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A route selection process using a multicriteria decision-making (MCDM) approach based on the simple additive weighting (SAW) method: Evidence from Thai fresh fruit exported to China by road transportation

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A B S T R A C T

This study identifies the optimal route for transporting agricultural fruits using the Simple Additive Weighting (SAW) method within a Multicriteria Decision-Making (MCDM) framework. Data was gathered through a literature review on transportation principles, route selection criteria, and truck routes, identifying eight critical factors for route selection. Transportation route data were also systematically collected, forming the basis of the proposed conceptual framework. The SAW analysis identified the highest-scoring routes for each segment: Route A1 (6.35406), Route B1 (6.38532), Route C1 (6.26248), and Route D3 (5.29061). Historical data from the past five years confirmed consistency in route selection. Comparatively, Dijkstra's Algorithm, based on single factors like distance, time, or cost, proved less effective for agricultural transportation. In contrast, the SAW method, integrating multiple factors, ensured more accurate route selection. Key influencing factors included road conditions, infrastructure or road width, and facility availability. The optimal route from Thailand to China was Route A1-B1, passing through Chanthaburi, Rayong, Chonburi, Chachoengsao, Samut Prakan, Bangkok, Pathum Thani, Ayutthaya, Ang Thong, Sing Buri, Chai Nat, Nakhon Sawan, Phichit, Phitsanulok, Uttaradit, Phrae, Lampang, Phayao, and Chiang Rai, terminating at Chiang Khong Customs Checkpoint. These findings offer practical guidance for planning and decision-making in agricultural transportation routes.

1. Introduction

Road transportation is the primary transportation system in Thailand, playing a significant role in the nation's economy and society. With an extensive road network that spans all regions, road transport is a critical factor in facilitating trade, investment, tourism, and regional development. Thailand's economy relies heavily on road transportation, especially within the agriculture, industrial, and retail sectors. Transporting goods via the road network enables efficient and cost-effective distribution from production areas to markets nationwide. Furthermore, road transport supports the delivery of raw materials to industrial facilities and ensures the widespread distribution of consumer goods. In 2023, road transportation remained the dominant mode of freight transport in Thailand, accounting for 78.02%, a slight decrease from 79.21% in 2022. Water transportation followed with a share of 19.40%, an increase from 18.48%. Rail transportation accounted for 2.21%, rising from 1.96%, while air transportation remained stable at 0.01%. These figures indicate changing trends in Thailand's modal share of transportation (Office of the National Economic and Social Development Council, 2024). In 2023, Thailand's total freight volume was 547,082 thousand tons, representing a decrease of 5.54% compared to 2022. This decline aligns with a 1.3% reduction in international trade value and a slowdown in industrial production, as evidenced by the Industrial Production Index dropping from 101.9 in 2022 to 98.5 in 2023. However, from late

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2023 through the first half of 2024, the volume and value of imports and exports are projected to improve. Data from the Chiang Khong Customs checkpoint revealed that the top ten fruit exports by value in October 2023 were led by durian, with an export value of 220.45-million-baht, accounting for 12.11% of total export value. Mangosteen and Longan followed, contributing 4.85% and 4.48%, respectively. These figures highlight the robust international demand for Thai fruits, particularly in China, which remains the primary market for these exports (Chiang Khong Customs Checkpoint, 2023). Additionally, the relevant research on fresh fruit supply and route selection is as follows. The analysis of land transport connectivity for international trade between Thailand and China identified Route R9 as the most efficient, with the lowest approximate transport cost (3.39 USD/km) and the highest average speed (44.52 km/h). Additionally, the average border process cost for routes R9, R8, and R12 accounted for approximately 40% of the total cost, while the average border process time constituted about 16–25% of the total time (Panichakarn and Pochan, 2023). The redesign of the fresh fruit logistics network in Guangxi Province, China, considers economic development, logistics development, and fruit industry growth. The proposed index system provides a holistic assessment of cities' logistics capabilities. Hub and spoke cities were identified through cluster analysis based on factor analysis, with city identification refined using the gravitational model and logistics affiliation degree. (Pan, et.al, 2024). Fresh Fruit Supply and Market Competition: Empirical Evidence from 14 Cities in Guangxi, China. This study applies to the Boston Matrix market competition model, focusing on market share and growth rate. The analysis identifies distinct market segments across the cities: Liuzhou, Yulin, Wuzhou, Fangchenggang, and Baise fall under the 'Dog' category; Guigang, Baise, Hezhou, Hechi, Laibin, and Chongzuo are classified as 'Child' markets; Nanning and Guilin are designated as 'Star' markets; and Qinzhou is categorized as a 'Cash Cow' market. (Pan et al., 2023)

Selecting an appropriate road transportation route for agricultural products, mainly fruits, is critical due to their time-sensitive nature and the meticulous handling required to maintain freshness and quality until reaching their destination. Inadequate route planning may lead to delays, product damage, or loss of value. Shorter routes with smooth traffic flow can significantly expedite transportation. Additionally, choosing shorter routes with better road conditions can reduce transportation costs. Currently, agricultural product transportation in Thailand faces numerous challenges affecting efficiency, cost-effectiveness, and product quality. Inappropriate route selection frequently forces truck drivers to deviate from their planned routes to avoid roads that could damage goods. Such unplanned route adjustments negatively impact overall transportation management, increasing costs, prolonging transit times, and reducing distribution efficiency. Furthermore, in some areas, trucks sharing roads with smaller vehicles can accelerate road surface deterioration and increase the risk of road accidents.

To address these issues, this study investigates the process of selecting optimal transportation routes for agricultural products, specifically fruits, using a multicriteria decision-making approach based on the Simple Additive Weighting (SAW) method. The research involves a comprehensive review of domestic and international literature and related theoretical concepts concerning agricultural product transportation route selection. This review identifies critical factors influencing route selection, which are subsequently utilized in data collection and mathematical modeling to determine the most suitable transportation routes for agricultural products.

2. Research Methodology

This study applies a multicriteria decision-making approach using the Simple Additive Weighting (SAW) method to select the optimal transportation routes for agricultural products, specifically fruits, from Thailand to China. The research process involves six key steps: (1) identifying relevant factors influencing agricultural product transportation, (2) analyzing route-related data to evaluate these factors, (3) calculating and analyzing factor weights, (4) selecting transportation routes through the multicriteria decision-making process using the SAW method, (5) determining the shortest route using Dijkstra's Shortest Path Algorithm, and (6) comparing and summarizing the results of the agricultural transportation route selection.

