Volume 27
Number 2
September 2025

ISSN 1410-9530 (Print) • ISSN 1979-570X (Online)

# CED

# Civil Engineering Dimension

JOURNAL OF CIVIL ENGINEERING SCIENCE AND APPLICATION

**DIMENSI TEKNIK SIPIL** – Jurnal Keilmuan dan Penerapan Teknik Sipil



**Accredited by DGHE No. 225/E/KPT/2022**

ced.petra.ac.id

PETRA CHRISTIAN UNIVERSITY - SURABAYA, INDONESIA

| Civil Engineering Dimension | Vol. 27 | No. 2 | Page 113-224 | Surabaya, September 2025 | ISSN 1410-9530 (Print) / ISSN 1979-570X (Online) |
|---|---|---|---|---|---|

# CIVIL ENGINEERING DIMENSION
## Journal of Engineering Science and Application

Volume 27, Number 2, September 2025 ISSN 1410-9530 (print)/ISSN 1979-570X (online)





**Editor and Administration Address:**
**Institute of Research and Community Outreach**
**Petra Christian University**
Jl. Siwalankerto 121-131, Surabaya 60236 – Indonesia
Phone: +62-31-2983392; +62-31-2983147
E-mail: dimensi-sipil@petra.ac.id; Home page: https://ced.petra.ac.id/;
Also available at: http://infotrac.galegroup.com.

The Civil Engineering Dimension (Dimensi Teknik Sipil) was first published in March 1999 to replace the civil engineering edition of Dimensi a journal published by Petra Christian University early in March 1980. The Civil Engineering Dimension was first accredited by the Directorate General of Higher Education of Indonesia in 2000, with its decree no395/DIKTI/Kep/2000, dated 27 November 2000. The Civil Engineering Dimension (Dimensi Teknik Sipil) is a refereed journal, published twice a year, in March and September.

**CIVIL ENGINEERING DIMENSION**
**Journal of Engineering Science and Application**

Volume 27, Number 2, September 2025 ISSN 1410-9530 (print)/ISSN 1979-570X (online)

# CIVIL ENGINEERING DIMENSION
**Journal of Civil Engineering Science and Application**

Volume 27, Number 2, September 2025 ISSN 1410-9530 (print)/ISSN 1979-570X (online)

## CONTENTS

# Civil Engineering Dimension

| COUNTRY | SUBJECT AREA AND CATEGORY | PUBLISHER | SJR 2024 |
|---|---|---|---|
| Indonesia<br>Universities and research institutions in Indonesia<br>Media Ranking in Indonesia | Engineering<br>- Building and Construction<br>- Civil and Structural Engineering<br>- Computational Mechanics<br>- Mechanics of Materials | Petra Christian University | 0.194 Q3<br><br>H-INDEX<br>3 |

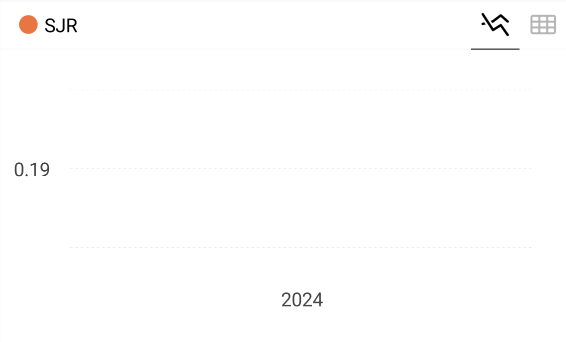
| PUBLICATION TYPE | ISSN | COVERAGE | INFORMATION |
|---|---|---|---|
| Journals | 14109530, 1979570X | 2022-2024 | Homepage<br>How to publish in this journal<br>ced-editor@petra.ac.id |

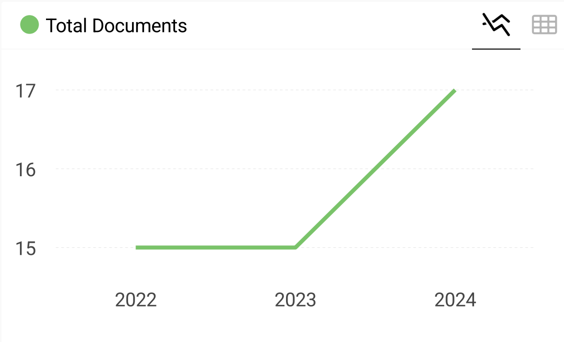
## SCOPE

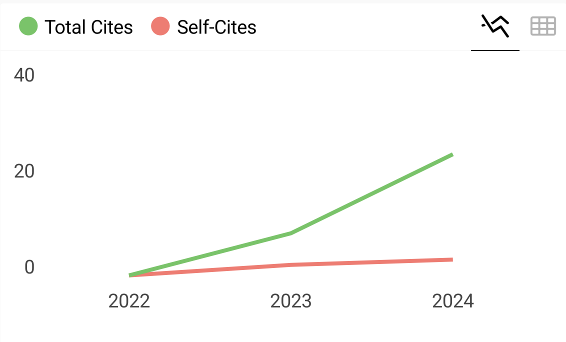
Civil Engineering Dimension (CED), published biannually in March and September by Petra Christian University, is committed to the following objectives: Advancing a comprehensive approach to civil engineering by integrating perspectives from diverse disciplines. Fostering academic collaboration and exchange with institutions worldwide. Encouraging scientists, practicing engineers, and others to engage in research and related endeavours. We invite submissions aligned with these aims and scopes. The editorial board supported by appointed reviewers, evaluates and selects papers for publication. Authors receive feedback and guidance based on reviewers' comments and suggestions. We also consider papers previously presented at conferences not affiliated with Petra Christian University Publication, though a copyright release may be necessary in such cases. Additionally, papers exploring tutorial or historical aspects within the field are welcomed for review and consideration.

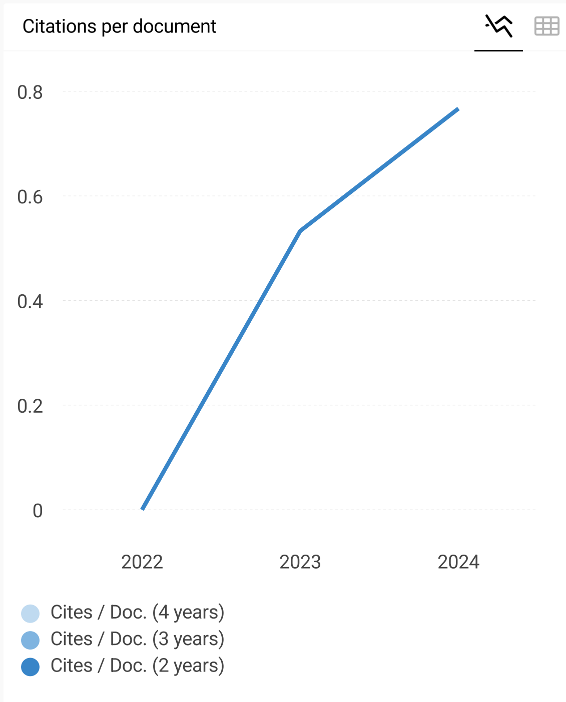
Join the conversation about this journal

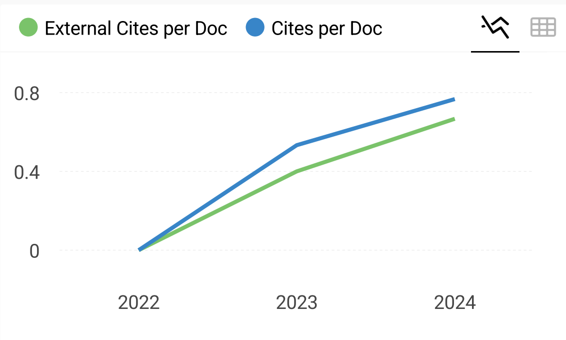
Quartiles

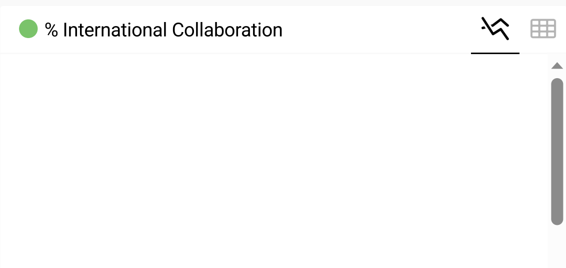


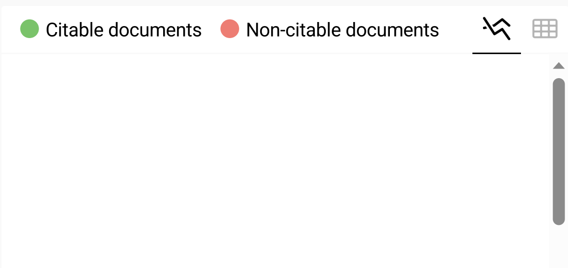



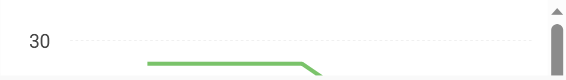



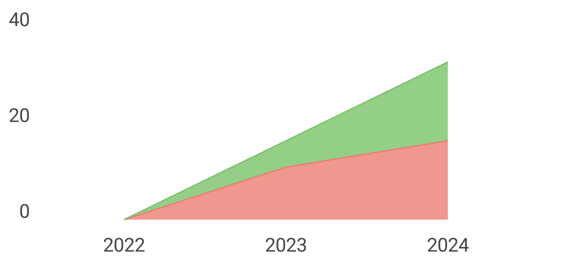



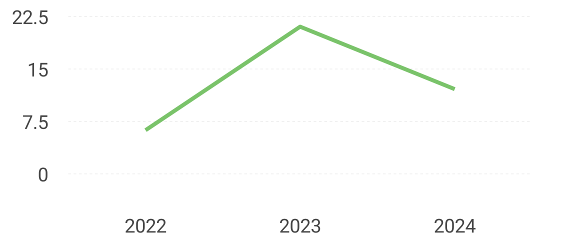




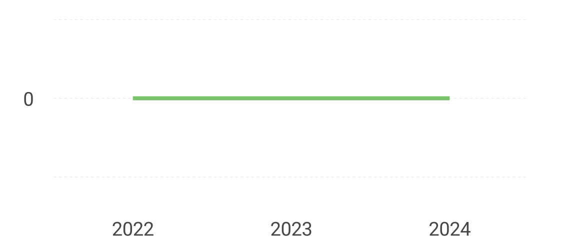
Cited documents Uncited documents



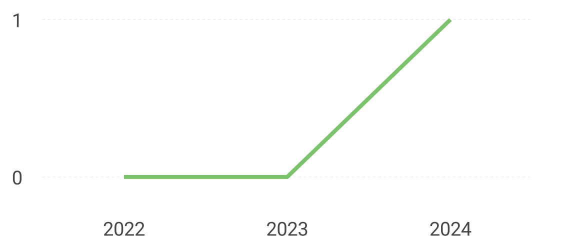

% Female Authors



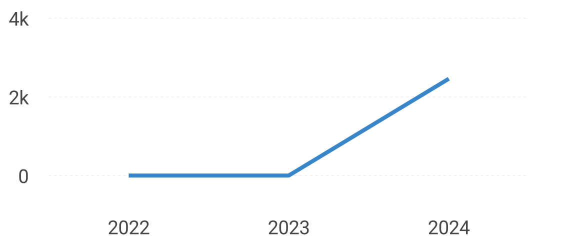

Documents cited by public policy (Overton)



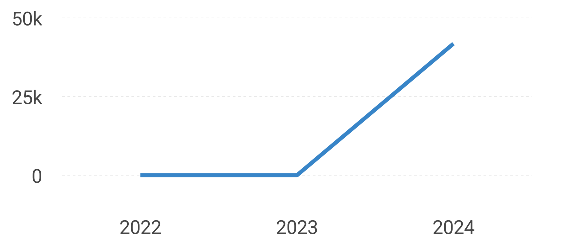

Documents related to SDGs (UN)




Estimated APC




Estimated financial value





← Show this widget in your own website

Just copy the code below and paste within your html code:

<a href="https://www.scimag

SCImago Graphica

Explore, visually communicate and make sense of data with our **new data visualization tool**.

Metrics based on Scopus® data as of March 2025

Loading comments...

# Source details

## Civil Engineering Dimension

*Open Access*

Years currently covered by Scopus: from 2022 to 2025

Publisher: Petra Christian University

ISSN: 1410-9530 E-ISSN: 1979-570X

Subject area: Engineering: Building and Construction | Engineering: Civil and Structural Engineering | Engineering: Computational Mechanics | Engineering: Mechanics of Materials

Source type: Journal

CiteScore 2024
0.7

SJR 2024
0.194

SNIP 2024
0.526

View all documents > Set document alert Save to source list

CiteScore CiteScore rank & trend Scopus content coverage

### CiteScore 2024

0.7 = 35 Citations 2021 - 2024 / 47 Documents 2021 - 2024

Calculated on 05 May, 2025

### CiteScoreTracker 2025

0.9 = 62 Citations to date / 67 Documents to date

Last updated on 05 November, 2025 • Updated monthly

### CiteScore rank 2024

| Category | Rank | Percentile |
|---|---|---|
| Engineering — Building and Construction | #194/239 | 18th |
| Engineering — Civil and Structural Engineering | #343/407 | 15th |

View CiteScore methodology > CiteScore FAQ > Add CiteScore to your site

Civil Engineering Dimension
https://ced.petra.ac.id

# Vehicle Routing Problem Optimization for Rebar Material Distribution using the Symbiotic Organisms Search Method

**Reynaldo, A.M.J.[1], Husada, W.[1]*, Wijaya, E.K.[2], and Vaphilio, D.[3]**
[1] Civil Engineering Department, Faculty of Civil Engineering and Planning, Petra Christian University, Jl. Siwalankerto 121-131, Surabaya 60236, INDONESIA
[2] CV. Benjamin Gideon & Associates, Surabaya, INDONESIA
[3] CV. Mitra Manado, Bitung, Sulawesi Utara, INDONESIA

DOI: https://doi.org/10.9744/ced.27.2.205-215

***Article Info:***
Submitted: May 05, 2025
Reviewed: July 02, 2025
Accepted: Aug 11, 2025

***Keywords***:
vehicle routing problem,
optimization,
rebar distribution,
symbiotic organisms search,
CVRP,
CVRPTW.

***Corresponding Author:***
**Husada, W.**
Civil Engineering Department, Faculty of Civil Engineering and Planning,
Petra Christian University,
Jl. Siwalankerto 121-131, Surabaya 60236,
INDONESIA
Email: willy.husada@petra.ac.id

## Abstract

The success rate of construction projects depends on subcontractors and material suppliers, especially in ensuring the material delivery to avoid delays and cost overruns. The Vehicle Routing Problem (VRP) addresses transportation management to minimize the distribution costs. This study presents a comparative analysis of three VRP scenarios: the existing case, the Capacitated Vehicle Routing Problem (CVRP), and the Capacitated Vehicle Routing Problem with Time Windows (CVRPTW). The Symbiotic Organisms Search (SOS) method is used to solve the VRP of a building materials supplier in Sulawesi, Indonesia in delivering rebar to 19 locations over 12 weeks while considering the vehicle capacity and the time window constraints. The results show that the SOS method effectively handles the rebar distribution problems with these constraints. The CVRP scenario achieves a total cost saving of Rp 23,263,278 (26.15%), while the CVRPTW scenario saves Rp 6,732,942 (7.57%).



## INTRODUCTION

Construction projects involve various stakeholders including architects, designers, main contractor, subcontractors, and material suppliers [1]. The success rate of these projects heavily depends on the performance of subcontractors and material suppliers, especially in ensuring the material delivery to avoid the delays and cost overruns. This delivery process relies on several key factors, including the transportation system, infrastructure, resources availability, and the effective communication among stakeholders [2]. However, the main challenges in the material distribution involve the design of the supply chain network and organizing the transportation processes. These efforts aim to minimize the transportation costs, ensure consistent material availability, and reduce the production expenses, and it is often called the Vehicle Routing Problem (VRP) [3].

VRP is a mathematical model for solving the transportation management problems introduced by Dantzig and Ramser in 1959 to model how the group of trucks could efficiently serve the oil demands from multiple gas stations originating from a central hub with a minimum traveling distance [4]. VRP problems are classified into the static and dynamic types, where the static problems assume constant parameters, such as travel time, demand, and costs. The Dynamic Vehicle Routing Problem (DVRP) overcomes the limitations of the static VRP by accommodating the changes in customer demand and travel time, which are variable in real-world scenarios [5]. Since then, various factors influencing the problem have been identified, leading to the development of multiple VRP variants based on the specific constraints encountered in each optimization scenario. The examples of VRP variations include the Capacitated Vehicle Routing Problem (CVRP) which considers the vehicle capacity constraints [6] and the VRP with Time Windows (VRPTW), where both the customers and vehicles operate within specified time frames or working

**Note** : Discussion is expected before November, 1st 2025, and will be published in the "Civil Engineering Dimension", volume 28, number 1, March 2026.
**ISSN** : 1410-9530 print / 1979-570X online
**Published by** : **Petra Christian University**

hours, requiring the services and operations to occur only within these certain periods [7]. Additionally, other variants have been developed to address various constraints, such as the multiple depot VRP and the VRP with pick-up and delivery requirements [8]. These VRP variants are closely linked to the real-world scenarios, with the goal of reducing the total distribution costs while maintaining high-quality distribution services [9]. The VRP is mathematically, a combinatorial optimization problem, where the number of possible solutions to the problem increases exponentially with the number of customers to be served [10,11]. The vehicle route selection process enables the selection of any combination of customers to assign the delivery route for each vehicle. Since there is no known polynomial algorithm to find the optimal solution in each instance, the problem of vehicle routing is considered Nondeterministic Polynomial Time Hard (NP-Hard) [11,12]. Figure 1 provides a general overview of the VRP problem.

