A Multi-Objective Vehicle Routing Model for Gender Equity in Freight Transport

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***Abstract*—Gender diversity remains a critical challenge in freight transport, where female drivers are significantly underrepresented due to demanding work conditions and wage disparities. This study presents a vehicle routing model that incorporates gender-differentiated energy expenditure rates and workload thresholds to reflect the physical and occupational differences between male and female drivers. The model addresses two objectives: minimizing total operational cost and reducing gender wage disparities. The ε-constraint method is employed to generate cost-efficient solutions while controlling wage gaps. The implementation of the proposed model has the potential to enhance female participation and empowerment in the logistics sector. Additionally, this research establishes a foundation for developing a driver-centric, gender-equitable, and sustainable vehicle routing framework.**

***Keywords*—women empowerment, social sustainability, female driver, freight transport, gender equality, vehicle routing**

I. Introduction

The freight transport industry faces persistent gender inequality, with women significantly underrepresented, especially in driving and managerial roles (Xiao and Konak, 2016). Wage disparities, unfavorable working conditions, and unsupportive workplace cultures limit female participation across the sector. These challenges are particularly pronounced in long-haul and remote-area transport, where safety concerns and the lack of adequate rest areas and sanitary facilities further discourage female involvement. Moreover, previous studies have identified other challenges that disproportionately impact female drivers, including harassment, poor sleep quality, and the burden of household responsibilities (Lin *et al.,* 2014; Qin *et al.,* 2019).

Reducing gender disparities in freight transport is essential for resolving persistent driver shortages and enhancing workforce diversity (Xiao and Konak, 2016). Establishing gender-equitable work conditions can also contribute to broader societal goals, including Sustainable Development Goals (SDGs) 5 (Gender Equality) and 10 (Reduced Inequality). However, despite these potential benefits, the existing Vehicle Routing Problem (VRP) research has largely overlooked gender-specific needs and risks, with most studies focusing primarily on cost efficiency and environmental impacts related to carbon emissions. To date, there has been limited exploration of how gender differences, particularly those related to physiological capacity and income disparities, can be incorporated into VRP models. Parameters and constraints specific to female drivers and optimization objectives focused on gender equity are largely overlooked in the existing literature. Therefore, integrating these considerations into routing decisions offers a new and important direction for creating more inclusive and socially sustainable logistics systems.

To address these gaps, this study proposes a multi-objective Gender Equality Vehicle Routing Problem (GE-VRP) model that incorporates gender-sensitive operational parameters and explicitly considers workload distribution between male and female drivers. The model aims to minimize total transportation costs, including fuel, driver wages, and fixed vehicle costs, while simultaneously reducing wage disparities and promoting equitable workload allocation. Using a case study from a province in Eastern Thailand, the model demonstrates how logistics operations can be optimized to promote a more inclusive transport system for male and female drivers within the freight transport sector.

The following parts of the paper are the literature review, mathematical model formulation, results, discussion, and conclusion.

II. Literature Review

Recent studies have extended traditional cost-efficient VRP models by incorporating environmental considerations such as fuel consumption and CO_2 emissions, leading to the development of Sustainable VRP frameworks (Xiao and Konak, 2016; Lin *et al.*, 2014). While environmental considerations have become more common in VRP research, social aspects remain relatively underexplored. Most studies that address social concerns tend to focus on customer satisfaction (Qin *et al.,* 2019; Wu *et al.,* 2023), or job creation (Rekabi *et al.,* 2022) with limited attention given to the drivers' working conditions. One such study by Dukkanci *et al.* proposed an SVRP that integrates fuel efficiency and improved driver and customer welfare, while Ghannadpour *et al.* considered public health risks and driver exposure in healthcare waste routing.

While gender equity and equality are pressing issues in freight transport, gender considerations have received little attention in the routing and logistics literature. The industry continues to exhibit a significant gender imbalance,

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particularly in freight logistics, where female drivers face wage disparities, safety concerns, and physically demanding working conditions. These challenges contribute to low levels of female participation and retention. Addressing these barriers requires a shift toward fair workload distribution, equitable compensation, and more inclusive operational planning, as suggested by recent studies (Sabet and Farooq, 2022; Dündar *et al.,* 2021).

Some recent works have begun to emphasize the importance of considering driver heterogeneity in VRP modeling. For instance, Lin *et al.* argued that realistic routing models should reflect diverse operational preferences and constraints. Mojtahedi *et al.* and Mahdavi *et al.* introduced social impact measures related to workload and risk within an SVRP framework, although these were not explicitly focused on gender. These studies demonstrate a growing interest in social considerations and highlight a research opportunity related to gender-based operational disparities in VRP modeling.

