Dynamic Programming-Based Distribution Route Optimization with WinQSB and Field Validation in a Footwear SME

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Abstract

Background : Product distribution is a logistics activity that affects the operational efficiency of MSMEs, particularly in the footwear industry in the Cibaduyut area of Bandung. The main problem identified is the lack of standardized distribution routes, resulting in deliveries still being based on drivers' intuition. This situation leads to inconsistent routes, fuel waste, and inefficient delivery times

Purpose : This study aims to optimize distribution routes using the Dynamic Programming method, validated with WinQSB, and compared against the Traveling Salesman Problem (TSP) and Dijkstra's Algorithm.

Methodology : The methodology employed is an applied quantitative approach using data on distances between distribution points, travel time, fuel consumption, and GPS tracking.

Findings : The optimization results show a reduction in distribution distance from 35.2 km to 26.8 km and in delivery time from 82 minutes to 61 minutes. Efficiency improvements were 23.86% for distance, 25.61% for time, and 24.26% for fuel costs. Validation using WinQSB and GPS data confirmed that the optimization results align with field conditions.

Implications : The proposed route optimization provides a practical decision-support tool for MSMEs to improve distribution efficiency, reduce transportation costs, and enhance delivery performance. The findings can assist logistics managers in developing standardized distribution routes and serve as a reference for implementing data-driven distribution planning in small and medium-sized manufacturing enterprises.

Originality : This study contributes by integrating Dynamic Programming with WinQSB validation and GPS-based field verification to optimize distribution routes for footwear MSMEs. Unlike previous studies that primarily relied on theoretical optimization or simulation, this research demonstrates the practical applicability of the proposed approach in a real distribution network while benchmarking its performance against the Traveling Salesman Problem (TSP) and Dijkstra's Algorithm.

Keywords: *dynamic programming, route optimization, WinQSB, logistics distribution, footwear SMEs*

INTRODUCTION

MSMEs play a vital role in Indonesia's economy, particularly in creating jobs and supporting the growth of the creative industries. One of the thriving sectors is the footwear industry in the

Cibaduyut area of Bandung, which is known as a shoe-manufacturing hub. Most of these businesses are still home-based enterprises with simple distribution systems that have not yet been digitally integrated (West Java BPS, 2023; UKM, 2022).

Distribution is a crucial component of the supply chain because it is directly linked to transportation costs, delivery timeliness, and the quality of customer service. Global reports indicate that transportation costs can account for 30–60% of total logistics costs, making distribution efficiency a key factor in business competitiveness (World Bank, 2023; Rodrigue, 2020). In practice, many SMEs still determine distribution routes manually based on drivers' experience without the support of data-driven systems (Sari and Nugroho, 2022; Prasetyo, 2021)

As a result, distribution routes tend to be inconsistent and frequently change. This situation leads to increased mileage, higher fuel consumption, and unstable delivery times, which ultimately reduce operational efficiency (Hidayat and Santoso, 2023; Utami et al., 2022).

This problem was also observed at a home-based shoe manufacturing business in the Cibaduyut area. Distribution is carried out using motorcycles to deliver goods to the Andir, Banjaran, and Cibaduyut areas. Observations revealed the absence of standardized routes or structured distribution SOPs, meaning deliveries still depend on drivers' habits. This situation leads to redundant routes and distribution delays. In a single trip, the distance traveled can reach approximately 35 km, with distribution times ranging from 65 to 85 minutes.

Several studies have shown that optimizing distribution routes can significantly improve operational efficiency. Optimization approaches such as the Vehicle Routing Problem (VRP) and the Traveling Salesman Problem (TSP) are widely used to minimize travel distance and distribution costs (Toth and Vigo, 2021; Braekers, 2020). Other studies have also shown that applying route optimization to logistics systems can reduce transportation costs by more than 20% (Saputro et al., 2023; Rahman and Supriyadi, 2021).

However, most studies still focus on large-scale companies or use simulated data, so their implementation in MSMEs has not yet been optimal (Putra et al., 2022; Sari et al., 2022). Research that integrates mathematical approaches with GPS-based field validation and the development of operational SOPs remains limited, particularly in the small-scale footwear industry. To date, no study has specifically integrated route optimization based on Dynamic Programming with field validation using GPS tracking and the implementation of operational SOPs in the distribution systems of home-based MSMEs, particularly in the footwear industry in Indonesia.