2.1 Step 1: A study of factors related to the transportation of agricultural products.

This study investigates the critical factors influencing the selection of transportation routes for agricultural products. It analyzes these factors to determine the optimal routes for transporting agricultural products from Thailand to China. The study involves a comprehensive review of domestic and international literature to identify these relevant factors. The concept of transportation efficiency involves several key principles, including speed, which is achieved by selecting appropriate routes or vehicles to minimize travel time (Rodrigue et al., 2017); cost-effectiveness, accomplished through selecting suitable transportation modes to reduce expenses; safety, ensuring accident prevention and minimizing losses; reliability, guaranteeing deliveries occur on schedule; and flexibility, allowing adjustments according to changing demands (Tseng et al., 2005). The concept of transportation routing addresses several critical factors influencing route selection. These include Distance, selecting the shortest possible route to minimize Time and costs (Zhang & Xie, 2008); cost considerations, such as toll fees, parking charges, and energy expenses; time management, particularly avoiding routes prone to heavy traffic congestion; safety concerns, including the avoidance of hazardous routes characterized by poor road conditions or risks of theft (Bovy & Stern, 1990); legal constraints, such as maximum allowable cargo weight; and environmental factors, including weather conditions and natural hazards (Ben-Akiva & Bierlaire, 1999).

The concept of route selection for truck transportation involves several critical factors that must be carefully considered. These include Distance and travel time, where selecting the shortest or quickest route can reduce fuel costs and enhance transportation efficiency; route conditions and traffic, as road quality and traffic density significantly impact the speed and safety of transport, making it beneficial to avoid congested or poorly maintained roads; transportation costs, where evaluating expenses such as fuel, toll fees, and vehicle maintenance is essential for selecting the most cost-effective route; safety, emphasizing routes that minimize risks related to accidents or theft; flexibility and convenience, which ensure smoother transportation operations and better responsiveness to customer needs; and regulatory compliance, including adherence to transport regulations such as cargo weight limits and restrictions on vehicle operation in certain areas or time periods (Soleimani & Ahmadi, 2015). Thus, the key factors influencing the selection of optimal routes for agricultural product transportation can be summarized as follows: (1) transportation time (Bigaran Aliotte & Ramos de Oliveira, 2022; Peterson et al., 2018), (2) transportation costs (Padilla et al., 2018; Orjuela-Castro et al., 2019), (3) Distance (Ren, 2022; Fernando et al., 2018), (4) road conditions (Namfon & Pattarnid, 2020), (5) road surface quality/type (Preeyaphon, 2020), (6) infrastructure/road width (Jun & Wei, 2010; Singh et al., 2024), (7) route characteristics (Al-Dairi et al., 2022; Zheng et al., 2022), and (8) available facilities (Igilar, 2023; Negi & Trivedi, 2021).

2.2 Step :2 Analysis of factors based on collected route data.

This study investigates the factors influencing route selection and route-related information in the transportation of agricultural products. A total of nine critical factors were analyzed, namely: (1) transportation time, (2) transportation cost, (3) Distance, (4) road conditions, (5) road surface quality/type, (6) infrastructure/road width, (7) frequency of acceleration, (8) route characteristics, and (9) availability of facilities. The analysis was conducted using multiple regression analysis to evaluate the significance of these factors by examining the relationship between the dependent variable and multiple independent variables. The coefficient of determination (R Square), ranging from 0 to 1, was employed to measure the model's explanatory power regarding the variance in the dependent variable. The analysis revealed that the highest R Square value obtained was 0.77319, as shown in Table 1.

Table 1
Calculation Results of Statistical Analysis

Factors	Regression (df)	Multiple R	R Square	Adjusted R Square	Standard Error
X1, X2, X3, X4, X5, X6, X8, X9	8	0.87931	**0.77319**	0.75429	36.72331
X2, X3, X4, X5, X6, X7, X8, X9		0.87456	0.76486	0.74526	37.39148
X1, X2, X3, X4, X5, X6, X7, X9		0.85259	0.72691	0.70416	40.29571
X1, X2, X3, X5, X6, X7, X8, X9		0.82941	0.68792	0.66191	43.07684
X1, X2, X3, X4, X5, X7, X8, X9		0.78462	0.61564	0.58361	47.80578
X1, X2, X3, X4, X5, X6, X7, X8, X9	9	0.84844	0.71986	0.69332	41.02705

The analysis identified eight key factors that significantly influenced route selection: transportation time, transportation cost, Distance, road conditions, road surface quality/type, infrastructure/road width, route characteristics, and facility availability. Based on these findings, variables representing each factor were established for subsequent application in the multi-criteria decision-making (MCDM) process, utilizing the Simple Additive Weighting (SAW) method, as illustrated in Table 2.

Table 2
Variables representing each factor

Variable	Description of Factor	Variable	Description of Factor
X1	Transportation Time	X5	Road Surface Quality/Type
X2	Transportation Cost	X6	Infrastructure/Road Width
X3	Distance	X7	Route Characteristics
X4	Road Conditions	X8	Available Facilities

Subsequently, the transportation routes for analysis were defined. This study focuses on durian transportation from the origin point in Chanthaburi Province to the destination at the Chiang Khong Customs Checkpoint in Chiang Rai Province. The analysis considers the logistics routes connecting the origin to intermediate junction points and from those junctions to the destination. The identified transportation routes are categorized into four main route groups, each covering different provinces along the supply chain.

Route 1 consists of three sub-routes: Route A1 passes through 14 provinces including Chanthaburi, Rayong, Chonburi, Chachoengsao, Samut Prakan, Bangkok, Pathum Thani, Ayutthaya, Ang Thong, Sing Buri, Chai Nat, Nakhon Sawan, Phichit, and Phitsanulok; Route A2 passes through 12 provinces including Chanthaburi, Sa Kaeo, Prachin Buri, Nakhon Nayok, Saraburi, Ayutthaya, Ang Thong, Sing Buri, Chai Nat, Nakhon Sawan, Phichit, and Phitsanulok; and Route A3 passes through 10 provinces including Chanthaburi, Sa Kaeo, Prachin Buri, Nakhon Ratchasima, Saraburi, Lop Buri, Phetchabun, Nakhon Sawan, Phichit, and Phitsanulok, as illustrated in Fig. 1.

Route 2 connects the junction points to the final destination and is divided into four sub-routes: Routes B1 and B2, which both pass through six provinces, including Phitsanulok, Uttaradit, Phrae, Lampang, Phayao, and Chiang Rai (ending at Chiang Khong Customs Checkpoint, Chiang Rai Province) but utilize different paths; Route B3 passes through seven provinces including Phitsanulok, Uttaradit, Phrae, Lampang, Lamphun, Chiang Mai, and Chiang Rai (ending at Chiang Khong Customs Checkpoint, Chiang Rai Province); and Route B4 passes through five provinces including Phitsanulok, Sukhothai, Lampang, Phayao, and Chiang Rai (ending at Chiang Khong Customs Checkpoint, Chiang Rai Province), as illustrated in Fig. 1.

