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A Mixed Integer Linear Programming Model for Packaged Drinking Water Distribution Routing Problem

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Abstract. *This study addresses the Vehicle Routing Problem with heterogeneous vehicles, simultaneous pickup and delivery, multiple trips, and time windows (HVRPSPDMTTW), formulated for the distribution of packaged drinking water (PDW) specifically gallon-packaged PDW. The model was developed to reflect real operational conditions of PDW depots which employs a heterogeneous fleet of pickup trucks and three-wheeled commercial motorcycles to deliver and collect gallon-packaged PDW within defined time windows. The mathematical model is constructed as a Mixed Integer Linear Programming (MILP) formulation with the objective of minimizing total transportation costs, consisting of both fixed and variable vehicle costs. Verification of the model was carried out using LINGO 18.0 software on hypothetical datasets generated through random numbers, with small-scale scenarios involving 5 customers. Computational results confirm that all constraints were satisfied and that the model produces logical and feasible routing solutions. The behavior verification further shows that the model accurately responds to parameter changes, such as reduced vehicle capacity and narrower time windows, demonstrating consistent and realistic results. This research validates the feasibility and reliability of the proposed MILP model in representing real-world distribution systems.*

Keywords: *heterogeneous; simultaneous pick-up and delivery; multi trip; time windows; MILP*

I. INTRODUCTION

Access to clean and safe drinking water is a fundamental human need (UN-Water, 2021) and a crucial component of public health and economic development (WHO/UNICEF JMP, 2025). As urbanization, population growth, and lifestyle changes continue to shape consumption patterns, the demand for practical and reliable drinking water solutions has significantly increased. One of the most notable developments addressing this need is the rise of Packaged Drinking Water (PDW) or Air Minum dalam Kemasan (AMDK), which has become an integral part of modern consumer behaviour in Indonesia. The concept of PDW in Indonesia has evolved as a significant response to the growing demand for safe and accessible drinking water. According to BPS (Badan Pusat Statistik (BPS), 2024), in 2024, approximately 34.49% of households in Indonesia now rely on refilled drinking water as their primary source, while branded packaged water ranks fifth after bore wells, protected wells, and protected springs. It is predicted that in 2026, 50% of Indonesian population will consume PDW (Ikhsan et al., 2022). This substantial rise in public consumption of both branded and refilled drinking water reflects a growing reliance on commercial water distribution systems. Consequently, the demand for efficient and adaptive distribution systems has become increasingly critical.

One of the most widely applied analytical approaches in distribution planning is the Vehicle Routing Problem (VRP). The distribution modelling of PDW using the VRP framework has been examined in (Nayak et al., 2025) with capacitated VRP, (Israh et al., 2025) which address multiple routes in the model, and (Rizkiani et al., 2024) which already mention simultaneous pick-up and delivery. Gallon-packaged PDW involves a simultaneous process of delivery and pick-up of empty gallon, reflecting the pickup-and-delivery characteristic of the VRP commonly applied to distribution systems involving reusable or returnable products. In the Vehicle Routing

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Problem with Simultaneous Pickup and Delivery (VRPSPD), the pickup and delivery demand of each customer must be fulfilled within a single visit, while ensuring that vehicle capacity constraints are not violated throughout the route (Koç et al., 2020). In the mathematical formulation, the VRPSPD separates each customer's demand into pickup and delivery components (Avci & Topaloglu, 2016). Beyond this foundational formulation, subsequent studies extended the VRPSPD by incorporating additional operational characteristics, most notably the time window constraint (Seixas & Mendes, 2013), (Sethanan & Jamrus, 2020), (Shi et al., 2020), (Liu et al., 2021), and (Oktafianto & Arvitrida, 2023). A further enhancement is the multi trip characteristic, which adds a route index to the decision variables (Garside & Cahyanti, 2018), enabling each vehicle to perform several routes per day (Seixas & Mendes, 2013). The two characteristics of the VRPSPD are adopted in this study to represent real-world distribution conditions, in which each customer has a specific service time window and each vehicle is allowed to perform multiple routes in order to maximize vehicle utilization.