To address this issue, an optimization approach is needed that can generate efficient distribution routes while being applicable to the operational conditions of MSMEs. Dynamic Programming is an optimization method capable of determining the minimum path by breaking down the problem into smaller subproblems (Bellman, 1957; Kumar and Dewi, 2021). This method was chosen because it can handle routing problems with a limited number of distribution points a common characteristic of SME distribution systems—and has a level of complexity that remains practically manageable (Snyder and Shen, 2019; Chopra and Meindl, 2021).

This study addresses this gap by combining a mathematical approach, software-based validation, and direct testing of actual distribution conditions. The optimization results are not only calculated mathematically but also validated using WinQSB software and GPS tracking to ensure alignment with on-site distribution conditions.

The novelty of this study lies in the integration of the Dynamic Programming method with software-based validation and direct field testing on the MSME distribution system. This approach not only generates optimal routes but also evaluates real-world implementation through measurements of

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distance, time, and fuel consumption, as well as the development of distribution SOPs that can be practically applied by business operators.

Based on these conditions, this study has several main objectives. First, to optimize distribution routes for footwear products in the Cibaduyut home industry using Dynamic Programming. Second, to compare the optimization results with those obtained using the Traveling Salesman Problem (TSP) and Dijkstra's Algorithm. Third, to analyze distribution efficiency based on distance traveled, delivery time, and fuel costs. Additionally, this study produces a simple distribution SOP to improve the operational consistency of SMEs.

RESEARCH METHODOLOGY

2.1 Research Design

This study employs an applied quantitative approach that integrates mathematical modeling, simulation, and field validation. Route optimization was performed using dynamic programming and then verified using WinQSB and GPS tracking to ensure consistency between the model and actual operational conditions.

2.2 Research Location and Subject

The study was conducted among small and medium-sized shoe enterprises (SMEs) in Cibaduyut, Bandung. The distribution system remains manual, involving a multi-drop delivery pattern using a single two-wheeled vehicle. The location was selected through purposive sampling because it represents the distribution characteristics of small-scale SMEs.

2.3 Data and Data Collection

The research data consists of primary and secondary data. Primary data includes the distances between distribution points, travel time, fuel consumption, actual routes obtained via GPS, and the distribution sequence. Meanwhile, secondary data was obtained from Google Maps, scientific literature, and operational documentation. All data was collected through observation, interviews, documentation, and GPS tracking over 14 operational days, totaling 10 distribution trips.

2.4 Model Assumptions

The model was developed based on several key assumptions: each distribution point is visited once per delivery cycle; the distribution route begins and ends at the main warehouse; and the distances between points are assumed to be symmetrical. Additionally, the distribution process is carried out using a single operational vehicle in stable condition, and traffic conditions are assumed to be normal, without considering congestion dynamics.

2.5 Research Variables

The main variables include distance traveled (km), distribution time (minutes), fuel consumption (liters), distribution cost (Rp), and efficiency (%).

2.6 Analysis Procedure

The analysis stages include identifying distribution nodes, compiling a distance matrix, route optimization using Dynamic Programming, validation with WinQSB, comparison with TSP and Dijkstra, field verification using GPS, and evaluation of distribution efficiency.

2.7 Optimization Model

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The Dynamic Programming formulation is expressed as Eq (1):

$$f(i,S) = \min_{j \in S}\{c_{ij} + f(j, S - \{j\})\} \quad \text{Eq.(1)}$$

where f(i, S) is the minimum cost of node i, c_(ij) is the distance between nodes, and S is the set of unvisited nodes.

2.8 Method Validation and Comparison

The optimization results were validated using WinQSB based on route consistency and total distance. The performance of the method was compared with TSP (exhaustive) and Dijkstra's algorithm to assess efficiency and computational complexity.

2.9 Efficiency Evaluation

Distribution efficiency was calculated using Eq (2) :

$$Efficiency(\%) = \frac{Initial\ Value - Final\ Value}{Initial\ Value} \times 100\% \quad \text{Eq (2)}$$

The evaluation covers reductions in distance, time, and operational costs.