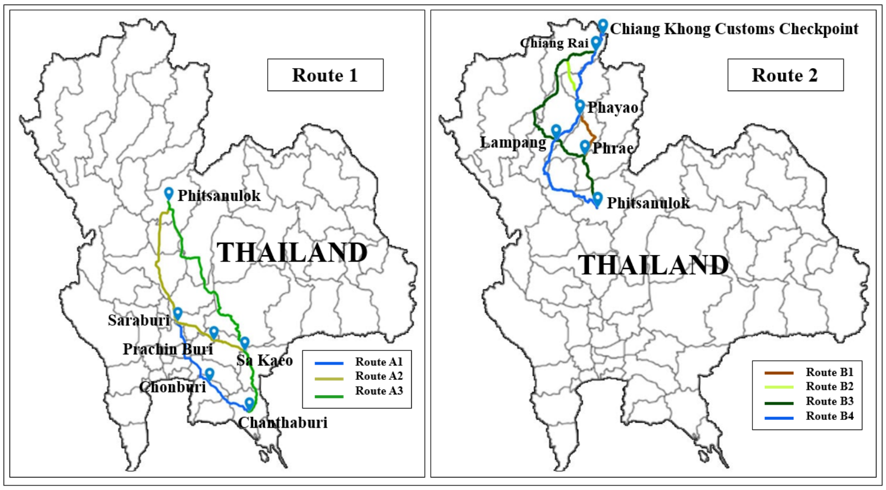

Fig. 1. Transportation Routes 1-2 Included in the Study.

Route 3 connects the origin point to the junction points and includes three sub-routes: Routes C1 and C2, both passing through 14 provinces, including Chanthaburi, Rayong, Chonburi, Chachoengsao, Prachin Buri, Nakhon Nayok, Saraburi, Ayutthaya, Ang Thong, Sing Buri, Chai Nat, Nakhon Sawan, Kamphaeng Phet, and Tak but employing different paths; and Route C3 passing through 12 provinces including Chanthaburi, Sa Kaeo, Prachin Buri, Nakhon Nayok, Saraburi, Ayutthaya, Ang Thong, Sing Buri, Chai Nat, Nakhon Sawan, Kamphaeng Phet, and Tak, as illustrated in Fig. 2.

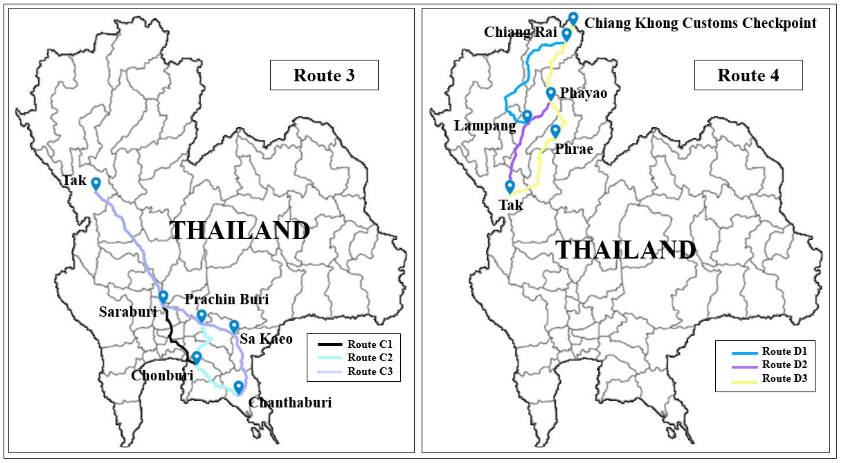

Fig. 2. Transportation Routes 3-4 Included in the Study.

Route 4 connects junction points to the final destination, divided into three sub-routes: Route D1 passes through five provinces including Tak, Lampang, Lamphun, Chiang Mai, and Chiang Rai (ending at Chiang Khong Customs Checkpoint, Chiang Rai

Province); Route D2 passes through four provinces including Tak, Lampang, Phayao, and Chiang Rai (ending at Chiang Khong Customs Checkpoint, Chiang Rai Province); and Route D3 passes through six provinces including Tak, Sukhothai, Phrae, Lampang, Phayao, and Chiang Rai (ending at Chiang Khong Customs Checkpoint, Chiang Rai Province), as illustrated in Fig. 2.

2.3 Step :3Analysis and Calculation of Factor Weights

Based on the significant factors identified for transportation route selection, the data can be categorized into two types: (1) Quantitative data, which involves data directly applicable for calculation purposes, and (2) Qualitative data, which requires conversion into numerical form before being used in calculations. This conversion involves creating a Pairwise Comparison Matrix to determine the weights of the factors. For n factors to be compared, the Pairwise Comparison Matrix will be an $n \times n$ matrix structured as follows:

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{a2} & \cdots & a_{nn} \end{bmatrix} \tag{1}$$

where a_{ij} is the relative importance value of factor i compared to factor j, based on Saaty's Scale, and $a_{ij} = \frac{1}{a_{ij}}$. Thus, if factor i is considered more important than factor j, the comparative value of j relative to i will be the reciprocal of a_{ij}. Calculation of Relative Priority involves assigning importance scores using the Analytic Hierarchy Process (AHP) Measurement Scale, which is divided into nine levels, as shown in Table 3. These values are then transformed into a Pairwise Comparison Matrix, which is utilized to calculate the relative priorities (Brunelli, 2014).

Table 3
Levels of Pairwise Importance Comparison

Intensity of Importance	Intensity of Importance	Intensity of Importance
1	Equal Importance	Two factors contribute equally to the objective
3	Moderate Importance of One Over Another	Moderate preference for one factor over another
5	Strong or Essential Importance	Strong preference for one factor over another
7	Very Strong or Demonstrated Importance	One factor is demonstrated to be strongly preferred over another
9	Extreme Importance	Highest possible evidence affirming that one factor is significantly preferred
2, 4, 6, 8	Intermediate Values	Used when compromise is necessary between the levels mentioned above

Source: Torgerson, W. S., (1958)

After determining the importance scores based on the specified importance levels, a Decision Matrix should be constructed. This matrix displays the values of each alternative under the evaluation criteria derived from the factors considered (Triantaphyllou & Mann, 1995).

$$D = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \tag{2}$$

where a_{ij} is the value of alternative i under criterion j, m represents the number of alternatives, and n denotes the number of criteria. After obtaining the vertical sums, proceed to calculate the weight of each evaluation factor by adjusting each factor's sum to equal 1. Subsequently, calculate the horizontal sums to determine the weights of the evaluation criteria by averaging the values across each factor.

2.4 Step 4 : Route selection process for transportation using a multi-criteria decision-making approach based on the Simple Additive Weighting (SAW) method.