The heterogeneous vehicle routing approach incorporated in this model accommodates variations in vehicle capacities resulting from access constraints between depots and customer locations, which in some cases involve navigating through narrow alleys or congested roads. This situation is exemplified in a distribution center in Bondowoso (Efendi, 2017), where the distribution of PDW utilizes pickup trucks and larger delivery trucks, while in Depo Air Minum AS also employ motorized tricycles (such as TOSSA or VIAR) to reach areas with limited accessibility. Seixas and Mendes (2013) specifically address VRP with multi trip and heterogeneous vehicles.

VRPSPD with characteristics heterogeneous fleet and multi trips has been elaborated in (Rizkiani et al., 2023) using a simulated annealing approach, although the time window constraint was not considered (HVRPSPDMT). Meanwhile, (Oktafianto & Arvitrida, 2023) investigated the HVRPSPDTW problem that incorporates time window constraints, but the multi-trip characteristic was not included in the model. Cavaliere et al. (2024) developed a heuristic approach for very large-scale VRPSPD to overcome the computational challenges of exact optimization methods. Meanwhile, Borumand and Nookabadi (2024) investigated an integrated fleet sizing and routing problem with simultaneous delivery and pickup under a closed-loop supply chain framework. Their applications focus on general logistics problems rather than the specific operational characteristics of packaged drinking water distribution. (Wang et al., 2024) developed a heterogeneous, multi trip electric vehicle routing model with pickup and delivery, yet without addressing customer time windows, while (Indrianti et al., 2025) combined time windows, simultaneous pickup and delivery, heterogeneous fleets, and multiple trips for LPG distribution, but did not formulate the model as an exact MILP.

Previous studies have investigated various extensions of the Vehicle Routing Problem by incorporating characteristics such as shown in Table 1. However, these characteristics are often studied in general distribution systems or specific applications that may not fully represent the operational conditions of packaged drinking water (PDW) distribution. In PDW distribution, vehicle routing decisions are influenced by the simultaneous delivery of filled gallons and collection of empty gallons, different vehicle accessibility conditions, repeated depot visits, and customer service time limitations. Therefore, an integrated routing model that considers these operational characteristics is required to better represent PDW distribution activities. This study addresses this gap by developing a mixed integer linear programming model for PDW distribution that integrates heterogeneous vehicle selection, simultaneous pickup and delivery, multi-trip operations, and time window constraints (HVRPSPDMTTW) to minimize total vehicle operating costs based on PDW distribution case in Depo Air Minum AS. Theoretically, this research contributes to the advancement of distribution optimization by integrating multiple complex VRP characteristics into a comprehensive mathematical framework. Practically, this research provides an optimization approach for Depo Air

Table 1. Summary of Studi

Reference	Heterogeneous Fleet	Simultaneous Pickup & Delivery	Multi Trip	Time Windows	PDW
Oktafianto & Arvitrida (2023)	✓	✓	✗	✓	✗
Rizkiani et al. (2023)	✓	✓	✓	✗	✓
Cavaliere et al. (2024)	✗	✓	✗	✗	✗
Rizkiani et al. (2024)	✗	✓	✓	✗	✓
Wang et al. (2024)	✓	✓	✓	✗	✗
Indrianti et al. (2025)	✓	✓	✓	✓	✗
***This Study* (2026)**	✓	✓	✓	✓	✓

Minum AS in planning distribution routes and allocating vehicles according to customer locations, demands, and accessibility conditions.