RESULTS AND DISCUSSION

3.1 Overview of the MSME Distribution System

The subject of this study is a shoe home industry in the Cibaduyut area of Bandung that produces casual shoes and sandals for local distribution. Distribution activities are carried out using a single two-wheeled vehicle with an average load capacity of 20–40 pairs of shoes per trip. Deliveries are made to several stores, regular customers, and additional suppliers spread across the Cibaduyut, Andir, and Banjaran areas.

Field observations show that the distribution system remains conventional. Route selection relies entirely on the driver's experience, with no documented standard routes. This situation results in frequently changing distribution routes, repeated trips on certain sections, and inconsistent delivery times. The initial findings regarding the distribution system are summarized in Table 1.

Table 1. Initial Findings on the Distribution System

No	Preliminary Findings	Operational Impact
1	There is no standard distribution route	Shipping routes are subject to change
2	Route planning based on intuition	Wasteful mileage
3	No distribution records	It's difficult to evaluate
4	There is no distribution SOP	Inconsistent delivery
5	Does not use an optimization system	Longer distribution time

Table 1 shows that the main problem lies in the lack of structured operational standards for distribution. Reliance on drivers' intuition makes it difficult to achieve efficiency and limits the evaluation process.

3.2 Identification of Distribution Points

The study used seven distribution points, consisting of one main warehouse and six delivery destinations. Locations were selected based on the highest delivery frequency during the observation period, which was considered representative of routine distribution patterns. Table 2 presents a list of the distribution points used in the study.

Table 2. Study Distribution Points

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Code	Distribution Locations	Type of Location
A	Warehouse/Home-Based Business	Distribution Center
B	Andir Store	Retail Store
C	Banjaran Store	Retail Store
D	Cibaduyut Outlet	Outlet
E	Regular Customer 1	Customers
F	Regular Customer 2	Customers
G	Additional Suppliers	Supplier

In Table 2, all of these points are treated as nodes in the optimization process. The pattern of connections between points prior to optimization shows unstructured and intersecting distribution routes, which could potentially increase travel distance. The pattern of connections between distribution points prior to optimization is shown in Diagram 1 below.

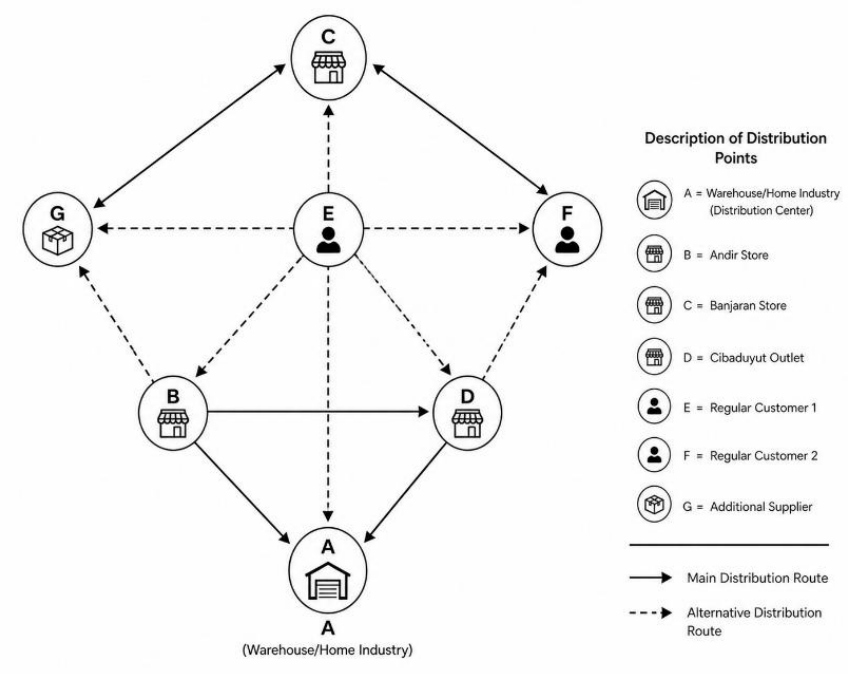


Figure 1. Initial Distribution Pattern

Diagram 1 shows that the distribution routes still follow an irregular and intersecting pattern. This situation makes distribution less efficient because some road segments are traversed more than once.