The process of normalization in multi-criteria decision-making using the Simple Additive Weighting (SAW) method involves converting raw data into comparable values by removing unit differences. According to MacCrimmon (1968), there are two cases to consider:

Case 1: Benefit Criteria (criteria where a higher value is desirable). The normalization equation for benefit criteria is as follows:

$$r_{ij} = \frac{x_{ij}}{max(x_{ij})} \tag{3}$$

Case 2: Cost Criteria (criteria where a lower value is preferable). The normalization equation for cost criteria is as follows:

$$r_{ij} = \frac{min(x_{ij})}{x_{ij}} \tag{4}$$

where: r_{ij} is the normalized value of alternative i with respect to criterion j, x_{ij} is the original value of alternative i under criterion j, $max(x_{ij})$ represents the maximum value of criterion j, and $min(x_{ij})$ represents the minimum value of criterion j. After calculating the normalized decision matrix, the weighted sum calculation is performed. This involves multiplying the normalized values by the weights of each criterion (w_j) and summing the results according to the following equation (Hwang & Yoon, 1981):

$$s_i = \sum_{j=1}^{n} (w_{j \times r_{ij})} \tag{5}$$

where: s_i is the total score of alternatives i, and w_j is the weight of criterion j, with each weight w_j constrained within the range $0 \leq w_i \leq 1$, and the sum of all weights must equal 1.

Conduct a ranking of the alternatives by sorting the s_i values from highest to lowest. The alternative with the highest s_i score is considered the best choice. Subsequently, perform a comparison and ranking of alternatives by arranging the s_i scores in descending order to clearly identify the best alternative (Triantaphyllou & Mann, 1995).

2.5 Step 5 :Calculation for solving the shortest path problem using logistics tools.

The data collected was applied to calculate the shortest route using Dijkstra's Algorithm, a widely recognized method in logistics operations. This algorithm utilizes collected data to determine the shortest possible transportation path. (Dijkstra, 1959).

$$d[v] = \min(d[v], d[u] + w(u, v)) \tag{6}$$

where: $d[v]$ represents the updated distance from node v to node u, $d[u]$ denotes the shortest distance from the starting node s to node u, and $w(u, v)$ indicates the weight of the edge connecting node u to node v. Additionally, $P[v]$ is the preceding node of node on the optimal path. (Cormen et al., 2009)

2.6 Step 6 :Comparison and analysis of transportation route selection results.

Comparison and analysis of route selection results using the Simple Additive Weighting (SAW) method, a multi-criteria decision-making approach, and Dijkstra's Algorithm for determining the shortest route. This analysis leads to identifying the optimal transportation route for agricultural products.

3. Analysis

The calculation of factor weights using the Simple Additive Weighting (SAW) technique involves the following steps:

Step 1: Construct a Pairwise Comparison Matrix to determine the weights of each factor, as exemplified in Table 4 below:

Table 4

Pairwise Comparison Matrix for Factor Weight Calculation

Factors	X1	X2	X3	X4	X5	X6	X7	X8
X1	1	3	3	3	3	5	5	7
X2	1/3	1	1	1	1	3	3	5
X3	1/3	1	1	1	1	3	3	5
X4	1/3	1	1	1	1	3	3	5
X5	1/3	1	1	1	1	3	3	5
X6	1/5	1/3	1/3	1/3	1/3	1	1	3
X7	1/5	1/3	1/3	1/3	1/3	1	1	3
X8	1/7	1/5	1/5	1/5	1/5	1/3	1/3	1

Step 2: To calculate the weights of each criterion, adjust the Pairwise Comparison Matrix so that the sum of each column equals one. Then, create a weight column by calculating the average of each row to determine the criteria weights, as illustrated in Table 5.

Table 5
Criteria Weights Calculation

Factors	X1	X2	X3	X4	X5	X6	X7	X8
X1	0.34768	0.38136	0.38136	0.38136	0.38136	0.25862	0.25862	0.20588
X2	0.11589	0.12712	0.12712	0.12712	0.12712	0.15517	0.15517	0.14706
X3	0.11589	0.12712	0.12712	0.12712	0.12712	0.15517	0.15517	0.14706
X4	0.11589	0.12712	0.12712	0.12712	0.12712	0.15517	0.15517	0.14706
X5	0.11589	0.12712	0.12712	0.12712	0.12712	0.15517	0.15517	0.14706
X6	0.06954	0.04237	0.04237	0.04237	0.04237	0.05172	0.05172	0.08824
X7	0.06954	0.04237	0.04237	0.04237	0.04237	0.05172	0.05172	0.08824
X8	0.04967	0.02542	0.02542	0.02542	0.02542	0.01724	0.01724	0.02941
Column sum	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**

Step 3: The values obtained from the Pairwise Comparison Matrix in Table 4 are used to calculate the priority scores by multiplying each value with the corresponding weight from Table 5. The results are then summed horizontally to determine the overall priority scores, as shown in Table 6.

Table 6
Results of the Pairwise Comparison Matrix and corresponding weights using the SAW technique.

Factors	X1	X2	X3	X4	X5	X6	X7	X8	Horizontal sum
X1	0.34768	0.38136	0.38136	0.38136	0.38136	0.25862	0.25862	0.20588	**2.59623**
X2	0.11589	0.12712	0.12712	0.12712	0.12712	0.15517	0.15517	0.14706	**1.08177**
X3	0.11589	0.12712	0.12712	0.12712	0.12712	0.15517	0.15517	0.14706	**1.08177**
X4	0.11589	0.12712	0.12712	0.12712	0.12712	0.15517	0.15517	0.14706	**1.08177**
X5	0.11589	0.12712	0.12712	0.12712	0.12712	0.15517	0.15517	0.14706	**1.08177**
X6	0.06954	0.04237	0.04237	0.04237	0.04237	0.05172	0.05172	0.08824	**0.43071**
X7	0.06954	0.04237	0.04237	0.04237	0.04237	0.05172	0.05172	0.08824	**0.43071**
X8	0.04967	0.02542	0.02542	0.02542	0.02542	0.01724	0.01724	0.02941	**0.21526**
Sum	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**8**

Step 4: Once the horizontal sums of the priority scores from Table 5 are calculated, these values are used to determine the weights of each criterion. These weights will then be applied to calculate and select the optimal route, as shown in Table 7.

Table 7
Weights of Each Criterion.

Factors	X1	X2	X3	X4	X5	X6	X7	X8	Total sum
Horizontal sum	2.59623	1.08177	1.08177	1.08177	1.08177	0.43071	0.43071	0.21526	**8**
Weights	0.32453	0.13522	0.13522	0.13522	0.13522	0.05384	0.05384	0.02691	**1**
Percentage of weights	32.45287	13.52215	13.52215	13.52215	13.52215	5.38389	5.38389	2.69073	**100**

Step 5: Calculate the decision normalization values to ensure that each criterion is adjusted within an appropriate range. The normalization formula standardizes values, allowing for direct comparisons without unit discrepancies. There are two cases: one for criteria where higher values are preferable and another for criteria where lower values are preferable, as shown in Table 8.

Table 8
Normalized Decision Matrix for Each Factor Based on Data from 2023.

