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Comprehensive Prioritization of Intersection Improvements with Multi-Criteria Decision Analysis

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Abstract

The practice of considering transportation choices involves several key components depending upon the factors, weights, and decision-making techniques. The current study used Multi-Criteria Decision Analysis (MCDA) tools in considering intersection improvements alongside traffic microscopic model. The findings revealed the following: (1) the level of complexity of the decision-making tools affects the prioritization of options and (2) the integration of decision-making models confirms the most suitable approach. In the case study of the Kalasin Intersection located in Maha Sarakham Province, the results of the analyses from SAW, WASPAS (λ = 0.5), TOPSIS, VIKOR (v = 0.5), and PROMETHEE (ϕ+(i)) converged towards Alternative 3.3: The new roundabouts at both intersections and VA traffic signal with a bypass left lane at the Kalasin intersection as the best option. The framework of this research describes new approaches to integrating the five MCDA tools, and exploring the intersection improvement options. This presentation of new decision-making frameworks illustrates the progress that is being made in the dimensions of transportation engineering decision-making with regard to intersection improvement prioritization.

1. Introduction

The issue of traffic congestion and road accidents at intersections, particularly those with traffic signal lights that connect secondary roads to nearby main roads, is commonly encountered in urban areas, especially those undergoing urban expansion. According to various dimensions studied by Hashem Dadashpoor and Gelare Shahhoseini [1] there is a significant relationship between transportation networks and land use, which directly impact time and space dimensions [2]. Data from the World Development Indicators: 3.12 Urbanization indicated a global average increase of 1.6% in the population of large cities, leading to an increased demand for urban transport mobility. This factor represents diverse and multidimensional impacts, such as the shift from using motorcycles to personal cars [3] and urban expansion in China [4],[5]. Previous studies have identified over 130 indicators related to urban sprawl development [1].

The mentioned issue describes the increasing density of urban communities, which in Thailand manifests as continuous expansion along main traffic arteries to the outskirts. People are beginning to relocate from urban communities to suburban areas, which is leading to traffic issues in the outskirts and the service area boundaries. Traffic engineering practices have evolved to accommodate the anticipated travel demand based on land use, where intersections play a vital role in transportation and logistical dimensions. Improving transport intersections to make them more efficient is a key objective, which is related to various factors, such as transport network delays, network stop points, and project costs. Decision-making in order to obtain the most suitable alternative is a critical consideration in current traffic engineering intersection evaluations with regard to the efficiency of decision-making tools and resulting options.

The decision-making components in this process consist of three parts: (1) the consideration criteria, (2) the data from surveys or simulations that is associated with factors that are relevant to the case study, and (3) the decision-making techniques, especially the application of Multi-Criteria Decision Analysis (MCDA) [6]. The MCDA techniques have been previously used in various fields of transportation such as Public transport mode choice, Evaluation of intersection performances, TOD and Traffic solutions, etc. [7],[8],[9],[10],[11].

According to the study, it was found that over 60% of transportation engineering research focuses on road-related cases. Furthermore, infrastructure is essential for sustaining life. Currently, there is widespread acceptance for the use of Analytical Hierarchy Process (AHP) to assess factor weights. However, considering alternatives along with utilizing new decision-making techniques, such as (1)Simple Additive Weight (SAW), (2)Weighted Aggregated Sum Product Assessment (WASPAS), (3) The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) [12], (4) VIseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR), and (5) Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) [13], respectively, is still a relatively new area of study. Moreover, these techniques are considered to have the potential to advance transportation engineering and logistics in terms of decision-making science. Therefore, this study aimed at developing a decision framework that can enhance decision-making processes in the field of transportation engineering (intersection improvements selection) by comparison of SAW, WASPAS, TOPSIS, VIKOR and PROMETHEE.

2. Method

The traditional method of evaluating alternatives for intersection improvement primarily considers indicators, which are mostly defined as qualitative criteria that cannot numerically compare alternatives. The framework of the study suggested using the microscopic simulation model as a tool to analyze and process alternatives in traffic management at intersections. This involved simulating vehicle movement behaviors and traffic conditions, as well as comparing different scenarios in a simulated environment before they actually occurred in reality. The study focused on addressing the decision-making problem of intersection management by utilizing Multi-Criteria Decision Analysis (MCDA) combined with a microscopic simulation model, which covers transportation engineering factors in three dimensions and ten sub-criteria, with a total of 15 performance indicators.