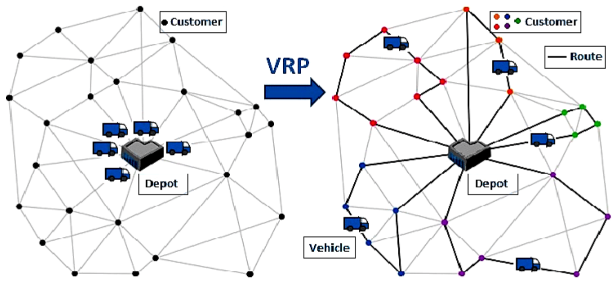



**Figure 1.** General Overview of VRP Problem

The VRP seeks to identify the optimal routes for multiple vehicles based on the customer demands by minimizing the total transportation costs. Solving the VRP often requires the material distributors to manually assign and adjust the delivery routes of each vehicle, which can be time-consuming. The optimization algorithms or metaheuristic methods can help identifying the best combinations of the delivery route for each vehicle, with the goal of determining the best transportation routes for multiple customers to obtain the lowest cost. The metaheuristic methods have been widely applied across various optimization problems in the construction industry. In construction site planning, the bio-inspired optimization methods have been used to improve the layout of site facilities, enhancing spatial efficiency and reducing overall project costs [13]. In project scheduling problem, the Symbiotic Organisms Search (SOS) algorithm has proven effective for resource leveling under multiple objective criteria, offering a robust solution to balance the workloads and timelines [14]. Similarly, in geotechnical engineering, the metaheuristic methods have been employed to optimize the design of counterfort retaining walls with shear key, resulting in more efficient and cost-effective structural designs [15]. Based on these facts, many studies have also used the metaheuristic methods as an optimizer for the VRP optimization problems. Ho et al. used the hybrid Genetic Algorithm (GA) to minimize the total delivery time for multi-depot VRP [16]. Khouadjia et al. compared the performance of the Particle Swarm Optimization (PSO) and Variable Neighborhood Search (VNS) to solve the VRP with dynamic requests [17]. Zhang et al. implemented the hybrid Ant Colony Optimization (ACO) to minimize the total distribution costs and maximize the overall customer satisfaction of multi-objective VRPTW [18]. These studies demonstrated that the metaheuristic methods can effectively solve the VRP optimization problems.

This research employs an optimization algorithm based on the swarm intelligence, specifically the Symbiotic Organisms Search (SOS) to examine and solve the VRP problem of a building materials supplier in delivering the steel rebar to multiple stores. Some challenges that faced by the company are such as a large number of stores located in diverse regions, geographically dispersed areas, and the need to optimize the vehicle capacity for efficient use. The study focuses on single-objective optimization, aiming to optimize the vehicle routes for the rebar delivery from a single distributor to multiple material store locations while considering the customer demand, the number of vehicles, the vehicle capacity, and the delivery time constraints.

## METHODS

### Symbiotic Organisms Search (SOS) Method

Symbiotic Organisms Search (SOS) method is a population-based algorithm inspired by the interactions of organisms within an ecosystem, known as symbiosis. It was developed by Cheng and Prayogo and has proven to be effective in solving various mathematical problems [19,20]. This method simulates the interactions among organisms within an ecosystem as they compete, grow, and survive. It incorporates the three fundamental types of symbiotic relationships: the mutualism phase, where both species benefit; the commensalism phase, where one species benefits without harming the other; and the parasitism phase, where one species gains at the expense of the other [21]. Unlike many competing methods, SOS does not need any parameter tuning, which enhances its performances stability [22]. The SOS method begins with an initial population called an ecosystem. In this ecosystem, a group of organisms emerges randomly in the search space. Each organism represents a solution to the optimization problem. Additionally, each organism has a fitness value reflecting its level of adaptation to the problem's objective. The organisms adapt according to the objective, and the optimization processes continue based on the number of organisms and specified iterations.

## Vehicle Routing Problem: Variables, Constraints, and Objective Function in Optimization

The VRP model can be described in the form of a graph $G(A, V)$. $V$ in Equation 1 is a set of nodes where each node represents the customer location to be served and a central depot. $A$ in Equation 2 is a set of arcs where there are pairs of nodes connecting connections between nodes $i$ and $j$ with a distance $d$ in the set in Equation 3. Each customer has a demand called $D$ according to the set in Equation 4. $M_m$ in Equation 5 represents a set of vehicles and capacities available for the material delivery. Each vehicle $M_m$ has a maximum capacity $cap_m$, limiting the amount of materials that can be carried.

$$V = \{v_0, v_1, v_2, \dots, v_n\} \tag{1}$$

$$A = \{(v_i, v_j): v_i, v_j \in V\} \tag{2}$$

$$d = \{d_{0,1}, d_{1,2}, d_{2,3}, \dots, d_{i,j}\} \tag{3}$$

$$D = \{D_0, D_1, D_2, \dots, D_n\} \tag{4}$$

$$M_m = \{m_1, m_2, \dots, m_m\} \tag{5}$$

where:

$v_n$ = nodes for customer and depot
$d_{i,j}$ = distance from node $i$ to $j$
$D_n$ = demand of customer $i$
$m_m$ = vehicle number $m$
$i$ = initial node index
$j$ = destination node index
$m$ = vehicle index
0 = depot index
$n$ = index of sum

The variables used in the VRP optimization process are the customer locations and vehicles, constrained by the upper bounds (UB) and lower bounds (LB). These upper and lower bounds are determined based on the number of locations and vehicles specified by the distributor company. These variables will be separated by the program into two parts, one for the sequence of the number of locations and the other for the sequence of vehicle indices. The variables will determine the distribution cost of building materials based on the operational costs of the vehicles and wage costs specified by the company. The variables, upper bounds, and lower bounds used in this study can be seen in Equation 6 to 8.

$$R = \{r_1, r_2, r_3, \dots, r_m\} \tag{6}$$

$$LB = 0 \tag{7}$$

$$UB = dmax \tag{8}$$

where:

$r_m$ = number of locations and the m-th vehicle.
$dmax$ = sum of location and vehicle

The constraints are needed to limit the objective function values so that they do not exceed the specified requirements. The constraints used in this study are presented in Equation 9 to 15. Subsequently, these constraints will eliminate the objective function values that exceed the limits, ensuring they do not become the optimal solution.

- Each vehicle must return to the depot.

$$\sum_{i=1}^{N} X_{i0,m} = 1 \tag{9}$$

- Each node can only be visited once for each route.

$$\sum_{m=1}^{M} \sum_{i=1}^{N} \sum_{j=1}^{N} X_{ij,m} = 1 \tag{10}$$

- After visiting a node, the vehicle must move to the next node.

$$\sum_{m=1}^{M}\sum_{i=1}^{N} X_{ip,m} = \sum_{m=1}^{M}\sum_{i=1}^{N} X_{ip,m} \tag{11}$$

- Limiting vehicle capacity and adjusting it to the customer demand.

$$\sum_{i=1}^{M}\sum_{j=1}^{N} X_{ij,m} \times D_j = Dm_{ij,m} \tag{12}$$

$$\sum_{i=1}^{N} Dm_{0i,m} \leq cap_m \tag{13}$$

- Limiting the number of available vehicles.

$$\sum_{m=1}^{M} X_{ij,m} \leq veh_m \tag{14}$$

- Time window constraints for the material delivery.

$$a_j \leq t_{ij} \leq b_j - tl_{ij} \tag{15}$$

where:
$D_j$ = customer demand from node i to j
$Dm_{ij,m}$ = capacity that the m-th type of vehicle can accommodate from node $i$ to $j$
$cap_m$ = maximum vehicle capacity
$veh_m$ = maximum number of vehicles
$p$ = index of the destination node
$t_{ij}$ = arrival time of the vehicle at the node
$h_{ij}$ = working days of the vehicle for each route taken
$tl_{ij}$ = loading and unloading time at the node
$[a_j, b_j]$ = time window for delivery at node j

The objective function in Equation 16 is implemented by minimizing the total delivery cost. The costs considered in this study include the fuel costs and the wage costs for each vehicle. The fuel and wage costs are determined based on the company's policy.

$$Minimize \sum_{m=1}^{M}\sum_{i=0}^{N}\sum_{j=0}^{N} X_{ij,m} \times fc_m + \sum_{m=1}^{M}\sum_{i=0}^{N}\sum_{j=0}^{N} h_{ij} \times vc_m \tag{16}$$

where:
$fc_m$ = fuel cost of the vehicle
$vc_m$ = wage cost of the vehicle

## RESULTS AND DISCUSSION

### Case Study

The case study used in this research involves a building materials distributor company located in Sulawesi, Indonesia. The distributor delivers the steel rebar material to 30 stores located in 19 different locations. The data obtained from this case study includes the information about the distributor and store locations, the customer purchase history of steel rebar material, the store operating hours, the types and capacities of vehicle, as well as the original routes commonly used by the distributor. This research is a single-objective optimization with the goal of optimizing the delivery routes of each vehicle in distributing the rebar based on the number of vehicles, vehicle capacities, and delivery time constraints. The optimization results in this study are based on a single run and were implemented on a computer equipped with a Ryzen 7 5800H 3.2 GHz processor and 16 GB RAM.

The distances between stores were obtained using the Google Waypoint Application Programming Interface (GWAPI), which retrieves the distances between points from Google Maps. Details of the distances between locations or nodes can be seen in Table 1. In this table, index 1 represents the material depot, and the other 18 indices represent the customer locations. For example, the distance from node 1 (depot) to node 3 is 6.49 km, and the distance from node 3 to node 1 (depot) is 5.51 km. This difference in traveling distance may happen because the distance for departure and return can be different according to Google Maps.

**Table 1.** Distance between Locations or Nodes (in km)

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| **1** | 0 | 8.37 | 5.51 | 38.49 | 21.39 | 32.56 | 34.9 | 73.4 | 116.4 | 126.3 |
| **2** | 8.2 | 0 | 11.92 | 43.42 | 26.33 | 41.91 | 44.25 | 66.48 | 109.4 | 119.3 |
| **3** | 6.49 | 13.13 | 0 | 33.31 | 16.21 | 37.07 | 39.41 | 77.91 | 120.9 | 130.8 |
| **4** | 38.09 | 46.46 | 31.6 | 0 | 17.1 | 49.49 | 37.06 | 93.85 | 136.8 | 146.7 |
| **5** | 21 | 29.37 | 14.5 | 17.1 | 0 | 32.39 | 24.52 | 76.75 | 119.7 | 129.6 |
| **6** | 32.24 | 40.05 | 35.18 | 48.48 | 31.38 | 0 | 12.02 | 72.92 | 115.9 | 125.8 |
| **7** | 35.53 | 43.34 | 38.48 | 37.06 | 24.52 | 9.49 | 0 | 80.45 | 123.4 | 133.3 |
| **8** | 74.03 | 64.7 | 76.97 | 93.79 | 76.69 | 77.23 | 79.57 | 0 | 43.02 | 52.91 |
| **9** | 117 | 107.7 | 120 | 136.8 | 119.7 | 120.3 | 122.6 | 43.08 | 0 | 9.9 |
| **10** | 126.9 | 117.6 | 129.9 | 146.7 | 129.6 | 130.1 | 132.5 | 52.98 | 9.9 | 0 |
| **11** | 160.5 | 153.4 | 166.9 | 199.9 | 182.8 | 192.1 | 194.4 | 99.56 | 56.48 | 46.58 |
| **12** | 227.3 | 220.2 | 233.7 | 266.7 | 249.6 | 258.9 | 261.2 | 155.6 | 112.5 | 102.6 |
| **13** | 160.9 | 153.8 | 167.3 | 200.3 | 183.2 | 192.5 | 194.8 | 141.1 | 115.4 | 105.5 |
| **14** | 187 | 180 | 193.4 | 226.4 | 209.3 | 218.6 | 220.9 | 167.2 | 141.5 | 131.6 |
| **15** | 277.3 | 270.3 | 283.8 | 316.7 | 299.6 | 308.9 | 311.3 | 257.5 | 231.8 | 221.9 |
| **16** | 317.8 | 310.8 | 324.3 | 357.2 | 340.1 | 349.4 | 351.8 | 298 | 272.3 | 262.4 |
| **17** | 345.8 | 338.8 | 352.3 | 385.3 | 368.2 | 377.5 | 379.8 | 326 | 300.4 | 290.5 |
| **18** | 363.3 | 356.3 | 369.8 | 402.7 | 385.6 | 394.9 | 397.3 | 343.5 | 317.8 | 307.9 |
| **19** | 392 | 385 | 398.5 | 431.4 | 414.3 | 423.6 | 426 | 372.2 | 333.4 | 323.5 |

Distance between Locations or Nodes (in km) – Continued

| | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
|---|---|---|---|---|---|---|---|---|---|
| **1** | 160.8 | 227.6 | 161.2 | 187.3 | 279.2 | 319.4 | 347.4 | 364.9 | 393.6 |
| **2** | 152.6 | 219.4 | 153 | 179.1 | 271 | 311.2 | 339.3 | 356.7 | 385.5 |
| **3** | 168 | 234.8 | 168.4 | 194.5 | 286.4 | 326.6 | 354.6 | 372.1 | 400.8 |
| **4** | 199.6 | 266.4 | 200 | 226.1 | 317.9 | 358.2 | 386.2 | 403.7 | 432.4 |
| **5** | 182.5 | 249.3 | 182.9 | 209 | 300.9 | 341.1 | 369.1 | 386.6 | 415.3 |
| **6** | 172.3 | 258.2 | 191.8 | 217.9 | 309.8 | 350 | 378 | 395.5 | 424.2 |
| **7** | 194.7 | 261.5 | 195.1 | 221.2 | 313.1 | 353.3 | 381.3 | 398.8 | 427.5 |
| **8** | 99.49 | 157.2 | 141 | 167.1 | 259 | 299.2 | 327.2 | 344.7 | 373.4 |
| **9** | 56.47 | 114.2 | 115.3 | 141.4 | 233.2 | 273.5 | 301.5 | 319 | 335.1 |
| **10** | 46.58 | 104.3 | 105.4 | 131.5 | 223.3 | 263.6 | 291.6 | 309.1 | 325.2 |
| **11** | 0 | 62.4 | 63.46 | 89.57 | 181.4 | 221.7 | 249.7 | 267.2 | 283.3 |
| **12** | 60.68 | 0.0 | 62.87 | 72.69 | 164.6 | 204.8 | 232.8 | 242.2 | 223.2 |
| **13** | 63.59 | 62.9 | 0 | 26.18 | 118.1 | 158.3 | 186.3 | 203.8 | 232.5 |
| **14** | 89.69 | 72.7 | 26.18 | 0 | 91.87 | 132.1 | 160.1 | 177.6 | 206.3 |
| **15** | 180 | 163.0 | 116.5 | 90.35 | 0 | 41.7 | 69.72 | 87.2 | 115.9 |
| **16** | 220.5 | 203.5 | 157 | 130.9 | 40.51 | 0 | 28.42 | 45.9 | 74.6 |
| **17** | 248.6 | 231.6 | 185.1 | 158.9 | 68.52 | 28.41 | 0 | 18.72 | 47.43 |
| **18** | 266 | 242.2 | 202.5 | 176.3 | 85.99 | 45.88 | 18.72 | 0 | 43.71 |
| **19** | 281.6 | 223.2 | 231.2 | 205.1 | 114.7 | 74.59 | 47.43 | 43.72 | 0 |

The detailed information about the rebar demands for each customer and the delivery routes from the company was obtained. The purchasing history data was processed and transformed into a weekly delivery schedule, which later be input into the program. Table 2 presents the rebar purchasing history data from the 19 locations for 12 weeks period or 3 months. The rows represent the number of weeks, and the columns represent the quantity of rebar purchased in kg. Based on the interviews conducted, the average operating hours for the customer stores are from 8:00 AM to 5:00 PM. These 8-9 working hours will become the time window constraint in this study.

The company operates 10 vehicles for the rebar delivery, consisting of two types: 7 units of type 1 vehicle with a capacity of 4000 kg and 3 units of type 2 vehicle with the capacity of 2200 kg. Based on the interview results, the fuel cost is Rp 680/km for type 1 vehicle and Rp 450/km for type 2 vehicle. All vehicles are assumed to travel at a speed of 40 km/h. In addition to the fuel expenses, each vehicle also incurs wage costs, which include the daily wages of the driver and assistants required for the delivery and operation. The daily wage for one driver is Rp 150,000, and for one assistant, it is Rp 100,000. A type 1 vehicle requires 1 driver and 3 assistants accumulating a total daily wage cost of Rp 450,000. Meanwhile, type 2 vehicle requires 1 driver and 2 assistants accumulating Rp. 350,000 in daily wage cost. The details for each vehicle type can be seen in Table 3.