	Factors							
Route	**X1**	**X2**	**X3**	**X4**	**X5**	**X6**	**X7**	**X8**
A1	0.72308	15,607.03	618.10	8.15385	9	8.30769	10	3.53846
A2	0.91818	15,897.40	629.60	7.36364	9	7.09091	10	3.72727
A3	1.25130	16,652.38	659.50	6.44444	9	5.88889	10	3.66667
B1	1.44000	12,667.93	501.70	7.44500	9	6.16667	8.667	4.16667
B2	1.42472	11,758.93	465.70	6.44500	9	5.83333	8.667	3.66667
B3	1.64667	13,527.13	605.50	7.28571	9	6.00000	7.429	3.57143
B4	2.15100	14,321.80	567.20	6.33400	9	5.60000	9.20	3.60
C1	0.75077	16,346.85	647.40	8.76923	9	8.46154	10	4.15385
C2	0.82615	16,642.28	659.10	7.69231	9	7.00000	10	4.07692
C3	0.95091	16,637.23	658.90	8.09091	9	7.27273	10	4.09091
D1	2.00933	13,897.60	550.40	7.60000	9	6.40000	8	4
D2	2.15583	11,864.98	469.90	7.00000	9	6.25000	9.5	4
D3	1.65556	13,314.33	527.30	6.33333	9	5.66667	9	3.66667

Step 6: Compute the selection scores for transportation routes using the Simple Additive Weighting (SAW) method, a multicriteria decision-making approach. This process involves utilizing the weight values from Table 6 and the normalized decision values. Normalization scores are assigned based on a nine-level classification system, and comparisons are conducted to determine the representative scores for each factor across all designated routes, as shown in Table 9.

Table 9

Selection Scores Using the SAW Method.

Factors	X1	X2	X3	X4	X5	X6	X7	X8	Total sum
Weights	0.32453	0.13522	0.13522	0.13522	0.13522	0.05384	0.05384	0.02691	1
A1	9	1.125	1.125	6.750	9	6.750	9	5.625	
A2	7.875	1.125	1.125	5.625	9	4.5	9	6.750	
A3	5.625	0	0	3.375	9	2.250	9	5.625	
SAW A1	2.92076	0.15212	0.15212	0.91275	1.21699	0.36341	0.48455	0.15135	**6.35406**
SAW A2	2.55566	0.15212	0.15212	0.76062	1.21699	0.24228	0.48455	0.18162	5.74598
SAW A3	1.82547	0	0	0.45637	1.21699	0.12114	0.48455	0.15135	4.25588
B1	4.5	7.875	7.875	5.625	9	3.375	7.875	7.875	
B2	4.5	9	9	3.375	9	2.25	7.875	5.625	
B3	3.375	5.625	2.25	4.5	9	3.375	6.750	5.625	
B4	0	4.5	4.5	3.375	9	2.25	9	5.625	
SAW B1	1.46038	1.06487	1.06487	0.76062	1.21699	0.18171	0.42398	0.21189	**6.38532**
SAW B2	1.46038	1.21699	1.21699	0.45637	1.21699	0.12114	0.42398	0.15135	6.26421
SAW B3	1.09528	0.76062	0.30425	0.60850	1.21699	0.18171	0.36341	0.15135	4.68212
SAW B4	0	0.60850	0.60850	0.45637	1.21699	0.12114	0.48455	0.15135	3.64740
C1	9	0	0	7.875	9	6.75	9	7.875	
C2	9	0	0	5.625	9	4.50	9	6.750	
C3	7.875	0	0	6.750	9	4.50	9	6.750	
SAW C1	2.92076	0	0	1.06487	1.21699	0.36341	0.48455	0.21189	**6.26248**
SAW C2	2.92076	0	0	0.76062	1.21699	0.24228	0.48455	0.18162	5.80682
SAW C3	2.55566	0	0	0.91275	1.21699	0.24228	0.48455	0.18162	5.59385
D1	0	6	5.625	6	9	3	6.750	6.750	
D2	0	9	7.875	5	9	3	9	6.750	
D3	3.375	6.750	6.750	3.375	9	2.250	7.875	5.625	
SAW D1	0	0.76062	0.76062	0.76062	1.21699	0.18171	0.36341	0.18162	4.22560
SAW D2	0	1.21699	1.06487	0.60850	1.21699	0.18171	0.48455	0.18162	4.95524
SAW D3	1.09528	0.91275	0.91275	0.45637	1.21699	0.12114	0.42398	0.15135	**5.29061**

From Table 8, which presents the SAW method scores, it was found that the highest-scoring route for each segment is as follows: Route A1 with a score of 6.35406, Route B1 with a score of 6.38532, Route C1 with a score of 6.26248, and Route D3 with a score of 5.29061. Based on these results, the optimal route from the origin to the destination is determined to be Route A1 and Route B1. Furthermore, when incorporating five years of historical data into the analysis, the Simple Additive Weighting (SAW) method was applied to identify the most suitable routes for agricultural product transportation. The analysis was conducted for all 13 transportation routes from origin to destination, and the results are summarized as follows:

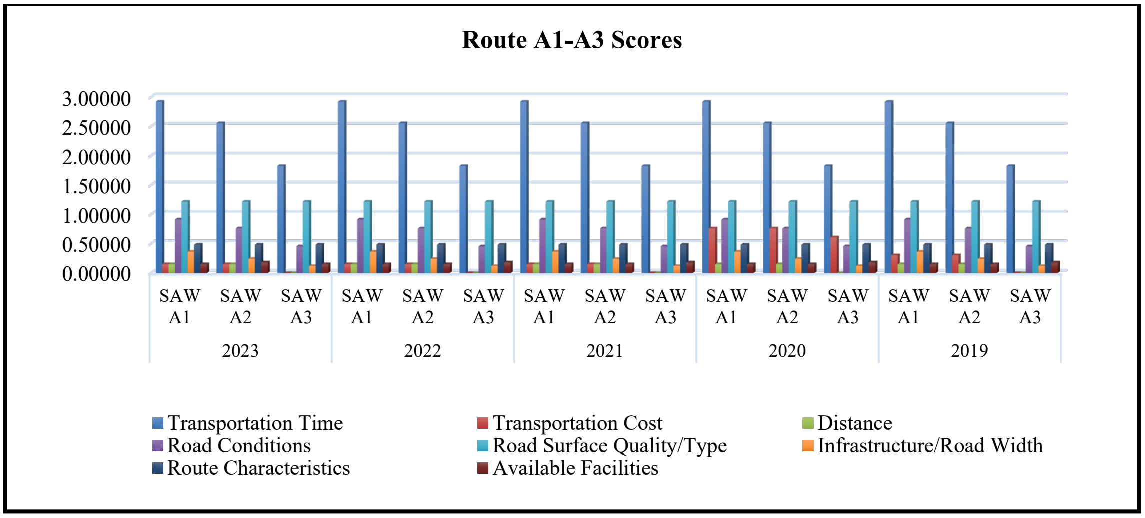

Fig. 3. illustrates a comparison of the factor scores for Routes A1 to A3 during the period 2019 to 2023

Route 1: The factor scores influencing the selection of agricultural transportation routes for Route A1, A2, and A3 during 2019–2023 indicate that transportation time (dark blue) consistently received the highest scores across all years and all routes. This suggests that transportation time is the most critical factor in route selection. Transportation cost (orange) and road surface quality (purple) were the most significant factors, with relatively similar scores across the three routes. In contrast, route characteristics (deep blue) and availability of facilities (brown) received lower scores than other factors, indicating that they may have less influence on route selection decisions. These findings are illustrated in Fig. 3.