II. RESEARCH METHOD

This study focuses on optimizing the distribution routing system for Packaged Drinking Water (PDW), illustrated through the operations of Depo Air Minum AS. The depot distributes gallon-packaged PDW using a heterogeneous fleet consisting of pickup trucks and three-wheeled commercial motorcycles. Each customer is served within a specific time window, a constraint derived from field observations at Depo Air Minum AS, where customers, including small retail outlets, food establishments, and households, have specific allowable delivery periods. Small retailers and food establishments generally receive deliveries during their business hours, while household customers have specific periods when they are available to receive deliveries. The constraint also reflects the depot's operational limitations, including fixed driver working schedules and recurring traffic conditions affecting distribution routes, and deliveries are conducted through multiple trips per day, resulting in a complex routing structure. These operational features define the problem as a Vehicle Routing Problem (VRP) with heterogeneous vehicle, simultaneous pickup and delivery, multi-trip, and time-window characteristics (HVRPSPDMTTW). The objective is to determine optimal vehicle routes that minimize total transportation costs, including both fixed and variable components, while satisfying vehicle capacity and service constraints.

To address these challenges, a mathematical model is developed and extended to include aforementioned characteristics. The data used for model validation consist of hypothetically generated datasets, structured in the form of random numbers that simulate realistic distribution patterns. The proposed model is systematically developed and verified using LINGO optimization software, ensuring its applicability in improving routing efficiency and vehicle utilization in PDW distribution systems. Model verification is conduct by assessing the computational result to the constraints to ensure that all constraints are fulfilled. Verification of the model's behavior is also conducted to determine whether the model's behavior reflects real-world common sense.

Problem Description

The problem of HVRPSPDMTTW can be respresented as a graph $G = (N, A)$ where $N = \{0,1,2,3, \ldots, n, n+1\}$ denotes the set of nodes and $A = \{(i,j), i,j \in N, i \neq j\}$ denotes the set of arcs. The nodes $\{0, n+1\}$ correspond to the depot, while $\{1, 2, 3, \ldots, n\}$ denote the customers. A dummy depot node $\{n+1\}$ is introduced to ensure that each route starts and ends at the depot. Each node N is associated with a pickup demand (P_i) and a delivery demand (D_i) , representing the quantity of product to be collected or delivered at that location. The pickup and delivery operations are performed by a heterogeneous fleet of vehicles denoted by $k \in K$, where each vehicle has distinct characteristics including speed (V_k), capacity (Q_k), and variable cost (VC_k). The loading and unloading processes are carried out sequentially within a single service period, with a loading rate (LR) and unloading rate (UR) per unit of goods handled. Each vehicle can serve $r \in R$ routes to fulfill all demand. Every customer node N must be serviced within its assigned time window, defined by the opening time (a_i) and closing time (b_i). If a vehicle arrives before the opening time, it must wait, whereas arrival after the closing time renders the service infeasible. Vehicles travel a distance DS_{ij} with a corresponding travel time TT_{ijk}. Each vehicle incurs a fixed cost (FC_k) for the planning horizon and a variable cost (VC_k) per unit of distance traveled. The objective of the mathematical model is to minimize the total transportation cost, achieved by minimizing both the number of vehicles utilized and the total travel distance.

Model Assumptions

The following assumptions are considered in the development of the proposed vehicle routing model:

1. The vehicle speed is assumed to be constant during the distribution process. Therefore, travel time between locations is determined based on the distance between nodes and the average vehicle speed.
2. The road conditions along the distribution routes are assumed to be known and relatively stable. Traffic congestion and unexpected road disruptions are not explicitly considered in the model; therefore, the travel time remains deterministic.
3. The depot has sufficient capacity to store packaged drinking water and returned empty gallons. Thus, depot storage limitations are not included as a constraint in the model.
4. The service time at each customer location is assumed to be known and constant, including the time required for unloading filled gallons and collecting empty gallons.
5. Each vehicle has a predetermined capacity based on its type, and the total load carried during a route must not exceed the vehicle capacity.
6. Each vehicle is allowed to perform multiple trips within the planning horizon, with the maximum number of trips determined based on operational limitations of the distribution system.
7. Customer demands for delivered and picked-up gallons are assumed to be known in advance during the planning period.
8. Each customer must be visited within the specified time window, and the vehicle is assumed to start and end its route at the depot.
9. The number and type of available vehicles are assumed to be known, and vehicle selection is included as part of the routing decision.
10. The distribution process considers simultaneous pickup and delivery, where filled gallons are delivered and empty gallons are collected during the same customer visit.