**Table 2.** Rebar Purchasing History Data (in kg)

| Week/Node | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 2239 | 14812 | 0 | 0 | 4720 | 3619 | 3642 | 0 | 0 |
| 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1451 | 0 | 0 |
| 3 | 0 | 1333 | 19214 | 0 | 75 | 0 | 9237 | 0 | 0 | 947 |
| 4 | 0 | 1747 | 0 | 0 | 0 | 0 | 9178 | 6137 | 237 | 0 |
| 5 | 0 | 533 | 0 | 0 | 0 | 0 | 947 | 0 | 250 | 0 |
| 6 | 0 | 95 | 95 | 4737 | 508 | 0 | 5798 | 0 | 0 | 0 |
| 7 | 0 | 0 | 0 | 0 | 0 | 0 | 2368 | 2368 | 0 | 0 |
| 8 | 0 | 142 | 0 | 0 | 2052 | 0 | 4312 | 0 | 0 | 0 |
| 9 | 0 | 0 | 8734 | 0 | 0 | 0 | 7905 | 1865 | 0 | 0 |
| 10 | 0 | 488 | 1480 | 0 | 0 | 1599 | 0 | 533 | 0 | 2665 |
| 11 | 0 | 1442 | 0 | 0 | 878 | 0 | 5595 | 0 | 0 | 0 |
| 12 | 0 | 637 | 0 | 0 | 290 | 0 | 6972 | 0 | 0 | 2013 |

Rebar Purchasing History Data (in kg) – Continued

| Week/Node | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2303 | 0 | 0 | 0 | 4613 | 0 | 1480 | 0 | 1251 |
| 2 | 0 | 0 | 4607 | 38 | 3656 | 0 | 0 | 0 | 8618 |
| 3 | 0 | 0 | 625 | 0 | 995 | 0 | 0 | 1850 | 0 |
| 4 | 0 | 0 | 0 | 0 | 0 | 0 | 711 | 1599 | 0 |
| 5 | 0 | 0 | 0 | 0 | 1673 | 0 | 0 | 0 | 7675 |
| 6 | 0 | 0 | 0 | 2132 | 1990 | 0 | 0 | 1421 | 1351 |
| 7 | 0 | 0 | 0 | 3162 | 2487 | 0 | 0 | 0 | 0 |
| 8 | 0 | 0 | 0 | 0 | 1332 | 0 | 497 | 0 | 0 |
| 9 | 0 | 533 | 1895 | 0 | 1232 | 0 | 0 | 1876 | 0 |
| 10 | 0 | 0 | 533 | 0 | 2280 | 13360 | 1480 | 0 | 534 |
| 11 | 0 | 8011 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 12 | 0 | 799 | 947 | 0 | 0 | 0 | 0 | 0 | 2949 |

**Table 3.** Detailed Vehicle Information

| Vehicle Type | Capacity (Ton) | Unit | Fuel Cost (fc) - Rp/km | Wage Cost (vc) - Rp/day |
|---|---|---|---|---|
| 1 | 4 | 7 | 680 | 450,000 |
| 2 | 2.2 | 3 | 450 | 350,000 |

**Table 4.** Existing Original Routes from the Distributor Company

| Vehicle/Week | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1 | [1, 17, 19, 1] | [1, 19, 1] | [1, 13, 15, 1] | [1, 17, 18, 1] | [1, 19, 1] | [1, 15, 18, 19, 1] |
| 2 | [1, 15, 1] | [1, 19, 1] | [1, 10, 18, 1] | [1, 8, 1] | [1, 19, 1] | [1, 14, 19, 1] |
| 3 | [1, 11, 15, 1] | [1, 19, 15, 1] | [1, 7, 1] | [1, 8, 9, 1] | [] | [1, 7, 1] |
| 4 | [1, 8, 1] | [1, 13, 1] | [1, 7, 1] | [1, 7, 1] | [] | [1, 5, 7, 1] |
| 5 | [1, 7, 1] | [1, 13, 14, 15, 1] | [1, 5, 7, 1] | [1, 7, 1] | [] | [1, 4, 1] |
| 6 | [1, 6, 1, 3, 1] | [] | [1, 3, 1, 3, 1] | [] | [] | [] |
| 7 | [1, 3, 1] | [] | [1, 3, 1, 3, 1] | [] | [] | [] |
| 8 | [1, 3, 1] | [1, 8, 1] | [1, 3, 1] | [1, 7, 1] | [1, 7, 1] | [1, 3, 4, 1] |
| 9 | [1, 3, 1, 3, 1] | [] | [1, 3, 1] | [1, 2, 1] | [1, 2, 1] | [1, 2, 1] |
| 10 | [1, 2, 1, 2, 3, 6, 1] | [] | [1, 2, 1] | [] | [1, 9, 15, 1] | [] |

Existing Original Routes from the Distributor Company – Continued

| Vehicle/Week | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|
| 1 | [1, 14, 15, 1] | [1, 15, 17, 1] | [1, 13, 15, 18, 1] | [1, 16, 1] | [1, 12, 1] | [1, 13, 19, 1] |
| 2 | [1, 8, 1] | [1, 7, 1] | [1, 8, 12, 18, 1] | [1, 16, 1] | [1, 12, 1] | [1, 10, 12, 1] |
| 3 | [1, 7, 1] | [1, 5, 7, 1] | [1, 7, 1] | [1, 16, 1] | [1, 7, 1] | [1, 7, 1] |
| 4 | [] | [] | [1, 7, 1] | [1, 16, 19, 17, 1] | [1, 5, 7, 1] | [1, 5, 7, 1] |
| 5 | [] | [] | [1, 3, 1] | [1, 13, 15, 1] | [] | [] |
| 6 | [] | [] | [1, 3, 1] | [1, 8, 10, 1] | [] | [] |
| 7 | [] | [] | [] | [] | [] | [] |
| 8 | [1, 15, 1] | [1, 2, 1] | [1, 3, 1] | [1, 6, 1] | [1, 12, 2, 1] | [1, 2, 1] |
| 9 | [] | [] | [] | [1, 3, 2, 1] | [] | [] |
| 10 | [] | [] | [] | [] | [] | [] |

Table 4 presents the delivery routes for 10 vehicles over the 12 weeks period. Vehicles 1-7 are type 1, and vehicles 8-10 are type 2. The routes show the sequence of nodes visited by the vehicles, starting and ending from and to the depot with node index 1. Empty cells ([]) indicate no rebar delivery assignment in that week for the respective vehicle. Based on the existing original routes made by the company, the total distribution cost of the rebar material in 12 weeks period is Rp 88,947,476 consisting of Rp 15,447,476 for the fuel cost and Rp 73,500,000 for the wage cost. The total distance covered is 23550.1 km. Each vehicle route includes details such as the load capacity, total distance, travel time, and equivalent working days (8 working hours/day). As an example, Table 5 shows the delivery route details from the first week (week 1). Vehicle 1 departs from the depot (node 1), delivers 1480.29 kg to customer 17, delivers 1250.84 kg to customer 19, and back again to the depot (node 1) with total travel distance of 786.88 km in 26 hours over around 4 working days. Some vehicles, like vehicle 6 and 10, make multiple trips in a week, returning to the depot between deliveries. This approach is also used in the optimization scenarios to resemble the real-world conditions.

**Table 5.** Delivery Route Details for Week 1 (Existing Original Routes)

| Week | Vehicle | Route | Customer | Loaded Capacity (kg) | Total Distance (km) | Travel Time (hours) | Working Day (days) |
|---|---|---|---|---|---|---|---|
| 1 | 1 | [1,17,19,1] | 17 | 1480.29 | 786.88 | 26 | 4 |
| | | | 19 | 1250.84 | | | |
| | 2 | [1,15,1] | 15 | 4000 | 556.49 | 26 | 4 |
| | 3 | [1,11,15,1] | 11 | 2303.32 | 619.54 | 26 | 4 |
| | | | 15 | 612.57 | | | |
| | 4 | [1,8,1] | 8 | 3641.50 | 147.43 | 5.065 | 1 |
| | 5 | [1,7,1] | 7 | 3619.30 | 70.43 | 4.095 | 1 |
| | 6 | [1,6,1,3,1] | 6 | 4000 | 76.8 | 5.773 | 1 |
| | | | 3 | 4000 | | | |
| | 7 | [1,3,1] | 3 | 4000 | 12 | 3.496 | 1 |
| | 8 | [1,3,1] | 3 | 2200 | 12 | 2.896 | 1 |
| | 9 | [1,3,1,3,1] | 3 | 2200 | 24 | 3.929 | 1 |
| | | | 3 | 2200 | | | |
| | 10 | [1,2,1,2,3,6,1] | 2 | 2000 | 195.77 | 7.515 | 1 |
| | | | 2 | 239.38 | | | |
| | | | 3 | 211.74 | | | |
| | | | 6 | 720.19 | | | |
| | | Total | | 38679.13 | 2501.34 | 110.767 | 19 |

## Optimization Result

This study examines the two optimization scenarios to minimize the total delivery costs for rebar material: the Capacitated Vehicle Routing Problem (CVRP) and the Capacitated Vehicle Routing Problem with Time Windows (CVRPTW), both solved using the SOS metaheuristic method. The CVRP optimization case assumes no delivery time window constraint, while the CVRPTW optimization case includes the delivery time window constraint, adding complexity to the problem. The SOS method runs using 200 organisms and 100 iterations, with the computational time between 16 to 35 hours.

## CVRP Optimization Result

Table 6 shows the optimum CVRP delivery routes with the total rebar material distribution cost of Rp 65,684,200, comprising Rp 14,784,200 in fuel cost and Rp. 50,900,000 in wage cost. The delivery routes cover 22257.14 km. Compared to the existing original routes, this yields a cost saving of Rp 23,263,276 (26.15%) and 1292.96 km less traveling distance (5.49%). These savings are achieved by maximizing the vehicle capacity and removing the working hours and time window constraints. Table 7 presents the detailed route information assigned from the first week. In this scenario, Vehicle 2 departs from the depot (node 1), delivers 1480.286 kg of rebar to customer 17, 1250.841 kg to customer 19, and 1268.873 kg to customer 15 before returning to the depot (node 1). The vehicle travels 786.88 km with travel time of 21.005 hours. Compared to the existing original route, the delivery to customer 15 is an addition. However, the total distance remains unchanged, as the program identifies more optimal combinations of delivery routes. The route requires 2 fewer working days due to the absence of time constraints.

After comparing the routes of the optimum CVRP scenario and existing original routes, it can be concluded that the program finds more optimal routes with fewer working days in the CVRP scenario. By maximizing the vehicle capacity without exceeding limits, all rebar orders are delivered very well. However, the lack of working hours and time window constraints makes the results less applicable to real-world scenarios. To improve the results applicability, the time window constraint will be added, leading to the optimization in the second case, CVRPTW.

**Table 6.** Optimum Delivery Routes for the CVRP Scenario

| Vehicle/Week | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1 | [1,2,11,8,1] | [1,19,15,1] | [1,3,1] | [1,8,7,1] | [1,15,2,7,1] | [1,4,5,1] |
| 2 | [1,17,19,15,1] | [1,19,1] | [1,18,15,13,2,1] | [1,9,17,18,2,1] | [1,9,19,1] | [1,18,19,15,1] |
| 3 | [1,8,3,1] | [1,15,14,13,1] | [1,3,1] | [1,7,1] | [] | [1,5,7,1] |
| 4 | [1,3,1,7,1] | [] | [1,3,5,7,1] | [] | [] | [] |
| 5 | [1,3,1] | [1,8,1] | [1,3,1] | [1,7,1] | [] | [] |
| 6 | [1,3,1] | [] | [1,7,1] | [] | [] | [] |
| 7 | [1,15,2,1] | [1,19,1] | [1,2,10,3,1] | [1,2,8,1] | [1,19,15,1] | [1,15,14,2,3,4,1] |
| 8 | [1,3,6,1] | [] | [1,7,1] | [] | [] | [] |
| 9 | [1,6,1] | [] | [1,7,1] | [] | [] | [] |
| 10 | [1,3,1,6,1] | [1,13,8,1] | [1,3,1] | [1,7,1] | [] | [1,7,1] |

Optimum Delivery Routes for the CVRP Scenario – Continued

| Vehicle/Week | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|
| 1 | [1,8,7,1] | [1,7,1] | [1,3,1] | [1,16,1] | [1,12,5,7,1] | [1,7,1] |
| 2 | [1,15,14,1] | [1,17,15,2,5,1] | [1,18,15,13,1] | [1,16,1] | [1,2,12,1] | [1,19,13,2,1] |
| 3 | [] | [] | [1,3,1] | [1,16,17,19,15,1] | [1,7,1] | [1,7,1] |
| 4 | [] | [] | [1,7,1] | [1,3,6,1] | [] | [] |
| 5 | [] | [] | [1,7,1] | [1,2,10,8,3,1] | [] | [] |
| 6 | [] | [] | [] | [] | [] | [] |
| 7 | [1,14,8,1] | [1,5,7,1] | [1,13,12,8,3,1] | [1,16,1] | [1,12,1] | [1,2,12,10,5,7,1] |
| 8 | [] | [] | [] | [] | [] | [] |
| 9 | [] | [] | [] | [] | [] | [] |
| 10 | [] | [] | [1,3,7,1] | [1,15,13,2,1] | [] | [] |

**Table 7.** Optimum Delivery Route Details for Week 1 (CVRP Scenario)

| Week | Vehicle | Route | Customer | Loaded Capacity (kg) | Total Distance (km) | Travel Time (hours) | Working Day (days) |
|---|---|---|---|---|---|---|---|
| 1 | 1 | [1,2,11,8,1] | 2 | 1583.074 | 334.56 | 9.697 | 2 |
| | | | 11 | 2303.325 | | | |
| | | | 8 | 113.602 | | | |
| | 2 | [1,17,19,15,1] | 17 | 1480.286 | 786.88 | 21.005 | 3 |
| | | | 19 | 1250.841 | | | |
| | | | 15 | 1268.873 | | | |
| | 3 | [1,8,3,1] | 8 | 3527.901 | 156.86 | 5.255 | 1 |
| | | | 3 | 472.099 | | | |
| | 4 | [1,3,1,7,1] | 3 | 4000 | 82.43 | 4.601 | 1 |
| | | | 7 | 3619.299 | | | |
| | 5 | [1,3,1] | 3 | 4000 | 12 | 1.633 | 1 |
| | 6 | [1,3,1] | 3 | 4000 | 12 | 1.633 | 1 |
| | 7 | [1,15,2,1] | 15 | 3343.697 | 557.67 | 15.275 | 2 |
| | | | 2 | 656.303 | | | |
| | 8 | [1,3,6,1] | 3 | 139.640 | 74.82 | 2.604 | 1 |
| | | | 6 | 2060.360 | | | |
| | 9 | [1,6,1] | 6 | 2200 | 64.8 | 2.353 | 1 |
| | 10 | [1,3,1,6,1] | 3 | 2200 | 76.8 | 2.807 | 1 |
| | | | 6 | 459.827 | | | |
| | Total | | | 38679.126 | 2158.82 | 66.8627 | 14 |

## CVRPTW Optimization Result

Table 8 presents the optimum CVRPTW routes with a total rebar material distribution cost of Rp 82,214,534, including Rp 15,514,534 for the fuel cost and Rp 66,700,000 for the wage cost. The total travel distance is 23052.92 km. Compared to the existing original routes, there is a traveling distance saving of 497.18 km (2.11%). However, the fuel costs are nearly the same due to the increased use of the type 1 vehicles compared to the existing original routes. This occurs because the CVRPTW scenario results in more usage of type 1 vehicles. Meanwhile, the optimization in the CVRPTW scenario reduces the wage costs by 9.25%, saving equivalent to 20 working days and lowering the operational expenses. As illustrated in Table 9, the detailed routes data and visualizations for the first week of the CVRPTW scenario are shown. In this example, Vehicle 5 follows a similar route to the CVRP results of vehicle 2 but in a different delivery order. The vehicle 5 departs from the depot (node 1), delivers the rebar material 1250.841 kg to customer 19, 1480.286 kg to customer 17, and 1268.873 kg to customer 15 before returning to the depot (node 1). The vehicle travels 786.89 km with a traveling time of 26 hours. The adjusted sequence reduces the working days and wage costs, demonstrating the program's ability to optimize the delivery time within the specified time windows.