Route 2: The factor scores influencing the selection of agricultural transportation routes for Routes B1, B2, B3, and B4 during the period 2019–2023 show that transportation time (dark blue) consistently received the highest scores across all years and routes. This underscores the importance of transportation time as the primary consideration in route selection. Road surface quality/type (purple) and transportation cost (orange) were the most significant factors. In contrast, route characteristics (deep blue) and availability of facilities (brown) received relatively lower scores, suggesting that these factors may have less influence on route selection decisions. These results are illustrated in Fig. 4.

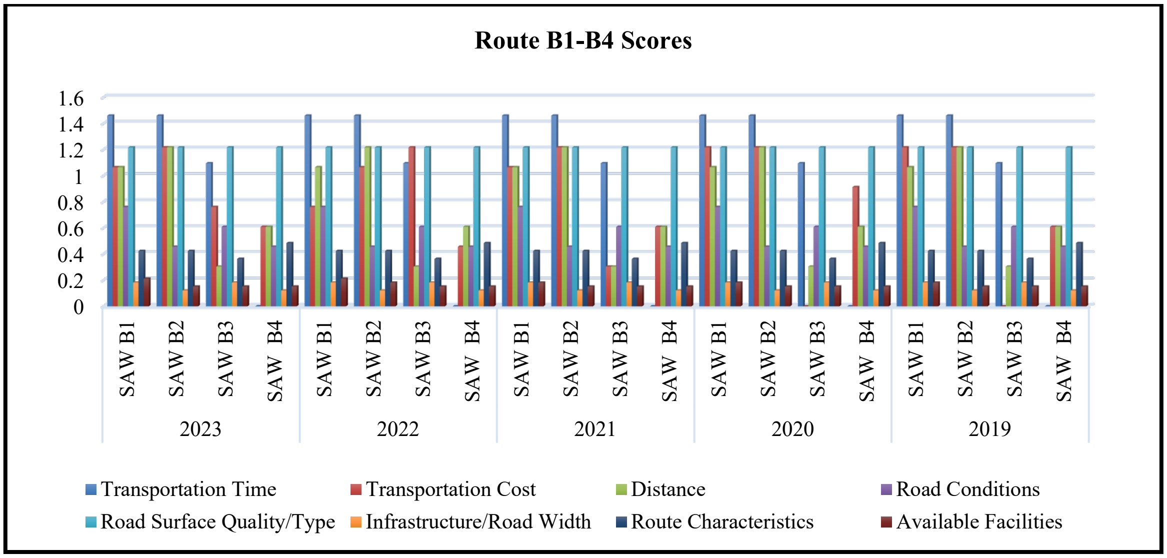

Fig. 4. illustrates a comparison of the factor scores for Routes B1 to B4 during the period 2019 to 2023

Route 3: The factor scores influencing the selection of agricultural transportation routes for Routes C1, C2, and C3 during the period 2019–2023 indicate that transportation time consistently received the highest scores across all years and routes, confirming its critical role in route selection decisions. Road surface quality and transportation cost were the second most significant factors, receiving high scores. This suggests that both the road surface quality and transportation cost are also influential in the decision-making process. In contrast, route characteristics and availability of facilities received lower scores than the other factors, indicating that they may have relatively less impact on the selection of transportation routes. These findings are presented in Figure 5.

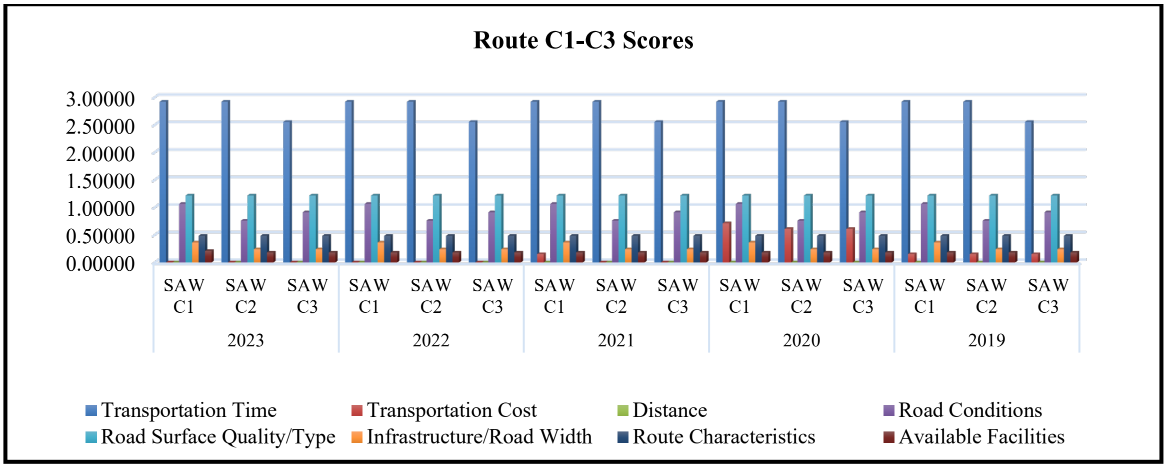

Fig. 5. The comparison of the factor scores for Routes C1 to C4 during the period 2019 to 2023

Route 4: The factor scores influencing the selection of agricultural transportation routes for Routes D1, D2, and D3 during the period 2019–2023 reveal that road surface quality and availability of facilities consistently received the highest scores across all years and routes. This contrasts with previous figures, in which transportation time was typically the most dominant factor. These findings suggest that road quality and supporting facilities are critical in selecting this group of routes. Transportation cost and infrastructure/road width were also notable secondary factors, receiving relatively high scores across all routes, indicating their considerable influence on decision-making. In contrast, transportation time and road conditions received lower scores compared to other factors, suggesting that transportation time may not be the primary consideration in route selection for these routes. These results are illustrated in Fig. 6.