3.3 Initial Distribution Conditions

Preliminary observations show that deliveries are made using the initial distribution route: A → D → B → G → E → C → F → A. This route was derived from operational practices prior to optimization. Observations over several trips reveal the distribution performance summarized in Table 3.

Table 3. Initial Distribution Conditions

Parameters	Observation Results
Total Distance Traveled	35,2 km
Shipping Time	82 minute

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Fuel Consumption	1,17 liter
Fuel Price per Liter	Rp. 13.000,-
Fuel Costs	Rp. 15.250,-

Based on Table 3, the initial distribution is still inefficient, as indicated by relatively long travel distances and long delivery times. The impact of this is evident in increased fuel consumption and operating costs.

3.4 Matrix of Distances Between Distribution Points

Distances between points were measured using Google Maps and validated through GPS tracking in the field. The matrix of distances between distribution locations is shown in Table 4.

Table 4. Matrix of Distances Between Distribution Points (km)

From/To	A	B	C	D	E	F	G
A	0	4,2	7,8	5,1	6,3	8,4	5,7
B	4,2	0	4,5	2,1	3,4	6,7	2,8
C	7,8	4,5	0	5,2	2,7	2,3	4,6
D	5,1	2,1	5,2	0	2,5	5,9	3,1
E	6,3	3,4	2,7	2,5	0	3,1	2,4
F	8,4	6,7	2,3	5,9	3,1	0	4,2
G	5,7	2,8	4,6	3,1	2,4	4,2	0

Table 4 shows the variations in distance between points, which serve as the basis for the route optimization process. The shortest distance is on the B-D route, while the longest distance is on the A-F route.

3.5 Dynamic Programming Calculations

Dynamic programming calculations are performed by arranging combinations of distribution routes based on the distance matrix in Table 4. The calculation process is carried out in stages to obtain the route with the minimum total cost. The mathematical model of dynamic programming used in this study is shown in the following equation.

$$f(i,S) = \min_{j \in S}\{c_{ij} + f(j, S - \{j\})\}$$

Based on the results of manual calculations, the optimal distribution route is as follows. Optimal Route Using Dynamic Programming: A → B → D → E → G → C → F → A

The total distance obtained from the optimization using Dynamic Programming is:

$$Total\ Distance = 26{,}8\ km$$

The results show that the Dynamic Programming method is capable of generating shorter distribution routes compared to the initial distribution routes.

3.6 Validation Using WinQSB

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The results of the manual calculations were then validated using WinQSB software through the Shortest Route and Transportation Model modules. The validation process was carried out from inputting the distance matrix to simulating the optimal routes. The validation results using WinQSB are shown in Table 5.

Table 5. WinQSB Validation Results

Parameters	Simulation Results
Optimal Route	A-B-D-E-G-C-F-A
Total Distance	26,8 km
Consistency of Results	According to

As shown in Table 5, this consistency indicates that the approach used has a good level of reliability.

3.7 Discussion of Method Comparison, Efficiency, and Position in the Literature

A comparison of the performance of optimization methods was conducted to test the effectiveness of Dynamic Programming in minimizing the total distribution distance in a multi-drop delivery system. The computational results show significant differences between methods, both compared to the initial route and other optimization approaches, indicating variations in their ability to achieve optimal solutions, as shown in Table 6.

Table 6. Comparison of Optimization Methods

Method	Total Distance	Characteristics
Dynamic Programming	26,8 km	Most optimal
TSP	27,4 km	More complex iteration
Dijkstra	29,1 km	Shortest Path Focus
Starting Route	35,2 km	Unstructured

Based on Table 6, Dynamic Programming yielded the lowest total distance traveled at 26.8 km, followed by the Traveling Salesman Problem (TSP) at 27.4 km and Dijkstra's Algorithm at 29.1 km, while the initial route totaled 35.2 km. These findings indicate that the application of mathematical modeling-based optimization can significantly improve distribution efficiency, particularly in systems with limited nodes and operational resources.