Model Notation

Indices:

i, j Index of customer nodes
k Index of vehicle
r Index of routes

Sets:

N Sets of nodes, $\mathrm{N} = \{0, \mathrm{n}+1\} \cup \{1,2, \dots, \mathrm{n}\}$
A Sets of arcs
K Sets of heterogeneous vehicles available

Parameters:

a_0 Depot opening time (minutes)
b_0 Depot closing time (minutes)
a_i Opening time of customer i (minutes)
b_i Opening time of customer i (minutes)
Q_k Maximum capacity of vehicle k (unit)
V_k Velocity of the vehicle k (m/minutes)
D_i Delivery demand for node i (unit)
P_i Pick-up demand for node i (unit)
DS_{ij} Distance between nodes in arc (i, j) (m)
FC_k Fixed cost of vehicle k (Rp.)
VC_k Variable cost of vehicle k per distance unit (Rp./m)
LR Loading rate per unit (minutes/unit)
UR Unloading rate per unit (minutes/unit)
R Maximum routes allowed for each vehicle
TT_{ijk} Travel time of arc (i, j) using vehicle k (minutes).

Model Formulation

$$\text{Min} \sum_{k\in K} FC_k \cdot Y_k + \sum_{r=1}^{R}\sum_{k\in K}\sum_{i\in N\backslash\{n+1\}}\sum_{j\in N\backslash\{0\}} VC_k \cdot DS_{ij} \cdot X_{ijkr} \quad (1)$$

$$\sum_{r=1}^{R}\sum_{k\in K}\sum_{j\in N\backslash\{0\}} X_{ijkr} = 1, \qquad i \in N\backslash\{0, n+1\} \quad (2)$$

$$\sum_{j\in N\backslash\{0\}} X_{0jkr} = 1, \qquad k \in K, r = 1, \dots, R \quad (3)$$

$$\sum_{i\in N\backslash\{n+1\}} X_{i(n+1)kr} = 1, \qquad k \in K, r = 1, \dots, R \quad (4)$$

$$\sum_{i\in N\backslash\{n+1\}} X_{ihkr} - \sum_{j\in N\backslash\{0\}} X_{hjkr} = 0, \qquad k \in K, h \in N\backslash\{0, n+1\}, \qquad r = 1, \dots, R \quad (5)$$

$$Y_k \geq \sum_{j\in N\{0,n+1\}} X_{0jkr}\,, \qquad k \in K, r = 1, \dots, R \quad (6)$$

$$\sum_{i\in N\backslash\{0\}} X_{i0kr} = 0, \qquad \forall k \in K, r = 1, \dots, R \quad (7)$$

$$\sum_{j\in N\backslash\{n+1\}} X_{(n+1)jkr} = 0, \qquad \forall k \in K, r = 1, \dots, R \quad (8)$$

$$PX_{0jkr} = 0, \qquad \forall j \in N\backslash\{0, n+1\}, \forall k \in K, r = 1, \dots, R \quad (9)$$

$$DX_{i(n+1)kr} = 0, \qquad \forall i \in N\backslash\{0, n+1\}, \forall k \in K, r = 1, \dots, R \quad (10)$$

$$\sum_{r=1}^{R}\sum_{k\in K}\sum_{i\in N} PX_{jikr} - \sum_{r=1}^{R}\sum_{k\in K}\sum_{i\in N} PX_{ijkr} = P_j, \qquad \forall j \in N\backslash\{0, n+1\} \quad (11)$$

$$\sum_{r=1}^{R}\sum_{k\in K}\sum_{i\in N} DX_{ijkr} - \sum_{r=1}^{R}\sum_{k\in K}\sum_{i\in N} DX_{jikr} = D_j, \qquad \forall j \in N\backslash\{0, n+1\} \quad (12)$$