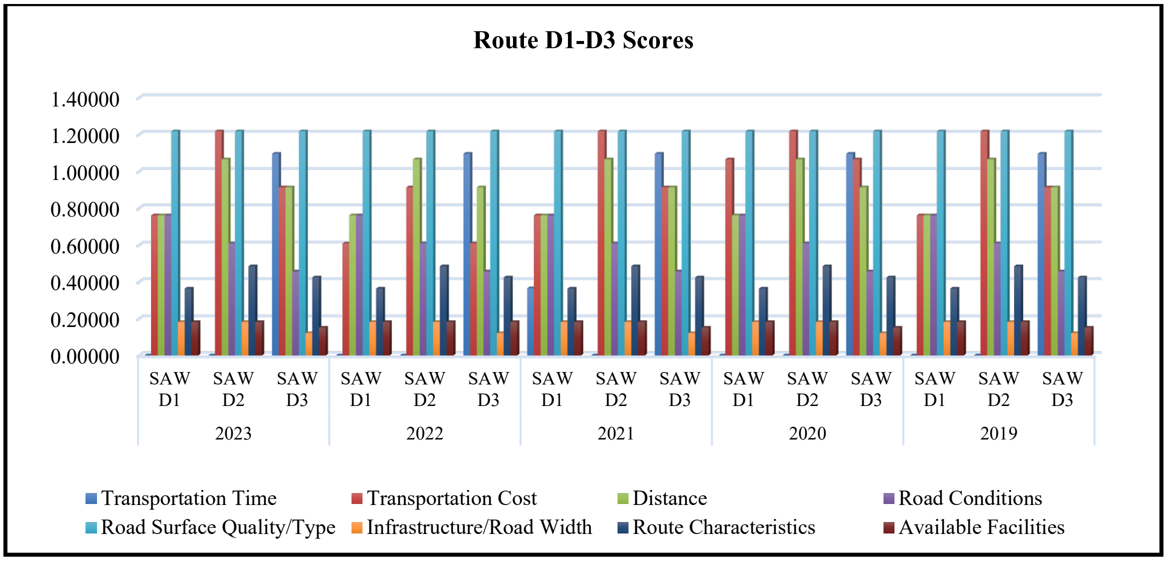

Fig. 6. The comparison of the factor scores for Routes D1 to D4 during the period 2019 to 2023

Summary of SAW Analysis Results: The analysis of SAW scores for 2019–2023 reflects the overall suitability trends of each transportation route. The results indicate that 2020 recorded the highest SAW scores for several routes, including A1, A2, C1, C2, and C3, suggesting a peak in route suitability during that year. In contrast, the SAW scores from 2021 to 2023 remained relatively stable across many routes, with no significant fluctuations observed. The analysis also reveals that Routes A1, B1, C1, and D3 attained the highest SAW scores within their respective route groups, indicating their superior suitability for agricultural transportation. Furthermore, based on the highest overall SAW scores, Routes A1 and B1 emerged as the most suitable routes for transporting agricultural products. These findings are illustrated in Fig. 7.

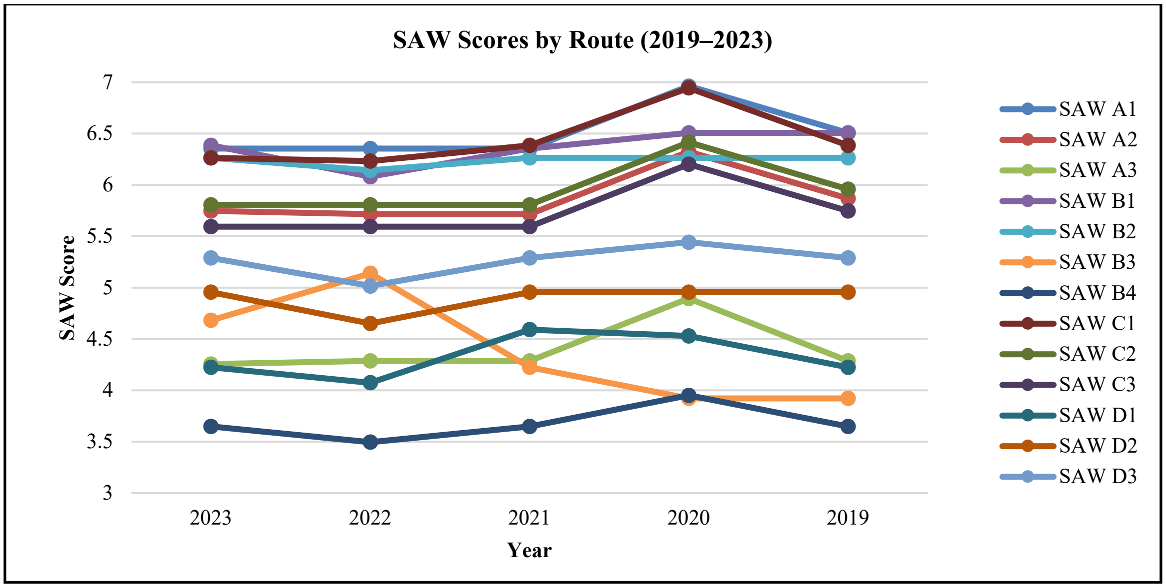

Fig. 7. SAW Method Scores for Each Transportation Route Between 2019 and 2023

Step 7: Utilizing route factor data to calculate the shortest path using Dijkstra's Algorithm. This method traditionally considers only a single factor; however, in this study, three factors are incorporated separately into the calculations. The results of each factor's computation are presented in Table 10.

Table 10
Results of the Shortest Path Calculation Using Dijkstra's Algorithm.

Node	Shortest Distance (kilometers)	Shortest Time (minutes)	Shortest Cost (baht)
A1-B1	1,092.90	1,075.00	28,274.96
A1-B2	**1,056.90**	**1,069.00**	27,365.96
A1-B3	1,196.70	1,248.00	30,895.92
A1-B4	1,158.40	1,201.00	28,278.52
A2-B1	1,131.30	1,119.00	28,565.33
A2-B2	1,095.30	1,113.00	27,656.33
A2-B3	1,235.10	1,292.00	31,186.29
A2-B4	1,196.80	1,245.00	28,568.89
A3-B1	1,172.70	1,187.00	27,401.44
A3-B2	1,136.70	1,181.00	26,492.44
A3-B3	1,276.50	1,360.00	30,022.40
A3-B4	1,238.20	1,313.00	27,405.00
C1-D1	1,197.80	1,182.00	30,244.47
C1-D2	1,117.30	1,095.00	28,211.84
C1-D3	1,174.70	1,173.00	29,661.19
C2-D1	1,209.50	1,241.00	30,539.89
C2-D2	1,129.00	1,154.00	28,507.26
C2-D3	1,186.40	1,232.00	29,956.61
C3-D1	1,209.30	1,226.00	27,339.65
C3-D2	1,128.80	1,139.00	**25,307.02**
C3-D3	1,186.20	1,217.00	26,756.37

Step 8: Comparison of Route Selection Results Using the SAW Method and Dijkstra's Algorithm. The results obtained from selecting transportation routes for agricultural products using the Simple Additive Weighting (SAW) method and Dijkstra's Algorithm were compared based on three key dimensions: Distance, transportation time, and transportation cost. This comparison aimed to identify the most suitable route for transporting fruits from Thailand to China. The criteria for determining the optimal route included: (1) the highest overall score from the SAW method, (2) a reasonable transportation Distance and time, and (3) a cost-effective total transportation cost. These criteria ensure that the selected route offers both efficiency and economic viability for cross-border agricultural logistics.