The research aimed at the following:(1) developing an advanced framework for intersection consideration in order to integrate decision-making strategies, and (2) identifying and filtering the appropriate intersection improvement alternatives in urban community settings that are connected to new urban areas. The findings from this study can serve as evidence for considering transportation engineering projects, particularly in the case of evaluating intersection improvements. The research methodology is illustrated in Fig. 1., and further details are provided below.

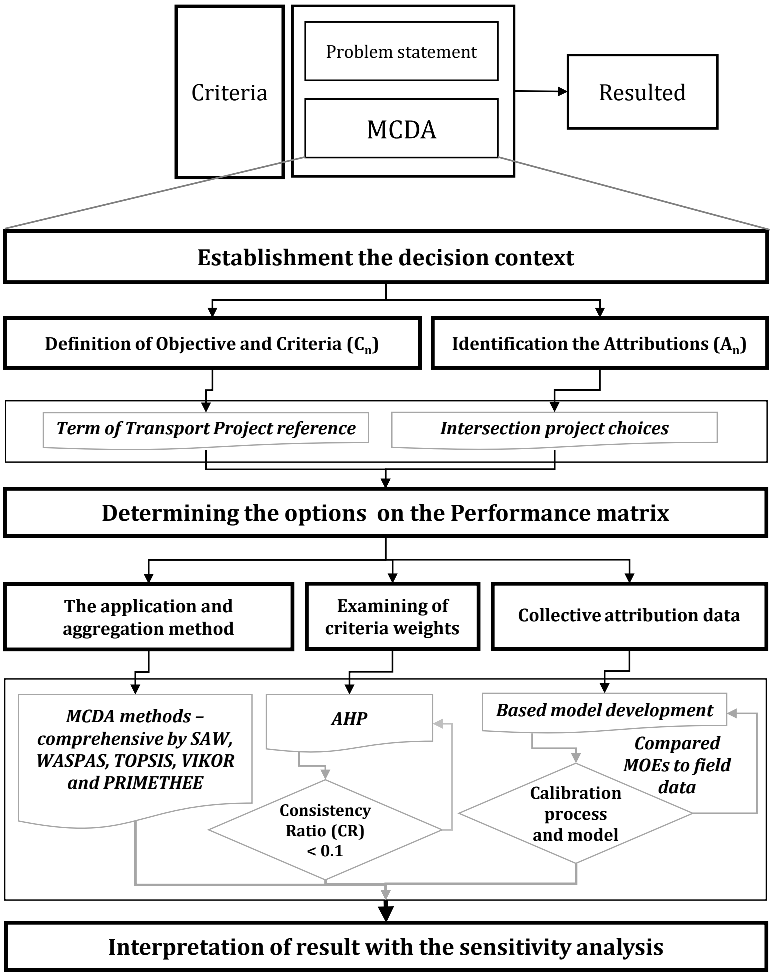

Fig. 1 *The research methodology*

2.1 Study Area

The Kalasin Intersection is a significant intersection controlled by traffic lights located in the municipality of Maha Sarakham in the Mueang District of Maha Sarakham Province. This intersection connects to the main provincial road. In the vicinity, there are secondary roads from neighboring communities converging on both sides in the form of an uncontrolled X-shaped intersection, as shown in Fig. 2.

Fig. 2 *Geographical characteristics Kalasin Intersection, Maha Sarakham Province*

In both areas, there are traffic congestion issues during rush hours and road accident problems, especially at the X-shaped intersection area. This area serves as a conflict point for traffic flow, posing a risk of road accidents. From the accident data from 2018 to 2021, there were 88 incidents, averaging 2 incidents per month. These incidents highlight the intersection's significance as a dangerous road risk point in the province, affecting the quality of life for route users, who must accept the risk every time they travel. Furthermore, this problem has persisted for a long time without any resolution, making it crucial for the relevant authorities to find practical solutions to alleviate or rectify the issue.