To address this gap, the current study proposes a GE-VRP model incorporating gender-sensitive parameters related to energy expenditure, wage differences, and workload thresholds. In doing so, the model contributes to more inclusive and socially conscious logistics planning while offering a practical framework to address gender-based inequalities in freight transport. This study advances the VRP literature by integrating gender equity into operational decision-making.

III. Mathematical Model Formulation

This study develops a GE-VRP model incorporating gender-sensitive operational parameters into logistics planning. The model consists of two optimization objectives: (1) to minimize total transportation costs, including fuel, driver wages, and fixed vehicle costs, and (2) to minimize the average wage gap between male and female drivers. The assumptions, notations, and constraints used in the model formulation are presented below.

A. Assumptions

- A single depot serves all customers using a homogeneous vehicle fleet.
- All drivers are paid at the same wage rate, but their actual income varies based on work hours and unloading tasks.
- Each driver works a standard 8-hour shift, with a maximum of 4 hours of overtime paid at 1.5 times the regular rate.
- All male drivers are assumed to have the same energy expenditure profile, which applies to female drivers.
- Customer demand is fixed and known in advance, with no real-time variations.
- Each delivery must be completed in a single trip and split deliveries are not allowed.

B. Mathematical Model

Indices

D	A depot, $D = \{0\}$
C	Set of customers, $C = \{1, 2, \ldots, n\}$
N	Set of all nodes, $N = D \cup C$
K	Set of vehicles
$K^f \subset K$	Subset of female-driven vehicles
$K^m \subset K$	Subset of male-driven vehicles

Input parameters

DIS_{ij}	Travel distance from node i to node j (km)
CA	Vehicle capacity (kg)
CD_i	Demand of customer i (kg)
TT_{ij}	Travel time from node i to node j (hr)
UT	Unloading time per kg (hr/kg)
RT	Regular working time (hr)
MT	Maximum working time (hr)
FC	Fuel cost ($/km)
WC	Regular wage rate ($/hr)
OC	Overtime wage rate ($/hr)
FIC	Fixed driver cost ($/driver)
UC	Unloading cost ($/kg)
α^d	Energy expenditure rate during driving (kcal/hr)
α^u	Energy expenditure rate during unloading (kcal/kg)
E_k	Maximum energy expenditure capacity of driver k (kcal)
θ_k	Daily allowable energy expenditure limit for driver k (kcal)

Decision variables

x_{ijk}	1 if vehicle k travels from nodes i to node j; 0 otherwise
l_{ijk}	Load carried by vehicle k when traveling from node i to node j (kg)
dl_{ik}	Amount of product delivered to customer i by vehicle k (kg)
wt_k	Total working time of driver k (hr)
ot_k	Overtime hours of driver k (hr)
u_k	Total energy expenditure for unloading by drive k (kcal)
d_k	Total energy expenditure for driving by driver k (kcal)
e_k	Excess energy expenditure of driver k beyond the daily allowable limit θ_k (kcal)
AWG	Absolute average wage gap between female and male drivers.

Objective functions

$$TW_k = WC\, wt_k + OC\, ot_k + FIC + \sum_{i\in C} UC\, dl_{ik} \quad (1)$$

$$FW = \frac{\sum_{k\in K^f} TW_k}{|K^f|},\ MW = \frac{\sum_{k\in K^m} TW_k}{|K^m|} \quad (2)$$

$$min\ TC = \sum_{k\in K}\left(\sum_{i\in N}\sum_{j\in N} FC\, DIS_{ij}\, x_{ijk} + TW_k\right) \quad (3)$$

$$\min \text{AWG} \quad (4)$$

Constraints

$$\sum_{j\in C} x_{0jk} = 1, \forall k \in K \quad (5)$$

$$\sum_{i\in C} x_{i0k} = 1, \forall k \in K \quad (6)$$

$$\sum_{j\in N\ j\neq i} x_{ijk} - \sum_{j\in N, j\neq i} x_{jik} = 0, \forall i \in N, \forall k \in K \quad (7)$$

$$\sum_{j\in N, j\neq i} \sum_{k\in K} x_{ijk} = 1, \forall i \in C \quad (8)$$

$$x_{ijk} = 0, \forall i, j \in N, i = j, \forall k \in K \quad (9)$$

$$\sum_{j\in N, j\neq i} l_{jik} - \sum_{j\in N, j\neq i} l_{ijk} = dl_{ik}, \forall i \in C, \forall k \in K \quad (10)$$

$$\sum_{k\in K} dl_{ik} = CD_i\ \forall i \in C \quad (11)$$

$$l_{ijk} \geq CD_j \times x_{ijk}, \forall i \in N, \forall j \in C, \forall k \in K \quad (12)$$

$$l_{ijk} \leq (CA - CD_i) \times x_{ijk}, \forall i, j \in N, i \neq j, \forall k \in K \quad (13)$$