The advantage of Dynamic Programming in this context lies in its ability to identify the global optimal solution through a systematic recursive optimization mechanism. The principles of optimal substructure and overlapping subproblems allow each partial solution to be stored and reused in subsequent iteration stages, thereby making the exploration of the solution space more efficient without sacrificing accuracy. These characteristics make Dynamic Programming highly effective for distribution problems on a limited scale, where the balance between computational complexity and solution quality is a crucial factor.

The TSP's performance yields results that are close to optimal because it is conceptually designed to solve cyclic routing problems. On a larger distribution scale, heuristic- or metaheuristic-based TSP implementations, such as Genetic Algorithms or Ant Colony Optimization, often provide near-optimal solutions with more efficient computation times (Toth and Vigo, 2021; Braekers, 2020). This indicates that the effectiveness of a method depends heavily on the size and complexity of the distribution network, with heuristic approaches becoming more adaptive as the number of nodes increases significantly.

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Conversely, the Dijkstra Algorithm's performance is relatively lower because its approach is limited to finding the shortest path between nodes locally. This algorithm does not consider the optimization of the overall visit sequence, making it less capable of producing optimal solutions for multi-drop delivery problems. This limitation explains why the total distance it produces is still higher than that of other methods that optimize routes globally.

From a logistics theory perspective, these findings confirm that distribution route optimization plays a strategic role in improving the operational efficiency of the supply chain. A reduction in travel distance directly leads to lower transportation costs, shorter delivery times, and reduced energy consumption key components of distribution activities. This reinforces the concept of cost efficiency in supply chain management, where the elimination of non-value-added activities is key to improving logistics system performance, particularly in the last-mile delivery stage (Rodrigue, 2020; Chopra and Meindl, 2021).

The evaluation of distribution efficiency was then conducted by comparing operational conditions before and after the implementation of route optimization. The results of the efficiency calculations are presented in Table 7.

Table 7. Distribution Efficiency Analysis

Parameters	Before Optimization	After Optimization	Efficiency
Mileage	35,2 km	26,8 km	23,86%
Shipping Time	82 minute	61 minute	25,61%
Fuel Consumption	1,17 liter	0,89 liter	23,93%
Fuel Costs	Rp15.250	Rp11.550	24,26%

The data in Table 7 show that route optimization resulted in a 23.86% reduction in distance traveled, a 25.61% reduction in distribution time, and a 24.26% reduction in fuel costs. The magnitude of these efficiency gains indicates that route improvements have a direct impact on enhancing distribution performance without requiring additional adjustments to vehicle capacity or fleet size.

These results are consistent with previous research findings stating that distribution route optimization can significantly reduce operational costs in small-scale logistics systems (Rahman and Supriyadi, 2021; Saputro et al., 2023). The efficiency rate obtained falls within a range comparable to other empirical studies, although it is slightly lower than that of heuristic approaches, which have been reported to achieve savings of over 30% (Saputro et al., 2023). This difference indicates that the use of actual distribution data and GPS validation in this study yields solutions that are more realistic for operational conditions, albeit with a more conservative efficiency level.

Validation using WinQSB showed consistency between the simulation results and manual calculations, which reinforces the reliability of the optimization model used. These findings support previous studies emphasizing the importance of software integration in improving the accuracy and validity of distribution decision-making (Putra et al., 2022). Integration with GPS tracking provides additional verification of field implementation, ensuring that the resulting solutions are not only theoretically optimal but also operationally viable.

The implementation of this approach in SMEs demonstrates that mathematically-based optimization can be applied without relying on complex technological infrastructure. The resulting optimal routes can be converted into standard operating procedures, which help improve distribution consistency and reduce reliance on individual drivers' experience. These implications are crucial for

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driving the transformation of SME distribution systems toward a more structured and data-driven approach.

3.8 GPS Tracking Validation and Route Implementation Consistency

GPS tracking validation was conducted to evaluate the degree of alignment between the route optimization results and actual distribution conditions in the field. This approach aims to ensure that the resulting solutions are not only mathematically optimal but also highly implementable in real-world operational contexts. Table 8 summarizes the validation results.