**Table 8.** Optimum Delivery Routes for the CVRPTW Scenario

| Vehicle/Week | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1 | [1,11,8,1] | [1,19,14,15,1] | [1,3,1] | [1,8,2,7,1] | [1,15,2,7,1] | [1,4,5,1] |
| 2 | [1,3,1,7,1] | [1,13,8,1] | [1,3,1] | [1,7,1] | [] | [1,7,1] |
| 3 | [1,3,1] | [] | [1,3,5,7,1] | [] | [] | [] |
| 4 | [1,3,1] | [] | [1,7,1] | [] | [] | [] |
| 5 | [1,19,17,15,1] | [1,19,1] | [1,18,15,13,10,1] | [1,17,18,9,8,1] | [1,19,1] | [1,19,18,14,1] |
| 6 | [1,15,11,1] | [1,19,1] | [1,10,2,3,1] | [1,8,1] | [1,19,9,15,1] | [1,14,15,2,3,4,1] |
| 7 | [1,8,2,3,1] | [1,15,13,1] | [1,3,1] | [1,7,1] | [] | [1,5,7,1] |
| 8 | [1,3,1,6,1] | [] | [1,3,1] | [] | [] | [] |
| 9 | [1,6,1] | [] | [1,7,1] | [] | [] | [] |
| 10 | [1,3,6,1] | [] | [1,7,1] | [] | [] | [] |

Optimum Delivery Routes for the CVRPTW Scenario – Continued

| Vehicle/Week | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|
| 1 | [1,8,7,1] | [1,7,1] | [1,3,1] | [1,16,1] | [1,12,5,7,1] | [1,7,1] |
| 2 | [1,15,14,1] | [1,17,15,2,5,1] | [1,18,15,13,1] | [1,16,1] | [1,2,12,1] | [1,19,13,2,1] |
| 3 | [] | [] | [1,3,1] | [1,16,17,19,15,1] | [1,7,1] | [1,7,1] |
| 4 | [] | [] | [1,7,1] | [1,3,6,1] | [] | [] |
| 5 | [] | [] | [1,7,1] | [1,2,10,8,3,1] | [] | [] |
| 6 | [] | [] | [] | [] | [] | [] |
| 7 | [1,14,8,1] | [1,5,7,1] | [1,13,12,8,3,1] | [1,16,1] | [1,12,1] | [1,2,12,10,5,7,1] |
| 8 | [] | [] | [] | [] | [] | [] |
| 9 | [] | [] | [] | [] | [] | [] |
| 10 | [] | [] | [1,3,7,1] | [1,15,13,2,1] | [] | [] |

**Table 9.** Optimum Delivery Route Details for Week 1 (CVRPTW Scenario)

| Week | Vehicle | Route | Customer | Loaded Capacity (kg) | Total Distance (km) | Travel Time (hours) | Working Day (days) |
|---|---|---|---|---|---|---|---|
| 1 | 1 | [1,11,8,1] | 11 | 1647.022 | 334.37 | 9.693 | 2 |
| | | | 8 | 2352.978 | | | |
| | 2 | [1,3,1,7,1] | 3 | 4000 | 82.43 | 6.463 | 1 |
| | | | 7 | 3619.299 | | | |
| | 3 | [1,3,1] | 3 | 4000 | 12 | 3.496 | 1 |
| | 4 | [1,3,1] | 3 | 4000 | 12 | 3.496 | 1 |
| | 5 | [1,19,17,15,1] | 19 | 1250.841 | 786.89 | 26 | 4 |
| | | | 17 | 1480.286 | | | |
| | | | 15 | 1268.873 | | | |
| | 6 | [1,15,11,1] | 15 | 3343.697 | 619.67 | 30.23 | 4 |
| | | | 11 | 656.303 | | | |
| | 7 | [1,8,2,3,1] | 8 | 1288.525 | 156.51 | 5.411 | 1 |
| | | | 2 | 2239.376 | | | |
| | | | 3 | 472.099 | | | |
| | 8 | [1,3,1,6,1] | 3 | 2200 | 77 | 4.669 | 1 |
| | | | 6 | 459.827 | | | |
| | 9 | [1,6,1] | 6 | 2200 | 65 | 3.539 | 1 |
| | 10 | [1,3,6,1] | 3 | 139.640 | 75 | 4.466 | 1 |
| | | | 6 | 2060.360 | | | |
| | | Total | | 38679.126 | 2220.29 | 97.462 | 17 |

### Optimization Result Comparison: Existing Original, CVRP, and CVRPTW

Table 10 provides a comparison between the existing original delivery routes and the optimum results from both the CVRP scenario and CVRPTW scenario. The evaluation includes the total traveling distance, travel time, equivalent working days, and total distribution costs. The existing original routes cover 23550.1 km of traveling distance with a total travel time 987.82 hours over equivalent 170 working days for 10 vehicles. The overall expenses are Rp 88,947,476 which includes Rp 15,447,476 for the fuel cost and Rp 73,500,000 for the wages. Through CVRP optimization scenario, these results are reduced to 22257.14 kilometers of traveling distance, 635.89 hours of travel time, and equivalent 116 working days for 10 vehicles, with the total distribution cost of Rp 65,684,200, comprising Rp 14,784,200 for the fuels and Rp 50,900,000 for the wages. In comparison, the CVRPTW optimization scenario results in 23052.95 kilometers of travel in 924.51 hours across equivalent 150 working days for 10 vehicles, with the total rebar material distribution cost of Rp 82,214,534, including Rp 15,514,534 for the fuel cost and Rp 66,700,000 for the wage cost.

**Table 10.** Comparison of the Existing Original Route, CVRP Scenario, and CVRPTW Scenario

| Route Scenario | Total Distance (km) | Travel Time (hours) | Total Working Day (days) | Operational Cost | | |
|---|---|---|---|---|---|---|
| | | | | Fuel Cost (fc) | Wage Cost (vc) | Total Cost |
| Existing Original | 23550.10 | 987.82 | 170 | Rp 15,447,476 | Rp 73,500,000 | Rp 88,947,476 |
| CVRP | 22257.14 | 635.889 | 116 | Rp 14,784,200 | Rp 50,900,000 | Rp 65,684,200 |
| CVRPTW | 23052.95 | 924.51 | 150 | Rp 15,514,534 | Rp 66,700,000 | Rp 82,214,534 |

The CVRP optimization scenario reduces the traveling distance by 1291.96 km, travel time by 351.93 hours, and equivalent 54 working days for 10 vehicles, resulting in a cost saving of Rp 23,263,276 (26.15%). This includes a 4.29% decrease in the fuel costs and a 30.75% reduction in wage expenses. On the other hand, CVRPTW offers a more realistic scenario with savings of 497.15 km of traveling distance, 63.31 hours of travel time, and equivalent 20 working days for 10 vehicles, and a total distribution cost reduction of Rp 6,732,942, or 7.57%. Despite a slight 0.43% increase in the fuel costs, the CVRPTW scenario is better suited for real-world conditions, making it a more practical choice for the distributor company.

In the first week, as shown in Table 11, a detailed analysis of the rebar material deliveries to nodes or locations 15, 17, and 19 highlights the differences between the existing original routes, CVRP scenario, and CVRPTW scenario. The current original routes use 2 vehicles but fail to optimize the delivery routes and vehicle capacity. In contrast, the CVRP scenario improves the delivery routes by assigning part of the orders to customer 15, optimizing the vehicle capacity. Furthermore, the CVRPTW optimization scenario not only maximizes the vehicle capacity but also reduces the equivalent working days by adjusting the delivery sequence.

**Table 11.** Comparison of the Optimum Rebar Material Delivery Route Details for Week 1

| Route Scenario | Vehicle | Route | Customer | Loaded Capacity (kg) | Total Distance (km) | Travel Time (hour) | Working Day |
|---|---|---|---|---|---|---|---|
| Existing Original | 1 | [1,17,19,1] | 17<br>19 | 1480.286<br>1250.841 | 786.88 | 26 | 4 |
| | 2 | [1,15,1] | 15 | 4000 | 556.49 | 26 | 4 |
| CVRP | 2 | [1,17,19,15,1] | 17<br>19<br>15 | 1480.286<br>1250.841<br>1268.873 | 786.88 | 21.005 | 3 |
| CVRPTW | 5 | [1,19,17,15,1] | 19<br>17<br>15 | 1250.841<br>1480.286<br>1268.873 | 786.89 | 26 | 4 |

## CONCLUSIONS

Based on the optimization results of the Capacitated Vehicle Routing Problem (CVRP) scenario and the Capacitated Vehicle Routing Problem with Time Windows (CVRPTW) scenario using the Symbiotic Organisms Search (SOS) method, it can be concluded that the SOS method is effective in addressing the challenges in the rebar material distribution, considering both the vehicle capacity constraint (CVRP) and time windows constraint (CVRPTW). The CVRP optimization scenario results show the delivery routes that maximize the vehicle capacity, while the CVRPTW scenario not only optimizes the vehicle capacity but also takes the delivery time windows constraint into account. As a result of the optimization, the CVRP scenario achieves a total distribution cost saving of Rp 23,263,278, or approximately 26.15%, while the CVRPTW scenario saves around Rp 6,732,942, or about 7.57%. These cost savings significantly enhance the operational efficiency and distribution of the building materials, especially the steel rebar.

## REFERENCES


1 Wegelius-Lehtonen, T. and Pahkala, S., Developing Material Delivery Processes in Cooperation: An Application Example of The Construction Industry, *International Journal of Production Economics*, *56–57*, 1998, pp. 689–698, doi: 10.1016/S0925-5273(98)00077-2.

2 Karundeng, T.N., Mandey, S.L., and Sumarauw, J.S.B., Analisis Saluran Distribusi Kayu (Studi Kasus di CV. Karya Abadi, Manado), *Jurnal EMBA: Jurnal Riset Ekonomi, Manajemen, Bisnis dan Akuntansi*, *6*(3), 2018, pp. 1748–1757, doi: 10.35794/emba.v6i3.20444.

3 Puspitasari, F.H. and Kurniawan, V.R.B., Designing Optimal Distribution Routes using a Vehicle Routing Problem (VRP) Model in a Logistics Service Provider, *IOP Conference Series: Material Science and Engineering*, *1071*(1), 2021, p. 012005, doi: 10.1088/1757-899X/1071/1/012005.

4 Dantzig, G.B. and Ramser, J.H., The Truck Dispatching Problem, *Management Science*, *6*(1), 1959, pp. 80–91, doi: 10.1287/mnsc.6.1.80.

5 Setak, M., Habibi, M., Karimi, H., and Abedzadeh, M., A Time-Dependent Vehicle Routing Problem in Multigraph with FIFO Property, *Journal of Manufacturing Systems*, *35*, 2015, pp. 37–45, doi: 10.1016/j.jmsy.2014.11.016.

6 Kumar, S.N. and Panneerselvam, R., A Survey on the Vehicle Routing Problem and Its Variants, *Intelligent Information Management*, *4*(3), 2012, pp. 66–74, doi: 10.4236/iim.2012.43010.

7 Marinakis, Y., Marinaki, M., and Migdalas, A., A Multi-Adaptive Particle Swarm Optimization for The Vehicle Routing Problem with Time Windows, *Information Sciences*, *481*, 2019, pp. 311–329, doi: 10.1016/j.ins.2018.12.086.

8 Braekers, K., Ramaekers, K., and Van Nieuwenhuyse, I., The Vehicle Routing Problem: State of The Art Classification and Review, *Computers & Industrial Engineering*, *99*, 2016, pp. 300–313, doi: 10.1016/j.cie.2015.12.007.

9 Konstantakopoulos, G.D., Gayialis, S.P., and Kechagias, E.P., Vehicle Routing Problem and Related Algorithms for Logistics Distribution: A Literature Review and Classification, *Operational Research*, *22*(3), 2022, pp. 2033–2062, doi: 10.1007/s12351-020-00600-7.

10 Wang, C.H. and Lu, J.Z., A Hybrid Genetic Algorithm That Optimizes Capacitated Vehicle Routing Problems, *Expert Systems with Applications*, *36*(2), 2009, pp. 2921–2936, doi: 10.1016/j.eswa.2008.01.072.

11 Khairy, O.M., Shehata, O.M., and Morgan, E.I., Meta-heuristic Algorithms for Solving The Multi-Depot Vehicle Routing Problem, *2020 2nd Novel Intelligent and Leading Emerging Sciences Conference (NILES)*, IEEE, Giza, Egypt, October, 2020, pp. 276–281, doi: 10.1109/NILES50944.2020.9257879.

12 Bodin, L. and Golden, B., Classification in Vehicle Routing and Scheduling, *Networks*, *11*(2), 1981, pp. 97–108, doi: 10.1002/net.3230110204.

13 Prayogo, D., Sutanto, J.C., Suryo, H.E., and Eric, S., A Comparative Study on Bio-Inspired Algorithms in Layout Optimization of Construction Site Facilities, *Civil Engineering Dimension*, *20*(2), 2018, pp. 102–110, doi: 10.9744/ced.20.2.102-110.

14 Prayogo, D. and Kusuma, C.T., Optimization of Resource Leveling Problem Under Multiple Objective Criteria Using A Symbiotic Organisms Search, *Civil Engineering Dimension*, *21*(1), 2019, pp. 43–51, doi: 10.9744/ced.21.1.43-49.

15 Budi, G.S., Chandra, J.G., Ongkowardhana, B.S., and Husada, W., Optimization of Counterfort Retaining Wall Structure with Shear Key using Metaheuristic Method, *Civil Engineering Dimension*, *26*(2), 2024, pp. 151–159, doi: 10.9744/ced.26.2.151-159.

16 Ho, W., Ho, G.T.S., Ji, P., and Lau, H.C.W., A Hybrid Genetic Algorithm for The Multi-Depot Vehicle Routing Problem, *Engineering Applications of Artificial Intelligence*, *21*(4), 2008, pp. 548–557, doi: 10.1016/j.engappai.2007.06.001.

17 Khouadjia, M.R., Sarasola, B., Alba, E., Jourdan, L., and Talbi, E.G., A Comparative Study Between Dynamic Adapted PSO and VNS for The Vehicle Routing Problem with Dynamic Requests, *Applied Soft Computing*, *12*(4), 2012, pp. 1426–1439, doi: 10.1016/j.asoc.2011.10.023.

18 Zhang, H., Zhang, Q., Ma, L., Zhang, Z., and Liu, Y., A Hybrid Ant Colony Optimization Algorithm for A Multi-Objective Vehicle Routing Problem with Flexible Time Windows, *Information Sciences*, *490*, 2019, pp. 166–190, doi: 10.1016/j.ins.2019.03.070.

19 Cheng, M.Y. and Prayogo, D., Symbiotic Organisms Search: A New Metaheuristic Optimization Algorithm, *Computers & Structures*, *139*, 2014, pp. 98–112, doi: 10.1016/j.compstruc.2014.03.007.

20 Ezugwu, A.E. and Prayogo, D., Symbiotic Organisms Search Algorithm: Theory, Recent Advances and Applications, *Expert Systems with Applications*, *119*, 2019, pp. 184–209, doi: 10.1016/j.eswa.2018.10.045.

21 Gharehchopogh, F.S., Shayanfar, H., and Gholizadeh, H., A Comprehensive Survey on Symbiotic Organisms Search Algorithms, *Artificial Intelligence Review*, *53*(3), 2020, pp. 2265–2312, doi: 10.1007/s10462-019-09733-4.

22 Abdullahi, M., Ngadi, M.A., Dishing, S.I., Abdulhamid, S.M., and Usman, M.J., A Survey of Symbiotic Organisms Search Algorithms and Applications, *Neural Computing & Applications*, *32*(2), 2020, pp. 547–566, doi: 10.1007/s00521-019-04170-4.

# Vehicle Routing Problem Optimization for Rebar Material Distribution using the Symbiotic Organisms Search Method

*by* Perpustakaan Referensi

Civil Engineering Dimension
https://ced.petra.ac.id

# Vehicle Routing Problem Optimization for Rebar Material Distribution using the Symbiotic Organisms Search Method

**Reynaldo, A.M.J.**[1], **Husada, W.**[1]*, **Wijaya, E.K.**[2], **and Vaphilio, D.**[3]
[1] Civil Engineering Department, Faculty of Civil Engineering and Planning, Petra Christian University, Jl. Siwalankerto 121-131, Surabaya 60236, INDONESIA
[2] CV. Benjamin Gideon & Associates, Surabaya, INDONESIA
[3] CV. Mitra Manado, Bitung, Sulawesi Utara, INDONESIA

DOI: https://doi.org/10.9744/ced.27.2.205-215

***Article Info:***
Submitted: May 05, 2025
Reviewed: July 02, 2025
Accepted: Aug 11, 2025

***Keywords***:
vehicle routing problem,
optimization,
rebar distribution,
symbiotic organisms search,
CVRP,
CVRPTW.

***Corresponding Author:***
**Husada, W.**
Civil Engineering Department, Faculty of Civil Engineering and Planning,
Petra Christian University,
Jl. Siwalankerto 121-131, Surabaya 60236,
INDONESIA
Email: willy.husada@petra.ac.id

## Abstract

The success rate of construction projects depends on subcontractors and material suppliers, especially in ensuring the material delivery to avoid delays and cost overruns. The Vehicle Routing Problem (VRP) addresses transportation management to minimize the distribution costs. This study presents a comparative analysis of three VRP scenarios: the existing case, the Capacitated Vehicle Routing Problem (CVRP), and the Capacitated Vehicle Routing Problem with Time Windows (CVRPTW). The Symbiotic Organisms Search (SOS) method is used to solve the VRP of a building materials supplier in Sulawesi, Indonesia in delivering rebar to 19 locations over 12 weeks while considering the vehicle capacity and the time window constraints. The results show that the SOS method effectively handles the rebar distribution problems with these constraints. The CVRP scenario achieves a total cost saving of Rp 23,263,278 (26.15%), while the CVRPTW scenario saves Rp 6,732,942 (7.57%).



## INTRODUCTION

Construction projects involve various stakeholders including architects, designers, main contractor, subcontractors, and material suppliers [1]. The success rate of these projects heavily depends on the performance of subcontractors and material suppliers, especially in ensuring the material delivery to avoid the delays and cost overruns. This delivery process relies on several key factors, including the transportation system, infrastructure, resources availability, and the effective communication among stakeholders [2]. However, the main challenges in the material distribution involve the design of the supply chain network and organizing the transportation processes. These efforts aim to minimize the transportation costs, ensure consistent material availability, and reduce the production expenses, and it is often called the Vehicle Routing Problem (VRP) [3].