$$\sum_{r=1}^{R}\sum_{k\in K}\sum_{i\in N\backslash\{0,n+1\}} PX_{i(n+1)kr} = \sum_{i\in N\backslash\{0,n+1\}} P_i \quad (13)$$

$$\sum_{r=1}^{R}\sum_{k\in K}\sum_{i\in N\backslash\{0,n+1\}} DX_{0ikr} = \sum_{i\in N\backslash\{0,n+1\}} D_i \quad (14)$$

$$PX_{ijkr} + DX_{ijkr} \leq Q_k \cdot X_{ijkr}, \qquad \forall i,j \in A, \forall k \in K, r = 1, \dots, R \quad (15)$$

$$U_{kr} = \sum_{i\in N\backslash\{0,n+1\}} PX_{i(n+1)kr} \cdot UR\,, \qquad \forall k \in K, r = 1, \dots, R \quad (16)$$

$$L_{kr} = \sum_{i\in N\backslash\{0,n+1\}} DX_{0ikr} \cdot LR\,, \qquad \forall k \in K, r = 1, \dots, R \quad (17)$$

$$a_i \leq T_{ikr}, \qquad \forall i \in N, \forall k \in K, r = 1, \dots, R \quad (18)$$

$$T_{ikr} + P_i \cdot LR + D_i \cdot UR \leq b_i, \qquad \forall i \in N\backslash\{0, n+1\}, \forall k \in K, \qquad r = 1, \dots, R \quad (19)$$

$$T_{(n+1)kr} \leq b_{(n+1)} - U_{kr}, \qquad \forall k \in K, r = 1, \dots, R \quad (20)$$

$$T_{0kr} + L_{kr} + TT_{0ik} - M(1 - X_{0ikr}) \leq T_{ikr}, \qquad \forall i \in N\{0, n+1\}, \qquad \forall k \in K, r = 1, \dots, R \quad (21)$$

$$T_{ikr} + P_i \cdot LR + D_i \cdot UR + TT_{ijk} - M\left(1 - X_{ijkr}\right) \leq T_{jkr}, \qquad \forall i,j \in N\backslash\{O_r, O_{r+1}\}, \forall k \in K, r = 1, \dots, R \quad (22)$$

$$T_{(n+1)k(r-1)} \leq T_{0kr} - U_{k(r-1)}, \qquad \forall k \in K, r = 2, \dots, R \quad (23)$$

$$T_{0kr} \leq T_{(n+1)kr}, \qquad \forall k \in K, r = 1, \dots, R \quad (24)$$

$$X_{ijkr} \in \{0,1\}, \qquad (i,j) \in A, k \in K, r = 1, \dots, R \quad (25)$$

$$Y_k \in \{0,1\}, \qquad k \in K \quad (26)$$

$$T_{ikr} \geq 0, \qquad k \in K, r = 1, \dots, R, i \in N \cup \{O_r, O_{r+1}\} \quad (27)$$

$$PX_{ijkr} \geq 0, \qquad (i,j) \in A, k \in K, r = 1, \dots, R \quad (28)$$

$$DX_{ijkr} \geq 0, \qquad (i,j) \in A, k \in K, r = 1, \dots, R \quad (29)$$

The objective function (1) aims to minimize the total transportation cost, is the sum of all fixed vehicle costs for the vehicles used and the total variable costs. Constraints (2) – (5) ensure that each customer is visited exactly once, every route starts and ends at the depot, and for each vehicle and route, the flow of arrivals and departures at each customer node is balanced, guaranteeing route continuity and feasibility. Constraint (6) represents the utilization status of vehicle k derived from (Seixas & Mendes, 2013). Constraints (7) and (8) ensure that vehicle movements are restricted between depots, allowing departures only from the origin depot and arrivals only at the destination depot. Constraints (9) and (10) ensures that no goods are unloaded at the origin depot and no goods are loaded at the destination depot, adapted from (Avci & Topaloglu, 2016) with index adjustments to accommodate multiple routes. Constraints (11) and (12) represents the flow equations for the simultaneous pickup and delivery model as described in (Ruiz-Meza et al., 2020). Constraints (13) and (14) state that the total quantity of goods entering the depot must equal the total pickup demand, while the total quantity of goods leaving the depot must equal the total delivery demand. Constraint (15) states the vehicle capacity constraint. Constraints (16) and (17) calculates service time in customer location for each unloading or loading activities. Constraints (18) and (19) represent the time window limitations while constraint (20) represents closing time window in depot. Constraints (21) – (24) define the sequence and flow of service times as well as the order of routes when a vehicle serves multiple routes, while constraints (25) – (29) specify the decision variable boundaries.