Table 8 GPS Tracking Validation Results

Evaluation Aspects	Results
Route consistency	Rising
Route Repetition	Decreased
Consistent delivery times	Better
Fuel Consumption	Declining

The data in Table 8 show an increase in distribution route consistency and a decrease in route repetition following the implementation of the optimization results. Improved delivery time stability also indicates that the generated routes are able to reduce the operational variability that previously occurred due to intuition-based route determination. The observed reduction in fuel consumption reinforces the efficiency analysis results from the previous section, thereby demonstrating alignment between the model results and actual conditions.

These findings provide empirical evidence that the optimization approach used has a good level of external validity. The alignment between the calculated results and field implementation indicates that the model is not only theoretical but also adaptive to the dynamic characteristics of MSME distribution.

A comparison of distribution routes before and after optimization reveals a more systematic and targeted change in route structure, as shown in Table 9.

Table 9. Comparison of Distribution Routes

Comparison	Route
Before Optimization	A→D→B→ G → E → C → F → A
After Optimization	A → B → D → E → G → C → F → A

The changes in the visit sequence in Table 9 reflect the elimination of inefficient routes and a reduction in potential trip duplication. A more organized route structure contributes to improved efficiency in terms of time and distance traveled, while also enhancing the overall regularity of the distribution flow.

These validation results reinforce the findings in Subsection 3.7 that Dynamic Programming is capable of generating route solutions that are not only computationally optimal but also feasible for operational implementation. The integration of mathematical modeling and GPS-based verification provides a more comprehensive approach to evaluating distribution systems, particularly at the MSME scale.

3.9 Development of Distribution SOPs

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Based on the distribution optimization results, a simple distribution standard operating procedure (SOP) was developed to help standardize MSME delivery operations. The steps of the distribution SOP are shown in Table 10.

Tabel 10. SOP for Product Distribution

Stage	Procedures
Preparations	Vehicle and cargo inspection
Shipping	Following the optimal route
Monitoring	Recording the departure time
Documentation	Recording of distributions
Evaluation	Checking shipment results

Based on Table 10, the implementation of the SOP is expected to improve operational consistency and facilitate periodic distribution evaluations.

3.10 Research Limitations

This study has several limitations, including the still-limited number of distribution points, the use of a single operational vehicle, and the assumption of normal traffic conditions without considering dynamic traffic congestion. In addition, distribution observations were conducted only during specific operational periods, so seasonal distribution patterns have not been analyzed in depth.
Nevertheless, the study utilized validation from actual GPS tracking data, ensuring that the optimization results accurately represent the real-world distribution conditions for shoe MSMEs in the Cibaduyut area of Bandung.

AUTHOR'S CONTRIBUTION

Nadiya Maharani contributed to the research conceptualization, methodology design, supervision, and manuscript review. Fadil Abdullah contributed to data collection, route optimization modeling, data analysis, manuscript preparation, and correspondence. Wan Habibi Rahman Barus contributed to the validation process, interpretation of results, and manuscript review. Muhammad Alif Ihsan contributed to data processing, field observations, and manuscript editing. All authors have read and approved the final version of the manuscript.

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DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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CONCLUSION

Based on the research results, the Dynamic Programming method was successfully used to determine the optimal distribution route for a shoe home industry in the Cibaduyut area of Bandung. The optimal route obtained A-B-D-E-G-C-F-A reduced the total distribution distance from 35.2 km to 26.8 km. Additionally, there was an improvement in distribution efficiency, including a 25.61% reduction in delivery time, a 23.93% decrease in fuel consumption, and a 24.26% improvement in fuel cost efficiency.

Validation results using WinQSB showed consistency with manual calculations, while GPS tracking validation proved that the optimized route can be practically implemented in the field with a more consistent and targeted distribution path. Compared to the TSP and Dijkstra's Algorithm methods, Dynamic Programming delivered the best performance in an SME distribution system with a limited number of distribution points.

This study also produced a simple distribution SOP that MSME operators can use to improve the consistency of their delivery operations. For future research, distribution optimization can be developed using multi-vehicle systems, real-time GPS integration, or a combination of heuristic methods and artificial intelligence to handle distribution with a higher level of complexity.

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