VRP is a mathematical model for solving the transportation management problems introduced by Dantzig and Ramser in 1959 to model how the group of trucks could efficiently serve the oil demands from multiple gas stations originating from a central hub with a minimum traveling distance [4]. VRP problems are classified into the static and dynamic types, where the static problems assume constant parameters, such as travel time, demand, and costs. The Dynamic Vehicle Routing Problem (DVRP) overcomes the limitations of the static VRP by accommodating the changes in customer demand and travel time, which are variable in real-world scenarios [5]. Since then, various factors influencing the problem have been identified, leading to the development of multiple VRP variants based on the specific constraints encountered in each optimization scenario. The examples of VRP variations include the Capacitated Vehicle Routing Problem (CVRP) which considers the vehicle capacity constraints [6] and the VRP with Time Windows (VRPTW), where both the customers and vehicles operate within specified time frames or working

**Note** : Discussion is expected before November, 1st 2025, and will be published in the "Civil Engineering Dimension", volume 28, number 1, March 2026.
**ISSN** : 1410-9530 print / 1979-570X online
**Published by** : **Petra Christian University**

hours, requiring the services and operations to occur only within these certain periods [7]. Additionally, other variants have been developed to address various constraints, such as the multiple depot VRP and the VRP with pick-up and delivery requirements [8]. These VRP variants are closely linked to the real-world scenarios, with the goal of reducing the total distribution costs while maintaining high-quality distribution services [9]. The VRP is mathematically, a combinatorial optimization problem, where the number of possible solutions to the problem increases exponentially with the number of customers to be served [10,11]. The vehicle route selection process enables the selection of any combination of customers to assign the delivery route for each vehicle. Since there is no known polynomial algorithm to find the optimal solution in each instance, the problem of vehicle routing is considered Nondeterministic Polynomial Time Hard (NP-Hard) [11,12]. Figure 1 provides a general overview of the VRP problem.

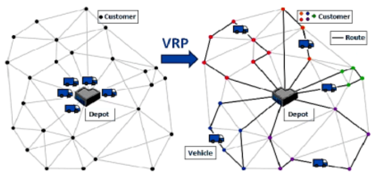



**Figure 1.** General Overview of VRP Problem

The VRP seeks to identify the optimal routes for multiple vehicles based on the customer demands by minimizing the total transportation costs. Solving the VRP often requires the material distributors to manually assign and adjust the delivery routes of each vehicle, which can be time-consuming. The optimization algorithms or metaheuristic methods can help identifying the best combinations of the delivery route for each vehicle, with the goal of determining the best transportation routes for multiple customers to obtain the lowest cost. The metaheuristic methods have been widely applied across various optimization problems in the construction industry. In construction site planning, the bio-inspired optimization methods have been used to improve the layout of site facilities, enhancing spatial efficiency and reducing overall project costs [13]. In project scheduling problem, the Symbiotic Organisms Search (SOS) algorithm has proven effective for resource leveling under multiple objective criteria, offering a robust solution to balance the workloads and timelines [14]. Similarly, in geotechnical engineering, the metaheuristic methods have been employed to optimize the design of counterfort retaining walls with shear key, resulting in more efficient and cost-effective structural designs [15]. Based on these facts, many studies have also used the metaheuristic methods as an optimizer for the VRP optimization problems. Ho et al. used the hybrid Genetic Algorithm (GA) to minimize the total delivery time for multi-depot VRP [16]. Khouadjia et al. compared the performance of the Particle Swarm Optimization (PSO) and Variable Neighborhood Search (VNS) to solve the VRP with dynamic requests [17]. Zhang et al. implemented the hybrid Ant Colony Optimization (ACO) to minimize the total distribution costs and maximize the overall customer satisfaction of multi-objective VRPTW [18]. These studies demonstrated that the metaheuristic methods can effectively solve the VRP optimization problems.

This research employs an optimization algorithm based on the swarm intelligence, specifically the Symbiotic Organisms Search (SOS) to examine and solve the VRP problem of a building materials supplier in delivering the steel rebar to multiple stores. Some challenges that faced by the company are such as a large number of stores located in diverse regions, geographically dispersed areas, and the need to optimize the vehicle capacity for efficient use. The study focuses on single-objective optimization, aiming to optimize the vehicle routes for the rebar delivery from a single distributor to multiple material store locations while considering the customer demand, the number of vehicles, the vehicle capacity, and the delivery time constraints.

## METHODS

### Symbiotic Organisms Search (SOS) Method

Symbiotic Organisms Search (SOS) method is a population-based algorithm inspired by the interactions of organisms within an ecosystem, known as symbiosis. It was developed by Cheng and Prayogo and has proven to be effective in solving various mathematical problems [19,20]. This method simulates the interactions among organisms within an ecosystem as they compete, grow, and survive. It incorporates the three fundamental types of symbiotic relationships: the mutualism phase, where both species benefit; the commensalism phase, where one species benefits without harming the other; and the parasitism phase, where one species gains at the expense of the other [21]. Unlike many competing m6hods, SOS does not need any parameter tuning, which enhances its performances stability [22]. The SOS method begins with an initial population called an ecosystem. In this ecosystem, a group of organisms emerges randomly in th22earch space. Each organism represents a solution to the optimization problem. Additionally, each organism has a fitness value reflecting its level of adaptation to the problem's objective. The organisms adapt according to the objective, and the optimization processes continue based on the number of organisms and specified iterations.

### Vehicle Routing Problem: Variables, Constraints, and Objective Function in Optimization

The VRP model can be described in the form of a graph $G(A,V)$. $V$ in Equation 1 is a set of nodes where each node represents the customer location to be served and a central depot. $A$ in Equation 2 is a set of arcs where there are pairs of nodes connecting connections between nodes $i$ and $j$ with a distance $d$ in the set in Equation 3. Each customer has a demand called $D$ according to the set in Equation 4. $M_m$ in Equation 5 represents a set of vehicles and capacities available for the material delivery. Each vehicle $M_m$ has a maximum capacity $cap_m$, limiting the amount of materials that can be carried.

$$V = \{v_0, v_1, v_2, \dots, v_n\} \quad (1)$$

$$A = \{(v_i, v_j): v_i, v_j \in V\} \quad (2)$$

$$d = \{d_{0,1}, d_{1,2}, d_{2,3}, \dots, d_{i,j}\} \quad (3)$$

$$D = \{D_0, D_1, D_2, \dots, D_n\} \quad (4)$$

$$M_m = \{m_1, m_2, \dots, m_m\} \quad (5)$$

where:
$v_n$ = nodes for customer and depot
$d_{i,j}$ = distance from node $i$ to $j$
$D_n$ = demand of customer $i$
$m_m$ = vehicle number $m$
$i$ = initial node index
$j$ = destination node index
$m$ = vehicle index
0 = depot index
$n$ = index of sum

The variables used in the VRP optimization process are the customer locations and vehicles, constrained by the upper bounds (UB) and lower bounds (LB). These upper and lower bounds are determined based on the number of locations and vehicles specified by the distributor company. These variables will be separated by the program into two parts, one for the sequence of the number of locations and the other for the sequence of vehicle indices. The variables will determine the distribution cost of building materials based on the operational costs of the vehicles and wage costs specified by the company. The variables, upper bounds, and lower bounds used in this study can be seen in Equation 6 to 8.

$$R = \{r_1, r_2, r_3, \dots, r_m\} \quad (6)$$

$$LB = 0 \quad (7)$$

$$UB = dmax \quad (8)$$

where:
$r_m$ = number of locations and the m-th vehicle.
$dmax$ = sum of location and vehicle

The constraints are needed to limit the objective function values so that they do not exceed the specified requirements. The constraints used in this study are presented in Equation 9 to 15. Subsequently, these constraints will eliminate the objective function values that exceed the limits, ensuring they do not become the optimal solution.

- Each vehicle must return to the depot.

$$\sum_{i=1}^{N} X_{i0,m} = 1 \quad (9)$$

- Each node can only be visited once for each route.

$$\sum_{m=1}^{M} \sum_{i=1}^{N} \sum_{j=1}^{N} X_{ij,m} = 1 \quad (10)$$

- After visiting a node, the vehicle must move to the next node.

$$\sum_{m=1}^{M}\sum_{i=1}^{N} X_{ip,m} = \sum_{m=1}^{M}\sum_{i=1}^{N} X_{ip,m} \quad (11)$$

- Limiting vehicle capacity and adjusting it to the customer demand.

$$\sum_{i=1}^{M}\sum_{j=1}^{N} X_{ij,m} \times D_j = Dm_{ij,m} \quad (12)$$

$$\sum_{i=1}^{N} Dm_{0i,m} \leq cap_m \quad (13)$$

- Limiting the number of available vehicles.

$$\sum_{m=1}^{M} X_{ij,m} \leq veh_m \quad (14)$$

- Time window constraints for the material delivery.

$$a_j \leq t_{ij} \leq b_j - tl_{ij} \quad (15)$$

where:
$D_j$ = customer demand from node i to j
$Dm_{ij,m}$ = capacity that the m-th type of vehicle can accommodate from node $i$ to $j$
$cap_m$ = maximum vehicle capacity
$veh_m$ = maximum number of vehicles
$p$ = index of the destination node
$t_{ij}$ = arrival time of the vehicle at the node
$h_{ij}$ = working days of the vehicle for each route taken
$tl_{ij}$ = loading and unloading time at the node
$[a_j, b_j]$ = time window for delivery at node j

The objective function in Equation 16 is implemented by minimizing the total delivery cost. The costs considered in this study include the fuel costs and the wage costs for each vehicle. The fuel and wage costs are determined based on the company's policy.

$$Minimize \sum_{m=1}^{M}\sum_{i=0}^{N}\sum_{j=0}^{N} X_{ij,m} \times fc_m + \sum_{m=1}^{M}\sum_{i=0}^{N}\sum_{j=0}^{N} h_{ij} \times vc_m \quad (16)$$

where:
$fc_m$ = fuel cost of the vehicle
$vc_m$ = wage cost of the vehicle

## RESULTS AND DISCUSSION

### Case Study

The case study used in this research involves a building materials distributor company located in Sulawesi, Indonesia. The distributor delivers the steel rebar material to 30 stores located in 19 different locations. The data obtained from this case study includes the information about the distributor and store locations, the customer purchase history of steel rebar material, the store operating hours, the types and capacities of vehicle, as well as the original routes commonly used by the distributor. This research is a single-objective optimization with the goal of optimizing the delivery routes of each vehicle in distributing the rebar based on the number of vehicles, vehicle capacities, and delivery time constraints. The optimization results in this study are based on a single run and were implemented on a computer equipped with a Ryzen 7 5800H 3.2 GHz processor and 16 GB RAM.

The distances between stores were obtained using the Google Waypoint Application Programming Interface (GWAPI), which retrieves the distances between points from Google Maps. Details of the distances between locations or nodes can be seen in Table 1. In this table, index 1 represents the material depot, and the other 18 indices represent the customer locations. For example, the distance from node 1 (depot) to node 3 is 6.49 km, and the distance from node 3 to node 1 (depot) is 5.51 km. This difference in traveling distance may happen because the distance for departure and return can be different according to Google Maps.

**Table 1.** Distance between Locations or Nodes (in km)

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| **1** | 0 | 8.37 | 5.51 | 38.49 | 21.39 | 32.56 | 34.9 | 73.4 | 116.4 | 126.3 |
| **2** | 8.2 | 0 | 11.92 | 43.42 | 26.33 | 41.91 | 44.25 | 66.48 | 109.4 | 119.3 |
| **3** | 6.49 | 13.13 | 0 | 33.31 | 16.21 | 37.07 | 39.41 | 77.91 | 120.9 | 130.8 |
| **4** | 38.09 | 46.46 | 31.6 | 0 | 17.1 | 49.49 | 37.06 | 93.85 | 136.8 | 146.7 |
| **5** | 21 | 29.37 | 14.5 | 17.1 | 0 | 32.39 | 24.52 | 76.75 | 119.7 | 129.6 |
| **6** | 32.24 | 40.05 | 35.18 | 48.48 | 31.38 | 0 | 12.02 | 72.92 | 115.9 | 125.8 |
| **7** | 35.53 | 43.34 | 38.48 | 37.06 | 24.52 | 9.49 | 0 | 80.45 | 123.4 | 133.3 |
| **8** | 74.03 | 64.7 | 76.97 | 93.79 | 76.69 | 77.23 | 79.57 | 0 | 43.02 | 52.91 |
| **9** | 117 | 107.7 | 120 | 136.8 | 119.7 | 120.3 | 122.6 | 43.08 | 0 | 9.9 |
| **10** | 126.9 | 117.6 | 129.9 | 146.7 | 129.6 | 130.1 | 132.5 | 52.98 | 9.9 | 0 |
| **11** | 160.5 | 153.4 | 166.9 | 199.9 | 182.8 | 192.1 | 194.4 | 99.56 | 56.48 | 46.58 |
| **12** | 227.3 | 220.2 | 233.7 | 266.7 | 249.6 | 258.9 | 261.2 | 155.6 | 112.5 | 102.6 |
| **13** | 160.9 | 153.8 | 167.3 | 200.3 | 183.2 | 192.5 | 194.8 | 141.1 | 115.4 | 105.5 |
| **14** | 187 | 180 | 193.4 | 226.4 | 209.3 | 218.6 | 220.9 | 167.2 | 141.5 | 131.6 |
| **15** | 277.3 | 270.3 | 283.8 | 316.7 | 299.6 | 308.9 | 311.3 | 257.5 | 231.8 | 221.9 |
| **16** | 317.8 | 310.8 | 324.3 | 357.2 | 340.1 | 349.4 | 351.8 | 298 | 272.3 | 262.4 |
| **17** | 345.8 | 338.8 | 352.3 | 385.3 | 368.2 | 377.5 | 379.8 | 326 | 300.4 | 290.5 |
| **18** | 363.3 | 356.3 | 369.8 | 402.7 | 385.6 | 394.9 | 397.3 | 343.5 | 317.8 | 307.9 |
| **19** | 392 | 385 | 398.5 | 431.4 | 414.3 | 423.6 | 426 | 372.2 | 333.4 | 323.5 |

Distance between Locations or Nodes (in km) – Continued

| | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
|---|---|---|---|---|---|---|---|---|---|
| **1** | 160.8 | 227.6 | 161.2 | 187.3 | 279.2 | 319.4 | 347.4 | 364.9 | 393.6 |
| **2** | 152.6 | 219.4 | 153 | 179.1 | 271 | 311.2 | 339.3 | 356.7 | 385.5 |
| **3** | 168 | 234.8 | 168.4 | 194.5 | 286.4 | 326.6 | 354.6 | 372.1 | 400.8 |
| **4** | 199.6 | 266.4 | 200 | 226.1 | 317.9 | 358.2 | 386.2 | 403.7 | 432.4 |
| **5** | 182.5 | 249.3 | 182.9 | 209 | 300.9 | 341.1 | 369.1 | 386.6 | 415.3 |
| **6** | 172.3 | 258.2 | 191.8 | 217.9 | 309.8 | 350 | 378 | 395.5 | 424.2 |
| **7** | 194.7 | 261.5 | 195.1 | 221.2 | 313.1 | 353.3 | 381.3 | 398.8 | 427.5 |
| **8** | 99.49 | 157.2 | 141 | 167.1 | 259 | 299.2 | 327.2 | 344.7 | 373.4 |
| **9** | 56.47 | 114.2 | 115.3 | 141.4 | 233.2 | 273.5 | 301.5 | 319 | 335.1 |
| **10** | 46.58 | 104.3 | 105.4 | 131.5 | 223.3 | 263.6 | 291.6 | 309.1 | 325.2 |
| **11** | 0 | 62.4 | 63.46 | 89.57 | 181.4 | 221.7 | 249.7 | 267.2 | 283.3 |
| **12** | 60.68 | 0.0 | 62.87 | 72.69 | 164.6 | 204.8 | 232.8 | 242.2 | 223.2 |
| **13** | 63.59 | 62.9 | 0 | 26.18 | 118.1 | 158.3 | 186.3 | 203.8 | 232.5 |
| **14** | 89.69 | 72.7 | 26.18 | 0 | 91.87 | 132.1 | 160.1 | 177.6 | 206.3 |
| **15** | 180 | 163.0 | 116.5 | 90.35 | 0 | 41.7 | 69.72 | 87.2 | 115.9 |
| **16** | 220.5 | 203.5 | 157 | 130.9 | 40.51 | 0 | 28.42 | 45.9 | 74.6 |
| **17** | 248.6 | 231.6 | 185.1 | 158.9 | 68.52 | 28.41 | 0 | 18.72 | 47.43 |
| **18** | 266 | 242.2 | 202.5 | 176.3 | 85.99 | 45.88 | 18.72 | 0 | 43.71 |
| **19** | 281.6 | 223.2 | 231.2 | 205.1 | 114.7 | 74.59 | 47.43 | 43.72 | 0 |

The detailed information about the rebar demands for each customer and the delivery routes from the company was obtained. The purchasing history data was processed and transformed into a weekly delivery schedule, which later be input into the program. Table 2 presents the rebar purchasing history data from the 19 locations for 12 weeks period or 3 months. The rows represent the number of weeks, and the columns represent the quantity of rebar purchased in kg. Based on the interviews conducted, the average operating hours for the customer stores are from 8:00 AM to 5:00 PM. These 8-9 working hours will become the time window constraint in this study.