$$wt_k = \sum_{i,j \in N} (TT_{ij} \times x_{ijk} + UT \times CD_i \times x_{ijk}), \ \forall k \in K \quad (14)$$

$$ot_k \geq 0$$

$$ot_k \geq wt_k - RT, \forall k \in K \quad (15)$$

$$wt_k \leq MT, \forall k \in K \quad (16)$$

$$u_k = \sum_{i \in C} (\alpha^u \times dl_{ik}), \forall k \in K \quad (17)$$

$$d_k = \alpha^d \times \sum_{i,j \in N} (TT_{ij} \times x_{ijk}), \forall k \in K \quad (18)$$

$$d_k + u_k \leq E_k, \forall k \in K \quad (19)$$

$$ex_k \geq (u_k + d_k) - \theta_k, \forall k \in K$$

$$ex_k \geq 0, \forall k \in K \quad (20)$$

$$AWG \geq FW - MW$$

$$AWG \geq MW - FW \quad (21)$$

$$l_{ijk}, dl_{ik}, wt_k, ot_k, u_k, d_k, e_k \geq 0, \ \forall i, j \in N, \forall k \in K$$

$$x_{ijk} = \{0,1\}, \forall i, j \in N, \forall k \in K \quad (22)$$

The total wage cost for each driver, including regular and overtime wages, fixed-driver costs, and unloading wage, is defined in Eq. (1). Eq. (2) computes the average wages of female and male drivers, which serves as the basis for measuring wage disparity. These components support the model's two objectives: minimizing the total cost (Eq. (3)) and minimizing the absolute average wage gap between genders (Eq. (4)).

Constraints (5) and (6) ensure that each vehicle departs from and returns to the depot exactly once. Constraint (7) enforces flow conservation for each customer node. Constraint (8) guarantees that each customer is visited exactly once. Constraint (9) prevents vehicles from traveling from and to the same node. Constraints (10)–(11) manage product flow and guarantee that customer demands are fully met. Constraints (12) and (13) ensure that the delivered quantity does not exceed the vehicle's capacity.

Drivers' working time and overtime are calculated in constraints (14) and (15), while constraint (16) ensures that drivers do not exceed the allowable working hours. Constraints (17)–(20) compute the energy expenditure from driving and unloading tasks, enforce energy capacity limits for each driver, and quantify any excessive expenditure. Wage disparity is defined in constraint (21), and constraint (22) specifies the domains of decision variables.

C. Case Study

To demonstrate the applicability of the proposed GE-VRP model, our case study focuses on a province in Eastern Thailand, selected for its dense population, industrial zones, and well-developed road network. In this case study, goods are delivered from a single depot to 20 customers. A map of the case study (Fig. 1), generated using Geographic Information System (GIS) developed by ESRI (version 3.30), identifies delivery locations and travel distances. Input parameters are summarized in Table 1.

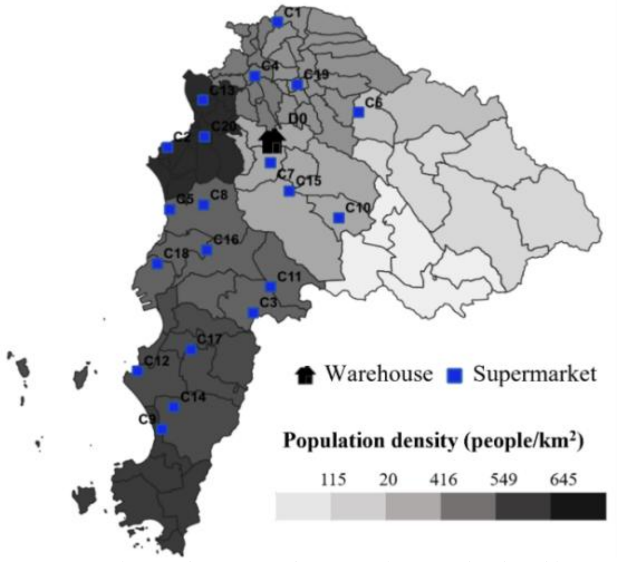

Fig. 1. Case study map from GIS software version 3.30 developed by ESRI.

Table 1. Input parameters.

Parameter	Value
Vehicle capacity (kg)	7,000
Fuel cost ($/km)	0.63
Driver wage ($/hr)	3.5
Energy expenditure coefficient for driving (kcal/hr)	146.89
Energy expenditure coefficient for unloading (kcal/kg)	0.42
Energy expenditure capacity (kcal/day)	Female: 2,400; Male: 3,000

The driver workforce composition and delivery demands are presented as a numerical example. The model considers a driver pool of three female and five male drivers, reflecting a typical gender distribution in a small- to medium-sized logistics company. These inputs are used to evaluate the impact of integrating gender-sensitive parameters into routing decisions under the proposed GE-VRP model.