4. Results

Based on the analysis, the results of optimal route selection for agricultural product transportation using the Simple Additive Weighting (SAW) method and Dijkstra's Algorithm can be summarized as follows. According to the SAW analysis shown in Table 11, the route with the highest SAW score is Route A1–B1, with a score of 6.43667. This indicates that A1–B1 is the most suitable route, based on evaluating eight key factors. When considering each factor individually, the most suitable routes identified are as follows: Transportation time: Routes A1–B1, A1–B2, and C1–D3, Transportation cost: Routes A1–B2 and A2–B2, Distance: Route A1–B2, Road conditions: Routes A1–B1, C1–D3, and C3–D1, Road surface quality/type: All routes, Infrastructure/road width: Route A1–B1, Route characteristics: Routes A1–B2, A2–B4, A3–B4, C1–D2, and C3–D2 and Availability of facilities: Routes A3–B1, C1–D1, and C1–D2. These findings highlight the multidimensional nature of route selection, reflecting how different routes may be optimal based on specific transportation factors. At the same time, Route A1–B1 stands out as the most balanced and overall suitable route. The results of the shortest path calculation using Dijkstra's Algorithm indicate the following optimal routes based on individual factors: The route with the shortest Distance is Route A1–B2, with a total Distance of 1,056.90 kilometers. The route with the shortest transportation time is also Route A1–B2, requiring 1,069 minutes for delivery. The route with the lowest transportation cost is Route C3–D2, with a total transportation cost of 25,307.02 Thai Baht. These results highlight the strengths of different routes depending on the selected criteria and reinforce the importance of applying multi-criteria decision-making when selecting the most suitable route for agricultural logistics. Based on the comparison of results from the two route selection methods, the most appropriate route for transporting agricultural products—specifically fruits—from Thailand to China can be identified. The selected route, reflecting the optimal balance of key factors, is summarized in Table 12.

Table 11

Conclusion of Optimal Route Selection for Agricultural Transportation Using the SAW Method.

8 Factors	Distance	Transportation time	Transportation cost	Road conditions	Road surface quality/type	Infrastructure/road width	Route characteristics	Available facilities
A1-B1	A1-B2	A1-B1	A1-B2	A1-B1	All Routes	A1-B1	A1-B4	A3-B1
		A1-B2	A2-B2			A1-B3	A2-B4	C1-D1
						C1-D1	A3-B4	C1-D2
						C1-D2	C1-D2	
							C2-D2	
							C3-D2	

Table 12

Comparison of Route Selection Results Using SAW and Dijkstra's Algorithm.

SAW Method	Dijkstra's Algorithm		
	Shortest Distance (kilometers)	Shortest Time (minutes)	Shortest Cost (baht)
A1-B1	A1-B2	A1-B2	C3-D1

From Table 11, the comparison of route selection using the SAW method and Dijkstra's Algorithm reveals that the two approaches produce different optimal routes. However, both methods identify Route A1 as the optimal starting route in the initial stage. This discrepancy necessitates further analysis of the latter segment of the transportation route. Upon further evaluation, Dijkstra's Algorithm selects Route B2, while the SAW method selects Route B1. The results indicate that Route B2 is shorter in Distance and requires less transportation time than Route B1. However, when considering additional critical factors, such as road conditions, infrastructure/road width, and available facilities, Route B1 exhibits superior values across all three factors compared to Route B2. Therefore, the primary factors for selecting an optimal agricultural transportation route should prioritize road conditions, infrastructure/road width, and available facilities. Based on this assessment, the most suitable transportation route for agricultural products is Route A1-B1. This route begins from Chanthaburi Province and passes through Rayong, Chonburi, Chachoengsao, Samut Prakan, Bangkok, Pathum Thani, Ayutthaya, Ang Thong, Sing Buri, Chai Nat, Nakhon Sawan, Phichit, Phitsanulok, Uttaradit, Phrae, Lampang, Phayao, and Chiang Rai, terminating at the Chiang Khong Customs Checkpoint in Chiang Rai Province.

5. Conclusion

The selection of the optimal transportation route for agricultural products, employing a multicriteria decision-making approach through the Simple Additive Weighting (SAW) method, involves the consideration of eight key factors that influence route selection. These factors include: (1) Transportation time, (2) Transportation cost, (3) Distance, (4) Road conditions, (5) Road surface quality/type, (6) Infrastructure/road width, (7) Route characteristics, and (8) Available facilities; by applying the SAW method, the determination of the most suitable transportation route is based on the weighted sum of these factors, ensuring an optimal balance between efficiency, cost-effectiveness, and infrastructure suitability. The results indicate that the highest-scoring route in each segment is as follows: Route A1 (6.35406), Route B1 (6.38532), Route C1 (6.26248), and Route D3 (5.29061). Based on the analysis, the optimal routes from the origin to the destination are identified as Route A1 and Route B1. Moreover, a comparison with historical data from the past five years reveals consistency in route selection. Application of Dijkstra's Algorithm for route selection indicated that the shortest distance and shortest transportation time factors both identified Route A1-B2 as optimal, while the lowest transportation cost factor selected Route C3-D1. This finding underscores that relying solely on a single-factor analysis may not yield the optimal transportation route. In contrast, the Simple Additive Weighting (SAW) method integrates multiple critical factors, ensuring a more comprehensive and balanced approach to route selection. The key factors influencing agricultural transportation route selection include road conditions, infrastructure and road width, and the availability of facilities. Consequently, the most suitable transportation route for fruit-based agricultural products from Thailand to China is identified as Route A1-B1. This route traverses Chanthaburi, Rayong, Chonburi, Chachoengsao, Samut Prakan, Bangkok, Pathum Thani, Ayutthaya, Ang Thong, Sing Buri, Chai Nat, Nakhon Sawan, Phichit, Phitsanulok, Uttaradit, Phrae, Lampang, Phayao, and Chiang Rai, culminating at the Chiang Khong Customs Checkpoint in Chiang Rai Province.

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Data availability

The data presented in this article is openly accessible and obtained from the following official sources: the Truck Transport Data Center, Department of Freight Transport, Department of Land Transport; the Information and Communication Technology Center, Office of the Permanent Secretary, Ministry of Transport; the Office of Transport and Traffic Policy and Planning (OTP); and the Department of Highways, Thailand.

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