The company operates 10 vehicles for the rebar delivery, consisting of two types: 7 units of type 1 vehicle with a capacity of 4000 kg and 3 units of type 2 vehicle with the capacity of 2200 kg. Based on the interview results, the fuel cost is Rp 680/km for type 1 vehicle and Rp 450/km for type 2 vehicle. All vehicles are assumed to travel at a speed of 40 km/h. In addition to the fuel expenses, each vehicle also incurs wage costs, which include the daily wages of the driver and assistants required for the delivery and operation. The daily wage for one driver is Rp 150,000, and for one assistant, it is Rp 100,000. A type 1 vehicle requires 1 driver and 3 assistants accumulating a total daily wage cost of Rp 450,000. Meanwhile, type 2 vehicle requires 1 driver and 2 assistants accumulating Rp. 350,000 in daily wage cost. The details for each vehicle type can be seen in Table 3.

**Table 2.** Rebar Purchasing History Data (in kg)

| Week/Node | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 2239 | 14812 | 0 | 0 | 4720 | 3619 | 3642 | 0 | 0 |
| 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1451 | 0 | 0 |
| 3 | 0 | 1333 | 19214 | 0 | 75 | 0 | 9237 | 0 | 0 | 947 |
| 4 | 0 | 1747 | 0 | 0 | 0 | 0 | 9178 | 6137 | 237 | 0 |
| 5 | 0 | 533 | 0 | 0 | 0 | 0 | 947 | 0 | 250 | 0 |
| 6 | 0 | 95 | 95 | 4737 | 508 | 0 | 5798 | 0 | 0 | 0 |
| 7 | 0 | 0 | 0 | 0 | 0 | 0 | 2368 | 2368 | 0 | 0 |
| 8 | 0 | 142 | 0 | 0 | 2052 | 0 | 4312 | 0 | 0 | 0 |
| 9 | 0 | 0 | 8734 | 0 | 0 | 0 | 7905 | 1865 | 0 | 0 |
| 10 | 0 | 488 | 1480 | 0 | 0 | 1599 | 0 | 533 | 0 | 2665 |
| 11 | 0 | 1442 | 0 | 0 | 878 | 0 | 5595 | 0 | 0 | 0 |
| 12 | 0 | 637 | 0 | 0 | 290 | 0 | 6972 | 0 | 0 | 2013 |

Rebar Purchasing History Data (in kg) – Continued

| Week/Node | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2303 | 0 | 0 | 0 | 4613 | 0 | 1480 | 0 | 1251 |
| 2 | 0 | 0 | 4607 | 38 | 3656 | 0 | 0 | 0 | 8618 |
| 3 | 0 | 0 | 625 | 0 | 995 | 0 | 0 | 1850 | 0 |
| 4 | 0 | 0 | 0 | 0 | 0 | 0 | 711 | 1599 | 0 |
| 5 | 0 | 0 | 0 | 0 | 1673 | 0 | 0 | 0 | 7675 |
| 6 | 0 | 0 | 0 | 2132 | 1990 | 0 | 0 | 1421 | 1351 |
| 7 | 0 | 0 | 0 | 3162 | 2487 | 0 | 0 | 0 | 0 |
| 8 | 0 | 0 | 0 | 0 | 1332 | 0 | 497 | 0 | 0 |
| 9 | 0 | 533 | 1895 | 0 | 1232 | 0 | 0 | 1876 | 0 |
| 10 | 0 | 0 | 533 | 0 | 2280 | 13360 | 1480 | 0 | 534 |
| 11 | 0 | 8011 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 12 | 0 | 799 | 947 | 0 | 0 | 0 | 0 | 0 | 2949 |

**Table 3.** Detailed Vehicle Information

| Vehicle Type | Capacity (Ton) | Unit | Fuel Cost (fc) - Rp/km | Wage Cost (vc) - Rp/day |
|---|---|---|---|---|
| 1 | 4 | 7 | 680 | 450,000 |
| 2 | 2.2 | 3 | 450 | 350,000 |

**Table 4.** Existing Original Routes from the Distributor Company

| Vehicle/Week | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1 | [1, 17, 19, 1] | [1, 19, 1] | [1, 13, 15, 1] | [1, 17, 18, 1] | [1, 19, 1] | [1, 15, 18, 19, 1] |
| 2 | [1, 15, 1] | [1, 19, 1] | [1, 10, 18, 1] | [1, 8, 1] | [1, 19, 1] | [1, 14, 19, 1] |
| 3 | [1, 11, 15, 1] | [1, 19, 15, 1] | [1, 7, 1] | [1, 8, 9, 1] | [] | [1, 7, 1] |
| 4 | [1, 8, 1] | [1, 13, 1] | [1, 7, 1] | [1, 7, 1] | [] | [1, 5, 7, 1] |
| 5 | [1, 7, 1] | [1, 13, 14, 15, 1] | [1, 5, 7, 1] | [1, 7, 1] | [] | [1, 4, 1] |
| 6 | [1, 6, 1, 3, 1] | [] | [1, 3, 1, 3, 1] | [] | [] | [] |
| 7 | [1, 3, 1] | [] | [1, 3, 1, 3, 1] | [] | [] | [] |
| 8 | [1, 3, 1] | [1, 8, 1] | [1, 3, 1] | [1, 7, 1] | [1, 7, 1] | [1, 3, 4, 1] |
| 9 | [1, 3, 1, 3, 1] | [] | [1, 3, 1] | [1, 2, 1] | [1, 2, 1] | [1, 2, 1] |
| 10 | [1, 2, 1, 2, 3, 6, 1] | [] | [1, 2, 1] | [] | [1, 9, 15, 1] | [] |

Existing Original Routes from the Distributor Company – Continued

| Vehicle/Week | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|
| 1 | [1, 14, 15, 1] | [1, 15, 17, 1] | [1, 13, 15, 18, 1] | [1, 16, 1] | [1, 12, 1] | [1, 13, 19, 1] |
| 2 | [1, 8, 1] | [1, 7, 1] | [1, 8, 12, 18, 1] | [1, 16, 1] | [1, 12, 1] | [1, 10, 12, 1] |
| 3 | [1, 7, 1] | [1, 5, 7, 1] | [1, 7, 1] | [1, 16, 1] | [1, 7, 1] | [1, 7, 1] |
| 4 | [] | [] | [1, 7, 1] | [1, 16, 19, 17, 1] | [1, 5, 7, 1] | [1, 5, 7, 1] |
| 5 | [] | [] | [1, 3, 1] | [1, 13, 15, 1] | [] | [] |
| 6 | [] | [] | [1, 3, 1] | [1, 8, 10, 1] | [] | [] |
| 7 | [] | [] | [] | [] | [] | [] |
| 8 | [1, 15, 1] | [1, 2, 1] | [1, 3, 1] | [1, 6, 1] | [1, 12, 2, 1] | [1, 2, 1] |
| 9 | [] | [] | [] | [1, 3, 2, 1] | [] | [] |
| 10 | [] | [] | [] | [] | [] | [] |

Table 4 presents the delivery routes for 10 vehicles over the 12 weeks period. Vehicles 1-7 are type 1, and vehicles 8-10 are type 2. The routes show the sequence of nodes visited by the vehicles, starting and ending from and to the depot with node index 1. Empty cells ([]) indicate no rebar delivery assignment in that week for the respective vehicle. Based on the existing original routes made by the company, the total distribution cost of the rebar material in 12 weeks period is Rp 88,947,476 consisting of Rp 15,447,476 for the fuel cost and Rp 73,500,000 for the wage cost. The total distance covered is 23550.1 km. Each vehicle route includes details such as the load capacity, total distance, travel time, and equivalent working days (8 working hours/day). As an example, Table 5 shows the delivery route details from the first week (week 1). Vehicle 1 departs from the depot (node 1), delivers 1480.29 kg to customer 17, delivers 1250.84 kg to customer 19, and back again to the depot (node 1) with total travel distance of 786.88 km in 26 hours over around 4 working days. Some vehicles, like vehicle 6 and 10, make multiple trips in a week, returning to the depot between deliveries. This approach is also used in the optimization scenarios to resemble the real-world conditions.

**Table 5.** Delivery Route Details for Week 1 (Existing Original Routes)

| Week | Vehicle | Route | Customer | Loaded Capacity (kg) | Total Distance (km) | Travel Time (hours) | Working Day (days) |
|---|---|---|---|---|---|---|---|
| 1 | 1 | [1,17,19,1] | 17<br>19 | 1480.29<br>1250.84 | 786.88 | 26 | 4 |
| | 2 | [1,15,1] | 15 | 4000 | 556.49 | 26 | 4 |
| | 3 | [1,11,15,1] | 11<br>15 | 2303.32<br>612.57 | 619.54 | 26 | 4 |
| | 4 | [1,8,1] | 8 | 3641.50 | 147.43 | 5.065 | 1 |
| | 5 | [1,7,1] | 7 | 3619.30 | 70.43 | 4.095 | 1 |
| | 6 | [1,6,1,3,1] | 6<br>3 | 4000<br>4000 | 76.8 | 5.773 | 1 |
| | 7 | [1,3,1] | 3 | 4000 | 12 | 3.496 | 1 |
| | 8 | [1,3,1] | 3 | 2200 | 12 | 2.896 | 1 |
| | 9 | [1,3,1,3,1] | 3<br>3 | 2200<br>2200 | 24 | 3.929 | 1 |
| | 10 | [1,2,1,2,3,6,1] | 2<br>2<br>3<br>6 | 2000<br>239.38<br>211.74<br>720.19 | 195.77 | 7.515 | 1 |
| | | Total | | 38679.13 | 2501.34 | 110.767 | 19 |

## Optimization Result

This study examines the two optimization scenarios to minimize the total delivery costs for rebar material: the Capacitated Vehicle Routing Problem (CVRP) and the Capacitated Vehicle Routing Problem with Time Windows (CVRPTW), both solved using the SOS metaheuristic method. The CVRP optimization case assumes no delivery time window constraint, while the CVRPTW optimization case includes the delivery time window constraint, adding complexity to the problem. The SOS method runs using 200 organisms and 100 iterations, with the computational time between 16 to 35 hours.

## CVRP Optimization Result

Table 6 shows the optimum CVRP delivery routes with the total rebar material distribution cost of Rp 65,684,200, comprising Rp 14,784,200 in fuel cost and Rp. 50,900,000 in wage cost. The delivery routes cover 22257.14 km. Compared to the existing original routes, this yields a cost saving of Rp 23,263,276 (26.15%) and 1292.96 km less traveling distance (5.49%). These savings are achieved by maximizing the vehicle capacity and removing the working hours and time window constraints. Table 7 presents the detailed route information assigned from the first week. In this scenario, Vehicle 2 departs from the depot (node 1), delivers 1480.286 kg of rebar to customer 17, 1250.841 kg to customer 19, and 1268.873 kg to customer 15 before returning to the depot (node 1). The vehicle travels 786.88 km with travel time of 21.005 hours. Compared to the existing original route, the delivery to customer 15 is an addition. However, the total distance remains unchanged, as the program identifies more optimal combinations of delivery routes. The route requires 2 fewer working days due to the absence of time constraints.

After comparing the routes of the optimum CVRP scenario and existing original routes, it can be concluded that the program finds more optimal routes with fewer working days in the CVRP scenario. By maximizing the vehicle capacity without exceeding limits, all rebar orders are delivered very well. However, the lack of working hours and time window constraints makes the results less applicable to real-world scenarios. To improve the results applicability, the time window constraint will be added, leading to the optimization in the second case, CVRPTW.

**Table 6.** Optimum Delivery Routes for the CVRP Scenario

| Vehicle/Week | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1 | [1,2,11,8,1] | [1,19,15,1] | [1,3,1] | [1,8,7,1] | [1,15,2,7,1] | [1,4,5,1] |
| 2 | [1,17,19,15,1] | [1,19,1] | [1,18,15,13,2,1] | [1,9,17,18,2,1] | [1,9,19,1] | [1,18,19,15,1] |
| 3 | [1,8,3,1] | [1,15,14,13,1] | [1,3,1] | [1,7,1] | [] | [1,5,7,1] |
| 4 | [1,3,1,7,1] | [] | [1,3,5,7,1] | [] | [] | [] |
| 5 | [1,3,1] | [1,8,1] | [1,3,1] | [1,7,1] | [] | [] |
| 6 | [1,3,1] | [] | [1,7,1] | [] | [] | [] |
| 7 | [1,15,2,1] | [1,19,1] | [1,2,10,3,1] | [1,2,8,1] | [1,19,15,1] | [1,15,14,2,3,4,1] |
| 8 | [1,3,6,1] | [] | [1,7,1] | [] | [] | [] |
| 9 | [1,6,1] | [] | [1,7,1] | [] | [] | [] |
| 10 | [1,3,1,6,1] | [1,13,8,1] | [1,3,1] | [1,7,1] | [] | [1,7,1] |

Optimum Delivery Routes for the CVRP Scenario – Continued

| Vehicle/Week | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|
| 1 | [1,8,7,1] | [1,7,1] | [1,3,1] | [1,16,1] | [1,12,5,7,1] | [1,7,1] |
| 2 | [1,15,14,1] | [1,17,15,2,5,1] | [1,18,15,13,1] | [1,16,1] | [1,2,12,1] | [1,19,13,2,1] |
| 3 | [] | [] | [1,3,1] | [1,16,17,19,15,1] | [1,7,1] | [1,7,1] |
| 4 | [] | [] | [1,7,1] | [1,3,6,1] | [] | [] |
| 5 | [] | [] | [1,7,1] | [1,2,10,8,3,1] | [] | [] |
| 6 | [] | [] | [] | [] | [] | [] |
| 7 | [1,14,8,1] | [1,5,7,1] | [1,13,12,8,3,1] | [1,16,1] | [1,12,1] | [1,2,12,10,5,7,1] |
| 8 | [] | [] | [] | [] | [] | [] |
| 9 | [] | [] | [] | [] | [] | [] |
| 10 | [] | [] | [1,3,7,1] | [1,15,13,2,1] | [] | [] |

**Table 7.** Optimum Delivery Route Details for Week 1 (CVRP Scenario)

| Week | Vehicle | Route | Customer | Loaded Capacity (kg) | Total Distance (km) | Travel Time (hours) | Working Day (days) |
|---|---|---|---|---|---|---|---|
| 1 | 1 | [1,2,11,8,1] | 2 | 1583.074 | 334.56 | 9.697 | 2 |
| | | | 11 | 2303.325 | | | |
| | | | 8 | 113.602 | | | |
| | 2 | [1,17,19,15,1] | 17 | 1480.286 | 786.88 | 21.005 | 3 |
| | | | 19 | 1250.841 | | | |
| | | | 15 | 1268.873 | | | |
| | 3 | [1,8,3,1] | 8 | 3527.901 | 156.86 | 5.255 | 1 |
| | | | 3 | 472.099 | | | |
| | 4 | [1,3,1,7,1] | 3 | 4000 | 82.43 | 4.601 | 1 |
| | | | 7 | 3619.299 | | | |
| | 5 | [1,3,1] | 3 | 4000 | 12 | 1.633 | 1 |
| | 6 | [1,3,1] | 3 | 4000 | 12 | 1.633 | 1 |
| | 7 | [1,15,2,1] | 15 | 3343.697 | 557.67 | 15.275 | 2 |
| | | | 2 | 656.303 | | | |
| | 8 | [1,3,6,1] | 3 | 139.640 | 74.82 | 2.604 | 1 |
| | | | 6 | 2060.360 | | | |
| | 9 | [1,6,1] | 6 | 2200 | 64.8 | 2.353 | 1 |
| | 10 | [1,3,1,6,1] | 3 | 2200 | 76.8 | 2.807 | 1 |
| | | | 6 | 459.827 | | | |
| | | Total | | 38679.126 | 2158.82 | 66.8627 | 14 |

## CVRPTW Optimization Result

Table 8 presents the optimum CVRPTW routes with a total rebar material distribution cost of Rp 82,214,534, including Rp 15,514,534 for the fuel cost and Rp 66,700,000 for the wage cost. The total travel distance is 23052.92 km. Compared to the existing original routes, there is a traveling distance saving of 497.18 km (2.11%). However, the fuel costs are nearly the same due to the increased use of the type 1 vehicles compared to the existing original routes. This occurs because the CVRPTW scenario results in more usage of type 1 vehicles. Meanwhile, the optimization in the CVRPTW scenario reduces the wage costs by 9.25%, saving equivalent to 20 working days and lowering the operational expenses. As illustrated in Table 9, the detailed routes data and visualizations for the first week of the CVRPTW scenario are shown. In this example, Vehicle 5 follows a similar route to the CVRP results of vehicle 2 but in a different delivery order. The vehicle 5 departs from the depot (node 1), delivers the rebar material 1250.841 kg to customer 19, 1480.286 kg to customer 17, and 1268.873 kg to customer 15 before returning to the depot (node 1). The vehicle travels 786.89 km with a traveling time of 26 hours. The adjusted sequence reduces the working days and wage costs, demonstrating the program's ability to optimize the delivery time within the specified time windows.