IV. Results and Discussion

The model was implemented in Python and solved using the Gurobi Optimizer (version 12.0.0) on a Windows 10 Home 64-bit PC equipped with an Intel Core i7-4770 CPU at 3.40 GHz and 8 GB of RAM. The analysis details are as follows.

To evaluate model performance, two objectives were optimized separately: minimizing total operational cost and the average wage gap between male and female drivers. In the cost-focused scenario, the model allocates more workload to male drivers due to their higher energy expenditure capacity, leading to longer working hours and greater earnings than female drivers. Conversely, minimizing the average wage gap requires reallocating more tasks to female drivers, increasing their working hours and excess workload (from 405 to 608 Kcal), and raising the total cost to $1,339—a 10% increase compared to the cost-focused scenario.

Table 2. Solutions of cost and average wage gap-minimizing objectives

Objective Function / Performance Metric	Min total cost	Min average wage gap
Total cost ($)	1215	1339
Wage Gap (%)	10.2	0
Average Wage – Female	93.7	102.4
Average Wage–Male	104.4	102.4
Average Working Hours–Female	10.2	11.3
Average Working Hours–Male	11.5	11.5
Average excessive workload–Female	405	608
Average excessive workload–Male	236	215

The Pareto frontier in Fig. 2 highlights the trade-off between the average wage gap percentage and total cost. It shows that substantial cost savings can be achieved with only a small allowance in wage disparity. For instance, permitting a 1–2% wage gap reduces the total cost to around $1,230, while further increases yield diminishing returns, with the lowest cost of $1,215 observed at a 10% gap. These results emphasize the value of a multi-objective approach in identifying solutions that balance operational efficiency and gender equity.

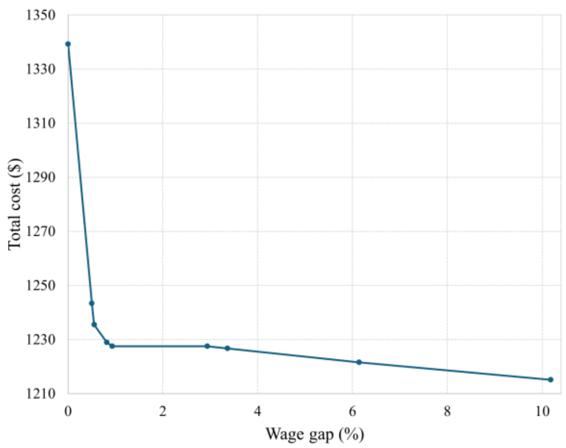

Fig. 2. Pareto frontier of cost and wage gap trade-off.

V. Conclusion

This study contributes a novel GE-VRP model that integrates gender-specific parameters, particularly differentiated energy expenditure thresholds into a multi-objective optimization framework. The model captures physiological differences between male and female drivers, a dimension often overlooked in traditional VRP formulations. A case study in Eastern Thailand demonstrated the model's practical relevance, showing how inclusive logistics planning can be supported through equitable task allocation and cost-efficiency trade-offs.

Results indicate that wage parity can be achieved, though at a moderate increase in total cost. This outcome underscores the trade-offs between fairness and physiological capacity, as equalizing wages leads to longer working hours and greater energy expenditure for female drivers. Nonetheless, the multi-objective solution shows that near-equity can be attained with only a 1–1.2% cost increase, offering practical insight for balancing efficiency with fairness in transport operations.

The GE-VRP model provides a scalable foundation for future research across various sectors and geographical contexts. Its structure can be adapted by adjusting gender-differentiated parameters, such as energy expenditure, service time, and workload thresholds, to reflect industry-specific conditions. These adjustments may depend on factors such as the type of product handling and the physical effort or time required for unloading, which can vary significantly between drivers or across sectors. Additionally, the model can be applied to different geographical areas to understand more about the effects of transportation risk factors.

Several limitations remain. The model does not directly account for environmental impacts on local communities, which are important considerations in transportation planning, as illustrated in the work of Olapiriyakul and Nguyen (Olapiriyakul and Nguyen, 2019). It also does not consider transportation-related risks, which may vary by gender and time of day, particularly in areas with limited infrastructure or safety concerns. Furthermore, the model was tested on a small scale; solving more extensive and more complex problems may require adopting heuristic or metaheuristic methods. Future work should integrate localized environmental and risk factors and extend the model to real-world applications involving larger datasets and diverse constraints.

Conflict of Interest

The authors declare no conflict of interest

Author Contributions

Phan Thi Kim Phung worked on conceptualization, data curation, formal analysis, methodology, validation, writing, review & editing; Pavinee Rerkjirattikal worked on conceptualization, writing original draft, writing, review & editing; SangGyu Nam worked on conceptualization, writing, review & editing; Sun Olapiriyakul worked on conceptualization, validation, supervision, writing original draft, writing review & editing; all authors had approved the final version.

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