meters or 105,739 km after applying the adjusted cost. In contrast, the round trip Mengwi to Ngurah Rai route has an actual distance of 57.955 meters, which increases to 63.755 meters or 63,755 km after adjustment.

### Carbon Emission Calculation on Existing Routes

Based on the carbon emission calculations for PT X's existing routes, a significant variance is observed across routes of differing distances. According to Mathers et al. (2024), each liter of diesel fuel generates 2,7 kg of CO<sub>2</sub>. The Ubud – Ngurah Rai route produced the highest emissions at 50,47 kg of CO<sub>2</sub> per trip, while the Mengwi Warehouse – Ngurah Rai route generated 34,45 kg of CO<sub>2</sub>.

These findings align with the study by Sudarti et al. (2022), which posits that route length and traffic conditions contribute directly to fuel consumption and vehicular CO<sub>2</sub> emissions. An increase in mileage is directly proportional to the volume of fuel required, thereby expanding the total carbon emissions released into the atmosphere. Detailed data are presented in Table 2 below:

Table 2.  
 Carbon Emission Calculation on Existing Routes

Route	Distance (km)	Ave. Speed (km/jam)	Fuel consumption (liter)	CO <sub>2</sub> Emission (Kg)	CO <sub>2</sub> Emission (Ton)
Ubud → Ngurah Rai	105,739	30	21,15	57,09	0,057
Mengwi → Ngurah Rai	63,775	35	12,75	34,45	0,034

### Optimized Route Analysis

Route optimization utilizing the Vehicle Routing Problem (VRP) model, executed via the ORS Tools plugin within the QGIS application, yielded a distance matrix adjusted for topographical factors. As detailed in Table 5.3, the adjusted cost incorporates an additional 50 meters of distance for every 1-meter increase in elevation. Consequently, the Ubud – Ngurah Rai (round trip) route resulted in an adjusted cost distance of 93.466 meters, or 93,466 km. Meanwhile, the Mengwi – Ngurah Rai (round trip) route produced an adjusted cost distance of 58.072 meters, or 58,072 km.



Figure 2. PT X Denpasar Optimal Route Map

A comparative efficiency analysis of two round-trip (P.P.) routes was conducted based on an adjusted cost model, in which gravitational resistance (elevation) is converted into an energy-equivalent distance penalty. This methodology applies a penalty factor of 50 meters to the travel distance for every 1-meter increase in elevation, aiming to model the elevated fuel consumption of heavy-duty vehicles (Hino 300 Series) during inclines. The calculation results indicate that in terms of physical distance (Total Distance), both routes are nearly identical, recorded at 54.666 meters for the Ubud Route and 53.772 meters for the Mengwi Route, as detailed in Table 3 below:

Table 3.  
 Rute Optimal PT X Denpasar

No	Segment	Elevation Change ( $\Delta h$ )	Positive Increase ( $\Delta h$ pos)	Driving Distance (m)	Elevation Cost (m)	Adjusted Cost (m)
A Ubud – Ngurah Rai route						
1	Ubud → Hayam Wuruk	-237 m	0	21701	0	21701
2	Hayam Wuruk → Ngurah Rai	-13 m	0	18855	0	18855
3	Ngurah Rai → Hayam Wuruk	+13 m	12	14650	600	15250
4	Hayam Wuruk → Ubud	+237 m	237	25790	11850	37640
TOTAL			249	80996	12450	93446
B Mengwi – Ngurah Rai route						
1	Mengwi → Seminyak	-111 m	0	19445	0	19445
2	Seminyak → Ngurah Rai	+5 m	5	6949	250	7199
3	Ngurah Rai → Seminyak	-5 m	0	6006	0	6006
4	Seminyak → Mengwi (Depot)	+111 m	111	19872	5550	25422
TOTAL			116	52.272	5.800	58.072

Fundamental differences were revealed in the elevation variables. The Ubud – Ngurah Rai (round trip) route exhibits a substantial cumulative elevation gain of 249 meters, whereas the Mengwi – Ngurah Rai (round trip) route records only 116 meters. This topographical disparity results in a significant difference in the Adjusted Cost as an energy cost metric. The Ubud route has an Adjusted Cost of 93.466 meters, implying an engine workload equivalent to traversing a flat distance of 93,4 km. In contrast, the Mengwi route generates an Adjusted Cost of only 58.072 meters. The difference of 35.394 meters (equivalent to a 60% increase in energy cost for the Ubud Route) demonstrates that the elevation factor, rather than physical distance, is the primary determinant of inefficiency and potential fuel waste within this logistics network, as detailed in Table 4 below.

Table 4.  
 Comparison of Carbon Emissions

No	Route	Pre-Optimization Distance (km)	Carbon Emissions (kg)	Post-Optimization Distance (km)	Carbon Emissions (kg)	Difference (kg)	%
1	Ubud → Ngurah Rai	105,739	57,09	93,446	50,46	6,63	11,61
2	Mengwi → Ngurah Rai	63,775	34,45	58,072	31,36	3,09	8,97

## CONCLUSION

The findings of this research are as follows:

1. The primary determinants of inefficiency and potential fuel wastage within the logistics network are not limited to distance alone, but also include the topographical factors of the

Bali region, particularly the Ubud area in Gianyar. Heavy-duty freight trucks consume 3,4% more fuel on inclined roads compared to flat or descending terrains.

2. Route optimization for PT X Denpasar's distribution network resulted in a carbon emission reduction of 11,61% for the Ubud – Ngurah Rai (round trip) route. Meanwhile, for the Mengwi – Ngurah Rai route, carbon emissions were mitigated by 8,97%.

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