**Table 8.** Optimum Delivery Routes for the CVRPTW Scenario

| Vehicle/Week | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1 | [1,11,8,1] | [1,19,14,15,1] | [1,3,1] | [1,8,2,7,1] | [1,15,2,7,1] | [1,4,5,1] |
| 2 | [1,3,1,7,1] | [1,13,8,1] | [1,3,1] | [1,7,1] | [] | [1,7,1] |
| 3 | [1,3,1] | [] | [1,3,5,7,1] | [] | [] | [] |
| 4 | [1,3,1] | [] | [1,7,1] | [] | [] | [] |
| 5 | [1,19,17,15,1] | [1,19,1] | [1,18,15,13,10,1] | [1,17,18,9,8,1] | [1,19,1] | [1,19,18,14,1] |
| 6 | [1,15,11,1] | [1,19,1] | [1,10,2,3,1] | [1,8,1] | [1,19,9,15,1] | [1,14,15,2,3,4,1] |
| 7 | [1,8,2,3,1] | [1,15,13,1] | [1,3,1] | [1,7,1] | [] | [1,5,7,1] |
| 8 | [1,3,1,6,1] | [] | [1,3,1] | [] | [] | [] |
| 9 | [1,6,1] | [] | [1,7,1] | [] | [] | [] |
| 10 | [1,3,6,1] | [] | [1,7,1] | [] | [] | [] |

Optimum Delivery Routes for the CVRPTW Scenario – Continued

| Vehicle/Week | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|
| 1 | [1,8,7,1] | [1,7,1] | [1,3,1] | [1,16,1] | [1,12,5,7,1] | [1,7,1] |
| 2 | [1,15,14,1] | [1,17,15,2,5,1] | [1,18,15,13,1] | [1,16,1] | [1,2,12,1] | [1,19,13,2,1] |
| 3 | [] | [] | [1,3,1] | [1,16,17,19,15,1] | [1,7,1] | [1,7,1] |
| 4 | [] | [] | [1,7,1] | [1,3,6,1] | [] | [] |
| 5 | [] | [] | [1,7,1] | [1,2,10,8,3,1] | [] | [] |
| 6 | [] | [] | [] | [] | [] | [] |
| 7 | [1,14,8,1] | [1,5,7,1] | [1,13,12,8,3,1] | [1,16,1] | [1,12,1] | [1,2,12,10,5,7,1] |
| 8 | [] | [] | [] | [] | [] | [] |
| 9 | [] | [] | [] | [] | [] | [] |
| 10 | [] | [] | [1,3,7,1] | [1,15,13,2,1] | [] | [] |

**Table 9.** Optimum Delivery Route Details for Week 1 (CVRPTW Scenario)

| Week | Vehicle | Route | Customer | Loaded Capacity (kg) | Total Distance (km) | Travel Time (hours) | Working Day (days) |
|---|---|---|---|---|---|---|---|
| 1 | 1 | [1,11,8,1] | 11<br>8 | 1647.022<br>2352.978 | 334.37 | 9.693 | 2 |
| | 2 | [1,3,1,7,1] | 3<br>7 | 4000<br>3619.299 | 82.43 | 6.463 | 1 |
| | 3 | [1,3,1] | 3 | 4000 | 12 | 3.496 | 1 |
| | 4 | [1,3,1] | 3 | 4000 | 12 | 3.496 | 1 |
| | 5 | [1,19,17,15,1] | 19<br>17<br>15 | 1250.841<br>1480.286<br>1268.873 | 786.89 | 26 | 4 |
| | 6 | [1,15,11,1] | 15<br>11 | 3343.697<br>656.303 | 619.67 | 30.23 | 4 |
| | 7 | [1,8,2,3,1] | 8<br>2<br>3 | 1288.525<br>2239.376<br>472.099 | 156.51 | 5.411 | 1 |
| | 8 | [1,3,1,6,1] | 3<br>6 | 2200<br>459.827 | 77 | 4.669 | 1 |
| | 9 | [1,6,1] | 6 | 2200 | 65 | 3.539 | 1 |
| | 10 | [1,3,6,1] | 3<br>6 | 139.640<br>2060.360 | 75 | 4.466 | 1 |
| | | Total | | 38679.126 | 2220.29 | 97.462 | 17 |

### Optimization Result Comparison: Existing Original, CVRP, and CVRPTW

Table 10 provides a comparison between the existing original delivery routes and the optimum results from both the CVRP scenario and CVRPTW scenario. The evaluation includes the total traveling distance, travel time, equivalent working days, and total distribution costs. The existing original routes cover 23550.1 km of traveling distance with a total travel time 987.82 hours over equivalent 170 working days for 10 vehicles. The overall expenses are Rp 88,947,476 which includes Rp 15,447,476 for the fuel cost and Rp 73,500,000 for the wages. Through CVRP optimization scenario, these results are reduced to 22257.14 kilometers of traveling distance, 635.89 hours of travel time, and equivalent 116 working days for 10 vehicles, with the total distribution cost of Rp 65,684,200, comprising Rp 14,784,200 for the fuels and Rp 50,900,000 for the wages. In comparison, the CVRPTW optimization scenario results in 23052.95 kilometers of travel in 924.51 hours across equivalent 150 working days for 10 vehicles, with the total rebar material distribution cost of Rp 82,214,534, including Rp 15,514,534 for the fuel cost and Rp 66,700,000 for the wage cost.

**Table 10.** Comparison of the Existing Original Route, CVRP Scenario, and CVRPTW Scenario

| Route Scenario | Total Distance (km) | Travel Time (hours) | Total Working Day (days) | Operational Cost | | |
|---|---|---|---|---|---|---|
| | | | | Fuel Cost (fc) | Wage Cost (vc) | Total Cost |
| Existing Original | 23550.10 | 987.82 | 170 | Rp 15,447,476 | Rp 73,500,000 | Rp 88,947,476 |
| CVRP | 22257.14 | 635.889 | 116 | Rp 14,784,200 | Rp 50,900,000 | Rp 65,684,200 |
| CVRPTW | 23052.95 | 924.51 | 150 | Rp 15,514,534 | Rp 66,700,000 | Rp 82,214,534 |

The CVRP optimization scenario reduces the traveling distance by 1291.96 km, travel time by 351.93 hours, and equivalent 54 working days for 10 vehicles, resulting in a cost saving of Rp 23,263,276 (26.15%). This includes a 4.29% decrease in the fuel costs and a 30.75% reduction in wage expenses. On the other hand, CVRPTW offers a more realistic scenario with savings of 497.15 km of traveling distance, 63.31 hours of travel time, and equivalent 20 working days for 10 vehicles, and a total distribution cost reduction of Rp 6,732,942, or 7.57%. Despite a slight 0.43% increase in the fuel costs, the CVRPTW scenario is better suited for real-world conditions, making it a more practical choice for the distributor company.

In the first week, as shown in Table 11, a detailed analysis of the rebar material deliveries to nodes or locations 15, 17, and 19 highlights the differences between the existing original routes, CVRP scenario, and CVRPTW scenario. The current original routes use 2 vehicles but fail to optimize the delivery routes and vehicle capacity. In contrast, the CVRP scenario improves the delivery routes by assigning part of the orders to customer 15, optimizing the vehicle capacity. Furthermore, the CVRPTW optimization scenario not only maximizes the vehicle capacity but also reduces the equivalent working days by adjusting the delivery sequence.

**Table 11.** Comparison of the Optimum Rebar Material Delivery Route Details for Week 1

| Route Scenario | Vehicle | Route | Customer | Loaded Capacity (kg) | Total Distance (km) | Travel Time (hour) | Working Day |
|---|---|---|---|---|---|---|---|
| Existing Original | 1 | [1,17,19,1] | 17 | 1480.286 | 786.88 | 26 | 4 |
| | | | 19 | 1250.841 | | | |
| | 2 | [1,15,1] | 15 | 4000 | 556.49 | 26 | 4 |
| CVRP | 2 | [1,17,19,15,1] | 17 | 1480.286 | 786.88 | 21.005 | 3 |
| | | | 19 | 1250.841 | | | |
| | | | 15 | 1268.873 | | | |
| CVRPTW | 5 | [1,19,17,15,1] | 19 | 1250.841 | 786.89 | 26 | 4 |
| | | | 17 | 1480.286 | | | |
| | | | 15 | 1268.873 | | | |

## CONCLUSIONS

Based on the optimization results of the Capacitated Vehicle Routing Problem (CVRP) scenario and the Capacitated Vehicle Routing Problem with Time Windows (CVRPTW) scenario using the Symbiotic Organisms Search (SOS) method, it can be concluded that the SOS method is effective in addressing the challenges in the rebar material distribution, considering both the vehicle capacity constraint (CVRP) and time windows constraint (CVRPTW). The CVRP optimization scenario results show the delivery routes that maximize the vehicle capacity, while the CVRPTW scenario not only optimizes the vehicle capacity but also takes the delivery time windows constraint into account. As a result of the optimization, the CVRP scenario achieves a total distribution cost saving of Rp 23,263,278, or approximately 26.15%, while the CVRPTW scenario saves around Rp 6,732,942, or about 7.57%. These cost savings significantly enhance the operational efficiency and distribution of the building materials, especially the steel rebar.

## REFERENCES


1 Wegelius-Lehtonen, T. and Pahkala, S., Developing Material Delivery Processes in Cooperation: An Application Example of The Construction Industry, *International Journal of Production Economics*, *56–57*, 1998, pp. 689–698, doi: 10.1016/S0925-5273(98)00077-2.

2 Karundeng, T.N., Mandey, S.L., and Sumarauw, J.S.B., Analisis Saluran Distribusi Kayu (Studi Kasus di CV. Karya Abadi, Manado), *Jurnal EMBA: Jurnal Riset Ekonomi, Manajemen, Bisnis dan Akuntansi*, *6*(3), 2018, pp. 1748–1757, doi: 10.35794/emba.v6i3.20444.

3 Puspitasari, F.H. and Kurniawan, V.R.B., Designing Optimal Distribution Routes using a Vehicle Routing Problem (VRP) Model in a Logistics Service Provider, *IOP Conference Series: Material Science and Engineering*, *1071*(1), 2021, p. 012005, doi: 10.1088/1757-899X/1071/1/012005.

4 Dantzig, G.B. and Ramser, J.H., The Truck Dispatching Problem, *Management Science*, *6*(1), 1959, pp. 80–91, doi: 10.1287/mnsc.6.1.80.

5 Setak, M., Habibi, M., Karimi, H., and Abedzadeh, M., A Time-Dependent Vehicle Routing Problem in Multigraph with FIFO Property, *Journal of Manufacturing Systems*, *35*, 2015, pp. 37–45, doi: 10.1016/j.jmsy.2014.11.016.

6 Kumar, S.N. and Panneerselvam, R., A Survey on the Vehicle Routing Problem and Its Variants, *Intelligent Information Management*, *4*(3), 2012, pp. 66–74, doi: 10.4236/iim.2012.43010.

7 Marinakis, Y., Marinaki, M., and Migdalas, A., A Multi-Adaptive Particle Swarm Optimization for The Vehicle Routing Problem with Time Windows, *Information Sciences*, *481*, 2019, pp. 311–329, doi: 10.1016/j.ins.2018.12.086.

8 Braekers, K., Ramaekers, K., and Van Nieuwenhuyse, I., The Vehicle Routing Problem: State of The Art Classification and Review, *Computers & Industrial Engineering*, *99*, 2016, pp. 300–313, doi: 10.1016/j.cie.2015.12.007.

9 Konstantakopoulos, G.D., Gayialis, S.P., and Kechagias, E.P., Vehicle Routing Problem and Related Algorithms for Logistics Distribution: A Literature Review and Classification, *Operational Research*, *22*(3), 2022, pp. 2033–2062, doi: 10.1007/s12351-020-00600-7.

10 Wang, C.H. and Lu, J.Z., A Hybrid Genetic Algorithm That Optimizes Capacitated Vehicle Routing Problems, *Expert Systems with Applications*, *36*(2), 2009, pp. 2921–2936, doi: 10.1016/j.eswa.2008.01.072.

11 Khairy, O.M., Shehata, O.M., and Morgan, E.I., Meta-heuristic Algorithms for Solving The Multi-Depot Vehicle Routing Problem, *2020 2nd Novel Intelligent and Leading Emerging Sciences Conference (NILES)*, IEEE, Giza, Egypt, October, 2020, pp. 276–281, doi: 10.1109/NILES50944.2020.9257879.

12 Bodin, L. and Golden, B., Classification in Vehicle Routing and Scheduling, *Networks*, *11*(2), 1981, pp. 97–108, doi: 10.1002/net.3230110204.

13 Prayogo, D., Sutanto, J.C., Suryo, H.E., and Eric, S., A Comparative Study on Bio-Inspired Algorithms in Layout Optimization of Construction Site Facilities, *Civil Engineering Dimension*, *20*(2), 2018, pp. 102–110, doi: 10.9744/ced.20.2.102-110.

14 Prayogo, D. and Kusuma, C.T., Optimization of Resource Leveling Problem Under Multiple Objective Criteria Using A Symbiotic Organisms Search, *Civil Engineering Dimension*, *21*(1), 2019, pp. 43–51, doi: 10.9744/ced.21.1.43-49.

15 Budi, G.S., Chandra, J.G., Ongkowardhana, B.S., and Husada, W., Optimization of Counterfort Retaining Wall Structure with Shear Key using Metaheuristic Method, *Civil Engineering Dimension*, *26*(2), 2024, pp. 151–159, doi: 10.9744/ced.26.2.151-159.

16 Ho, W., Ho, G.T.S., Ji, P., and Lau, H.C.W., A Hybrid Genetic Algorithm for The Multi-Depot Vehicle Routing Problem, *Engineering Applications of Artificial Intelligence*, *21*(4), 2008, pp. 548–557, doi: 10.1016/j.engappai.2007.06.001.

17 Khouadjia, M.R., Sarasola, B., Alba, E., Jourdan, L., and Talbi, E.G., A Comparative Study Between Dynamic Adapted PSO and VNS for The Vehicle Routing Problem with Dynamic Requests, *Applied Soft Computing*, *12*(4), 2012, pp. 1426–1439, doi: 10.1016/j.asoc.2011.10.023.

18 Zhang, H., Zhang, Q., Ma, L., Zhang, Z., and Liu, Y., A Hybrid Ant Colony Optimization Algorithm for A Multi-Objective Vehicle Routing Problem with Flexible Time Windows, *Information Sciences*, *490*, 2019, pp. 166–190, doi: 10.1016/j.ins.2019.03.070.

19 Cheng, M.Y. and Prayogo, D., Symbiotic Organisms Search: A New Metaheuristic Optimization Algorithm, *Computers & Structures*, *139*, 2014, pp. 98–112, doi: 10.1016/j.compstruc.2014.03.007.

20 Ezugwu, A.E. and Prayogo, D., Symbiotic Organisms Search Algorithm: Theory, Recent Advances and Applications, *Expert Systems with Applications*, *119*, 2019, pp. 184–209, doi: 10.1016/j.eswa.2018.10.045.

21 Gharehchopogh, F.S., Shayanfar, H., and Gholizadeh, H., A Comprehensive Survey on Symbiotic Organisms Search Algorithms, *Artificial Intelligence Review*, *53*(3), 2020, pp. 2265–2312, doi: 10.1007/s10462-019-09733-4.

22 Abdullahi, M., Ngadi, M.A., Dishing, S.I., Abdulhamid, S.M., and Usman, M.J., A Survey of Symbiotic Organisms Search Algorithms and Applications, *Neural Computing & Applications*, *32*(2), 2020, pp. 547–566, doi: 10.1007/s00521-019-04170-4.