Data Set

The data used for model testing in this study consist of hypothetical datasets generated statistically using random numbers. The customer location distribution follows a random spatial pattern, while the time windows are a combination of narrow and wide intervals to reflect varying service constraints. The model is tested using small-sized datasets, consisting of 5 customers.

III. Result and Discussion

Computational Result

The developed mathematical model was implemented and executed using LINGO 18.0 software. Model verification was carried out on a computer equipped with an Intel® Core™ i7-6500U CPU @ 2.50GHz 2.59GHz processor, 8 GB RAM, and Windows 10 Pro 64-bit operating system. Experiments were conducted using small-scale hypothetical data shown in Table 2 and Table 3 to ensure that the results were logical and satisfied all defined constraints. The result of the computation is presented in Table 4.

Based on the solution presented above, it can be observed that one tour was generated using Vehicle 1, which has a maximum capacity of 10 units. A total of four routes were formed, where the first route was not executed for it is serving as a dummy route. All customers were successfully served within their respective time windows, and the service times corresponded to the quantity of goods loaded and unloaded. The total load carried by the vehicle did not exceed its capacity. The sequence of routes was executed in order—from the first to the last—according to departure time, travel duration, and vehicle arrival schedule. Verification of each constraint was carried out based on the computational results presented above. From this verification, it can be concluded that the HVRSPDPMTTW mathematical model satisfies all defined constraints.

Verification of Model's Behaviour

Verification of the model's behavior was carried out to evaluate whether the developed model accurately and logically represents real-world system conditions. This verification was conducted by adjusting several model parameters to determine whether the resulting solutions align with expected outcomes. In this study, the verification process involved reducing vehicle capacities and narrowing customer time windows to test the model's responsiveness and consistency under varying operational conditions.

The result of model's behaviour verification is presented in Table 5.

Table 4 shows that reducing vehicle capacity leads to changes in vehicle utilization and the sequence of customers served. Moreover, the objective function value increases because Vehicle 2, which replaces Vehicle 1, has a higher variable cost. Narrowing the time windows (changing from mixed to tighter time windows) results in the need for more than two vehicles to serve two trips. Consequently, the objective function value rises significantly due to the additional fixed costs of the vehicles. The model's behaviour in response to parameter changes indicates that the developed model behaves logically and consistently, as it produces solutions

Table 2. Demand and Time Windows Data for Model Computation

Node (i)	Demand (unit)		Time windows (minutes)	
	Pick-up (P_i)	Delivery (D_i)	Opening time (a_i)	Closing time (b_i)
0	0	0	0	600
1	1	1	51	168
2	2	2	107	289
3	6	6	242	358
4	1	5	99	534
5	7	2	54	392

Table 3. Distance (m)

DS_{ij}	**0**	**1**	**2**	**3**	**4**	**5**
0	0	374	278.7	44.4	286.9	225.4
1	374	0	95.8	411.5	191	384
2	278.7	95.8	0	315.8	155.6	304.1
3	44.4	411.5	315.8	0	331.2	215
4	286.9	191	155.6	331.2	0	408.8
5	225.4	384	304.1	215	408.8	0