# Vehicle Routing Problem Optimization for Rebar Material Distribution using the Symbiotic Organisms Search Method

ORIGINALITY REPORT

| 9% | 5% | 7% | 3% |
|---|---|---|---|
| SIMILARITY INDEX | INTERNET SOURCES | PUBLICATIONS | STUDENT PAPERS |

PRIMARY SOURCES

| | | |
|---|---|---|
| 1 | www.mdpi.com<br>Internet Source | 1% |
| 2 | Submitted to Forum Komunikasi Perpustakaan Perguruan Tinggi Kristen Indonesia (FKPPTKI)<br>Student Paper | 1% |
| 3 | Submitted to University College London<br>Student Paper | 1% |
| 4 | Bell, J.E.. "Ant colony optimization techniques for the vehicle routing problem", Advanced Engineering Informatics, 200401<br>Publication | <1% |
| 5 | Omar M. Khairy, Omar M. Shehata, Elsayed I. Morgan. "Enhanced Group Teaching Optimization Algorithm for Solving the Capacitated Vehicle Routing Problem", 2020 8th International Conference on Control, Mechatronics and Automation (ICCMA), 2020<br>Publication | <1% |
| 6 | Cheng, Min-Yuan, and Doddy Prayogo. "Symbiotic Organisms Search: A new metaheuristic optimization algorithm", Computers & Structures, 2014.<br>Publication | <1% |
| 7 | M. Diah, Arief Setyanto, Emha Taufiq Luthfi. "Systematic Literature Review Of Particle Swarm Optimization Implementation For Time-Dependent Vehicle Routing Problem", Jurnal Online Informatika, 2022 | <1% |

Publication

| | | |
|---|---|---|
| 8 | Submitted to University of Edinburgh<br>Student Paper | <1% |
| 9 | dokumen.pub<br>Internet Source | <1% |
| 10 | www.springerprofessional.de<br>Internet Source | <1% |
| 11 | www.researchgate.net<br>Internet Source | <1% |
| 12 | Submitted to Asia e University<br>Student Paper | <1% |
| 13 | journal.ump.edu.my<br>Internet Source | <1% |
| 14 | Congzheng Liu, Jing Lyu, Ke Fang. "Integrated packing and routing: A model and its solutions", Computers & Operations Research, 2024<br>Publication | <1% |
| 15 | Zhenping Li, Li Cao, Hao Li, Ruoda Wang, M Muren. "Research on Optimization of Electric Vehicle Routing Problem with Time Window", IEEE Access, 2020<br>Publication | <1% |
| 16 | Pushpa Choudhary, Sambit Satpathy, Arvind Dagur, Dhirendra Kumar Shukla. "Recent Trends in Intelligent Computing and Communication", CRC Press, 2025<br>Publication | <1% |
| 17 | coek.info<br>Internet Source | <1% |
| 18 | d-nb.info<br>Internet Source | <1% |
| 19 | eprints.undip.ac.id<br>Internet Source | <1% |

| | | |
|---|---|---|
| 20 | utilitiesone.com<br>Internet Source | <1 % |
| 21 | www.tandfonline.com<br>Internet Source | <1 % |
| 22 | www2.mdpi.com<br>Internet Source | <1 % |
| 23 | Absalom E. Ezugwu, Micheal O. Olusanya, Prinolan Govender. "Mathematical model formulation and hybrid metaheuristic optimization approach for near-optimal blood assignment in a blood bank system", Expert Systems with Applications, 2019<br>Publication | <1 % |
| 24 | Grigorios D. Konstantakopoulos, Sotiris P. Gayialis, Evripidis P. Kechagias, Georgios A. Papadopoulos, Ilias P. Tatsiopoulos. "An algorithmic approach for sustainable and collaborative logistics: A case study in Greece", International Journal of Information Management Data Insights, 2021<br>Publication | <1 % |
| 25 | Kavita Shelke, Subhash Shinde. "A Comparative Study of Symbiotic Organism Search and Glow-Worm Swarm Optimization", 2023 International Conference on Computational Intelligence, Networks and Security (ICCINS), 2023<br>Publication | <1 % |
| 26 | Muhammad Khahfi Zuhanda, Hartono, Samsul A. Rahman Sidik Hasibuan, Yose Yefta Napitupulu. "An exact and metaheuristic optimization framework for solving Vehicle Routing Problems with Shipment Consolidation using population-based and Swarm Intelligence", Decision Analytics Journal, 2024<br>Publication | <1 % |

| | | |
|---|---|---|
| 27 | Sasan Mahmoudinazlou, Changhyun Kwon. "A hybrid genetic algorithm with type-aware chromosomes for Traveling Salesman Problems with Drone", European Journal of Operational Research, 2024<br>Publication | <1 % |
| 28 | Thomas Weise, Alexander Podlich, Christian Gorldt. "Chapter 2 Solving Real-World Vehicle Routing Problems with Evolutionary Algorithms", Springer Science and Business Media LLC, 2009<br>Publication | <1 % |
| 29 | Wang, Xin. "Integrated Computational Materials Design for Alloy Additive Manufacturing: Introducing Data-Driven Approach to Physical Metallurgy.", University of Pittsburgh, 2024<br>Publication | <1 % |
| 30 | Xiao Zhou, Jun Wang, Wenbing Liu, Fan Jiang, Rui Li. "Intelligent Emergency Logistics Route Model Based on Cellular Space AGNES Clustering and Symmetrical Fruit Fly Optimization Algorithm", Symmetry, 2025<br>Publication | <1 % |
| 31 | nzdr.ru<br>Internet Source | <1 % |
| 32 | rekayasasipil.ub.ac.id<br>Internet Source | <1 % |
| 33 | repository.tudelft.nl<br>Internet Source | <1 % |
| 34 | studentsrepo.um.edu.my<br>Internet Source | <1 % |
| 35 | unsworks.unsw.edu.au<br>Internet Source | <1 % |
| 36 | www.readkong.com | |

Internet Source <1%

37 Abbas Fadhil Jasim AL-Gburi, Mohd Zakree Ahmad Nazri, Mohd Ridzwan Bin Yaakub, Zaid Abdi Alkareem Alyasseri. "A systematic review of symbiotic organisms search algorithm for data clustering and predictive analysis", Journal of Intelligent Systems, 2024
Publication <1%

38 David S. Zamar, Bhushan Gopaluni, Shahab Sokhansanj. "A Constrained K-Means and Nearest Neighbor Approach for Route Optimization in the Bale Collection Problem", IFAC-PapersOnLine, 2017
Publication <1%

39 Seyisoglu, Basak. "Integrated Resource Leveling and Cash Flow Optimization for Construction Projects Using Symbiotic Organisms Search Algorithm.", Middle East Technical University (Turkey), 2024
Publication <1%

40 Anand J. Kulkarni, Patrick Siarry. "Handbook of AI-based Metaheuristics", CRC Press, 2021
Publication <1%

41 Teymourian, Ehsan, Vahid Kayvanfar, GH.M. Komaki, and M. Zandieh. "Enhanced intelligent water drops and cuckoo search algorithms for solving the capacitated vehicle routing problem", Information Sciences, 2016.
Publication <1%

| | | | |
|---|---|---|---|
| Exclude quotes | On | Exclude matches | Off |
| Exclude bibliography | On | | |

**BUKTI KORESPONDENSI**

**Vehicle Routing Problem Optimization for Rebar Material Distribution using the Symbiotic Organisms Search Method**

Reynaldo, A.M.J., Husada, W.*, Wijaya, E.K., and Vaphilio, D.

* Corresponding Author

Civil Engineering Dimension, Vol. 27, No. 2, September 2025

**Daftar Isi:**

1. Initial Submission/Submission Acknowledgement: 05 Mei 2025
2. Minor Revision: 02 Juli 2025
3. Revision Submitted: 29 Juli 2025
   - Response Letter
4. Article Accepted: 11 Agustus 2025
5. Article Production: 10 September 2025

UNIVERSITAS KRISTEN PETRA

**Willy Husada <willy.husada@petra.ac.id>**

---

## [ced] Submission Acknowledgement

---

**Editor CED** <ced-editor@petra.ac.id> Mon, May 5, 2025 at 2:24 AM
To: "Mr. Willy Husada" <willy.husada@petra.ac.id>

Mr. Willy Husada:

Thank you for submitting the manuscript, "Vehicle Routing Problem Optimization for Rebar Material Distribution using the Symbiotic Organisms Search Method" to Civil Engineering Dimension. With the online journal management system that we are using, you will be able to track its progress through the editorial process by logging in to the journal web site:

Manuscript URL: https://ced.petra.ac.id/index.php/civ/authorDashboard/submission/30954
Username: willyhusada

If you have any questions, please contact me. Thank you for considering this journal as a venue for your work.

Editor CED

---

Civil Engineering Dimension: Journal of Civil Engineering Science and Application
Published by: Institute of Research and Community Outreach Petra Christian University
Jl. Siwalankerto 121-131 Surabaya 60236 Indonesia Phone: +62-31-2983147

UNIVERSITAS KRISTEN PETRA

Willy Husada <willy.husada@petra.ac.id>

# [ced] Editor Decision

**Dr. Doddy Prayogo** <prayogo@petra.ac.id> Wed, Jul 2, 2025 at 12:31 AM
To: Ambrosius Matthew Junius Reynaldo <matthew.junius@petra.ac.id>, Willy Husada <willy.husada@petra.ac.id>, Ezra Kenzie Wijaya <b11200108@john.petra.ac.id>, Denish Vaphilio <b11200114@john.petra.ac.id>

Dear Ambrosius Matthew Junius Reynaldo, Willy Husada, Ezra Kenzie Wijaya, Denish Vaphilio,

We have reached a decision regarding your submission to *Civil Engineering Dimension*, titled **"Vehicle Routing Problem Optimization for Rebar Material Distribution using the Symbiotic Organisms Search Method."**

Our decision is to request a **minor revision**.

Please refer to the reviewer comments provided below to guide your revisions. Kindly address each point carefully.

**Revision Requirements:**
**- Response Letter:** Provide a point-by-point response to the reviewer comments, detailing the revisions made.
**- Highlighted Version:** Submit a version of the manuscript with all changes clearly highlighted.
**- Clean Version:** Submit a clean version of the revised manuscript with all changes incorporated.

Please submit the revised manuscript and required documents no later than **15 July 2025**.

We look forward to receiving your revised submission.

Best regards,
Doddy Prayogo
Editor
*Civil Engineering Dimension*

------------------------------------------------------
Reviewer A:
Recommendation: Revisions Required

------------------------------------------------------

Is the topic appropriate for publication in this journal?

Yes

Is the paper scientifically sound?

Yes

Is the coverage of the topic sufficiently comprehensive and balanced?

Important information is missing or superficially treated

How would you describe the scientific depth of the paper?

Appropriate for the generally knowledgeable individual working in the field

How would you rate the overall organization of the paper?

Could be improved

Are the abstract satisfactory?

Yes

Are symbols, terms, and concepts adequately defined?

Yes

How would you rate accordance of material to the journal requirements?

Good

How would you rate the technical contents of the paper?

Good

How would you rate the novelty of the paper?

Sufficiently novel

How would you rate orthographic and grammatical style of the represented material?

Mostly accessible

Detailed comments. Feel free to make comments and notes on the manuscript.

The authors proposed a research paper entitled "Vehicle Routing Problem Optimization for Rebar Material Distribution using the Symbiotic Organisms Search Method". Please address the following issues.

1. Captions for figures, tables, and numbering appear misaligned after download.
2. The time window constraint is briefly mentioned, but how is it actually applied in the model? Is early or late arrival allowed with penalties? Or is the solution rejected entirely?
3. The paper mentions a penalty function (Equation 17), but there is no explanation of how it is used. What is the value of the penalty constant? Are all constraints penalized equally? For example, is violating capacity treated the same as violating time window?
4. Are the results based on a single run or multiple runs?
5. For a paper submitted to Civil Engineering Dimension, the civil engineering context must be stronger. How does the proposed optimization approach support better project execution, improve delivery reliability, or reduce construction delays?
6. Abstract exceeds 150 words. Please revise to fit the journal limit.

Recommendation:

Publish in minor, required changes

------------------------------------------------------

## Revisions

Search | Upload File

| | | | |
|---|---|---|---|
| 57257 | CED-Reynaldo-Vehicle (Revised 1) - Highlighted Ver.docx | July 29, 2025 | Article Text |
| 57258 | CED-Reynaldo-Vehicle (Revised 1).docx | July 29, 2025 | Article Text |
| 57260 | Response Letter - Vehicle Routing Problem Optimization for Rebar Material Distribution using the SOS Method.docx | July 29, 2025 | Other |

**RESPONSE LETTER**

Title: ***Vehicle Routing Problem Optimization for Rebar Material Distribution using the Symbiotic Organisms Search Method***

Dear Editor and Reviewer,

Thank you very much for reviewing our paper and providing your detailed feedback. We greatly value your important insights and suggestions which will improve the quality of our work. Please find our responses to the reviewer's comments outlined below.

**Reviewer Comments and Author Responses:**

**1. Reviewer A**

<table>
<tr><th>No</th><th>Reviewer Comments</th><th>Author Responses</th></tr>
<tr><td>1</td><td>Captions for figures, tables, and numbering appear misaligned after download.</td><td>The captions for all figures and tables, as well as their numbering, have been carefully reviewed and realigned in the revised manuscript.</td></tr>
<tr><td>2</td><td>The time window constraint is briefly mentioned, but how is it actually applied in the model? Is early or late arrival allowed with penalties? Or is the solution rejected entirely?</td><td rowspan="2">We acknowledge that the original manuscript incorrectly described the use of a penalty function. In practice, no penalty function was applied in the optimization process. Instead, the constraints were handled directly within the model logic. For the capacity constraints, if a delivery exceeded a vehicle's maximum capacity (e.g., 6,000 kg rebar with a 4,000 kg vehicle capacity limit), the algorithm will automatically assigned an additional vehicle to transport the remaining rebar—thus avoiding the capacity violations. For the time window constraints (e.g., 08:00–17:00), if a vehicle arrived outside the time window (e.g., at 19:00), it was set to stay overnight until the time window reopened the following day at 08:00. In such cases, the wage cost for the extended delivery time was automatically included in the total cost calculation, and the working day count was added accordingly. These mechanisms ensured that no constraints were violated, and therefore, no penalty constants were used in the model. The manuscript has been revised to reflect these corrections in the last paragraph of section 2.2.</td></tr>
<tr><td>3</td><td>The paper mentions a penalty function (Equation 17), but there is no explanation of how it is used. What is the value of the penalty constant? Are all constraints penalized equally? For example, is violating capacity treated the same as violating time window?</td></tr>
<tr><td>4</td><td>Are the results based on a single run or multiple runs?</td><td>The results presented in the manuscript are based on a single run, using a computer equipped with a Ryzen 7 5800H 3.2 GHz processor and 16 GB RAM. A clarification has been added to the revised manuscript in the Case Study section (section 3.1).</td></tr>
<tr><td>5</td><td>For a paper submitted to Civil Engineering Dimension, the civil engineering context must be stronger. How does the proposed optimization approach support better project execution, improve delivery reliability, or reduce construction delays?</td><td>Regarding the need to strengthen the civil engineering context, while this study focuses on delivery route optimization, it directly supports the civil project execution by ensuring timely delivery of rebar—a critical construction material—thus preventing schedule delays and idle labor. Cost efficiency in material distribution also reduces procurement expenses, which form a substantial part of civil project budgets. Moreover, the reliable deliveries enable better resource planning on-site, allowing for efficient manpower and equipment allocation, ultimately contributing to smoother construction operations.</td></tr>
</table>

| | | |
|---|---|---|
| 6 | Abstract exceeds 150 words. Please revise to fit the journal limit. | The abstract has been revised in manuscript and contains 141 words to meet the required word limit. |

UNIVERSITAS KRISTEN PETRA

**Willy Husada <willy.husada@petra.ac.id>**

---

# [ced] Editor Decision

---

**Dr. Doddy Prayogo** <prayogo@petra.ac.id> Mon, Aug 11, 2025 at 6:16 PM
To: Ambrosius Matthew Junius Reynaldo <matthew.junius@petra.ac.id>, Willy Husada <willy.husada@petra.ac.id>, Ezra Kenzie Wijaya <b11200108@john.petra.ac.id>, Denish Vaphilio <b11200114@john.petra.ac.id>

Dear Ambrosius Matthew Junius Reynaldo, Willy Husada, Ezra Kenzie Wijaya, Denish Vaphilio,

We have reached a decision regarding your submission to *Civil Engineering Dimension*, titled *"Vehicle Routing Problem Optimization for Rebar Material Distribution using the Symbiotic Organisms Search Method"*.

Our decision is to **accept** the manuscript for publication.

Your manuscript will now proceed to the copyediting and production stages. You may be contacted by the editorial office if any further information or minor revisions are required to ensure compliance with the journal's formatting and style.

Thank you for your contribution to *Civil Engineering Dimension*.

Best regards,
Doddy Prayogo
Editor
*Civil Engineering Dimension*

------------------------------------------------------
Reviewer A:
Recommendation: Accept Submission

------------------------------------------------------

Is the topic appropriate for publication in this journal?

Yes

Is the paper scientifically sound?

Yes

Is the coverage of the topic sufficiently comprehensive and balanced?

Yes

How would you describe the scientific depth of the paper?

Appropriate for the generally knowledgeable individual working in the field

How would you rate the overall organization of the paper?

Satisfactory

Are the abstract satisfactory?

Yes

Are symbols, terms, and concepts adequately defined?

Yes

How would you rate accordance of material to the journal requirements?

Good

How would you rate the technical contents of the paper?

Good

How would you rate the novelty of the paper?

Sufficiently novel

How would you rate orthographic and grammatical style of the represented material?

Mostly accessible

Detailed comments. Feel free to make comments and notes on the manuscript.

The authors have satisfied all of my comments

Recommendation:

Publish as is

------------------------------------------------------

UNIVERSITAS
KRISTEN
PETRA

**Willy Husada <willy.husada@petra.ac.id>**

# [ced] Editor Decision

**eJournal Admin** <admin_ejournal@petra.ac.id> Wed, Sep 10, 2025 at 2:58 PM
To: Ambrosius Matthew Junius Reynaldo <matthew.junius@petra.ac.id>, Willy Husada <willy.husada@petra.ac.id>, Ezra Kenzie Wijaya <b11200108@john.petra.ac.id>, Denish Vaphilio <b11200114@john.petra.ac.id>

Ambrosius Matthew Junius Reynaldo, Willy Husada, Ezra Kenzie Wijaya, Denish Vaphilio:

The editing of your submission, "Vehicle Routing Problem Optimization for Rebar Material Distribution using the Symbiotic Organisms Search Method," is complete. We are now sending it to production.

Submission URL: https://ced.petra.ac.id/index.php/civ/authorDashboard/submission/30954

Civil Engineering Dimension: Journal of Civil Engineering Science and Application
Published by: Institute of Research and Community Outreach Petra Christian University
Jl. Siwalankerto 121-131 Surabaya 60236 Indonesia Phone: +62-31-2983147