Table 4. Tour Solution and Model Verification

Tour 1, Vehicle 1, Capacity 10 unit, velocity 15 m/minute														
Customer	*P*	*D*	*Status P*	*Status D*	*Status Q*	*Opening Time*	*Arrival Time*	*Starting Time*	*Service Time*			*Departure*	*Travel Time*	*Closing Time*
									Unloading	*Loading*	*Total*			
Route 1														
0	*0*	*0*	*0*	*8*	*8*	*0*	*0.00*	*80.42*	*0*	*8*	*8*	*88.42*	*18.58*	*600*
2	*2*	*2*	*2*	*6*	*8*	*107*	*107.00*	*107.00*	*2*	*2*	*4*	*111.00*	*6.39*	*289*
1	*1*	*1*	*3*	*5*	*8*	*51*	*117.39*	*117.39*	*1*	*1*	*2*	*119.39*	*12.73*	*168*
4	*1*	*5*	*4*	*0*	*4*	*99*	*132.12*	*132.12*	*5*	*1*	*6*	*138.12*	*19.13*	*534*
0	*0*	*0*	*4*	*0*	*4*	*0*	*157.25*	*157.25*	*4*	*0*	*4*	*161.25*	*0.00*	*600*
Route 2														
0	*0*	*0*	*6*	*6*	*0*	*0*	*161.25*	*161.25*	*0*	*6*	*6*	*167.25*	*2.96*	*600*
3	*6*	*6*	*6*	*0*	*6*	*242*	*170.21*	*242.00*	*6*	*6*	*12*	*254.00*	*2.96*	*258*
0	*0*	*0*	*6*	*0*	*6*	*0*	*256.96*	*359.97*	*6*	*0*	*6*	*365.97*	*0.00*	*600*
Route 3														
0	*0*	*0*	*0*	*2*	*2*	*0*	*365.97*	*365.97*	*0*	*6*	*6*	*371.97*	*15.03*	*600*
5	*7*	*2*	*7*	*0*	*7*	*54*	*387.00*	*383.00*	*2*	*7*	*9*	*392.00*	*15.03*	*392*
0	*0*	*0*	*7*	*0*	*7*	*0*	*407.03*	*588.64*	*7*	*0*	*7*	*595.64*	*0.00*	*600*

Table 5. Result of Model's Behaviour Verification

Alteration	**Initial data**	**Reducing vehicle capacity**	**Narrowing customer's time windows**
Tour	1	1	2
Number of Routes	3	3	2 and 1
Vehicle	Vehicle 1	Vehicle 2	Vehicle 1 and 2
Routes	0-2-1-4-0-3-0-5-0	0-5-0-4-1-2-0-3-0	0-1-4-0-3-0 and 0-5-2-0
Objective Function	12,784.10	14,176.10	24,306.10

that align with real-world expectations and common sense.

IV. CONCLUSION

Based on the conducted research, it can be concluded that the developed mathematical model is capable of solving the vehicle routing problem with heterogeneous vehicles, simultaneous pickup and delivery, multiple trips, and single time windows (HVRPSPDMTTW). The model has been verified using hypothetical data and demonstrated logical solution behavior while satisfying all defined constraints, including route continuity, vehicle capacity limitations, pickup-delivery requirements, multi-trip operations, and customer time windows.

Theoretically, this study contributes to the development of vehicle routing models by integrating several operational characteristics into a unified mathematical framework for packaged drinking water (PDW) distribution. The proposed model extends the application of VRP by considering the combination of heterogeneous fleet selection, simultaneous delivery and collection of reusable gallons, multi-trip operations, and time window constraints.

Practically, this study provides a decision-support framework for PDW distribution operators in determining vehicle assignments and distribution routes. The model can assist companies in planning delivery and pickup activities, improving vehicle utilization, and reducing unnecessary transportation costs while maintaining customer service requirements.

This study is limited to mathematical model development and verification using hypothetical data. Although the model successfully represents the PDW distribution process, further validation using larger real-world datasets is required. Additionally, the increasing number of customers may lead to higher computational complexity; therefore, future research may focus on developing heuristic or metaheuristic solution approaches to solve larger-scale routing problems. Furthermore, incorporating additional VRP characteristics, such as multi-item distribution with three-dimensional loading constraints, may improve the realism of vehicle capacity representation and enhance practical applicability.

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