2.2 AHP Approach

In this study, the decision-making components or criteria used in the AHP method for selecting intersection layouts consisted of three main criteria: traffic engineering, economic, and environmental impact criteria. These main criteria were further broken down into 10 sub-criteria and sub-indicators derived from the processing of traffic, economics, and the environmental data obtained from the microscopic simulation model. They were categorized into a decision-making hierarchy structure, illustrating the inter-relationships of the decision-making components from left to right in the decision-making hierarchy structure diagram, as depicted in Fig. 3.

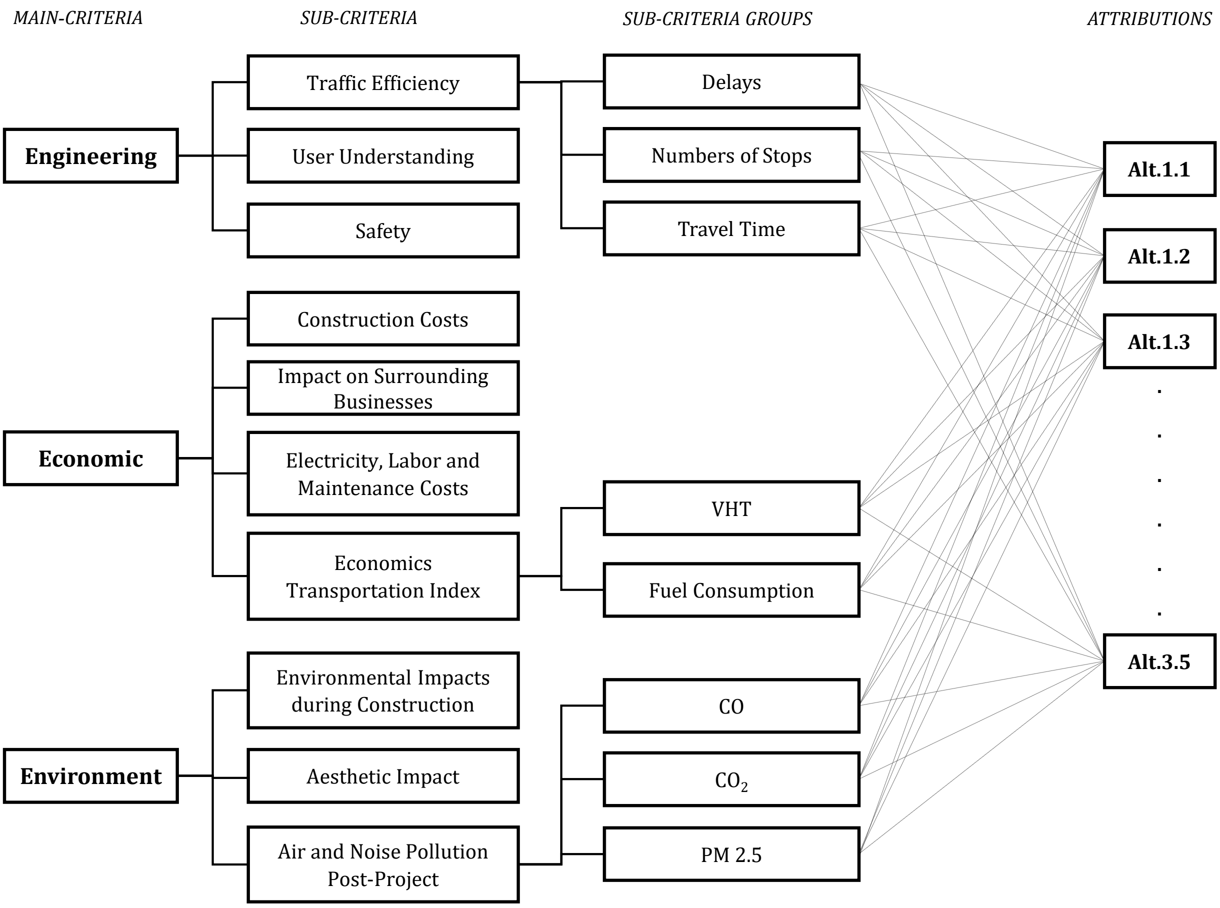

Fig. 3 *The research parameters and the hierarchical decision tree*

Assigning the weights of importance to each decision criterion at each level was based on comparing the weights of importance at the same level in pairs from the interviews with the decision-makers or experts. The numbers of experts are not as important as the quality of the experts [14]. Greenbaum (1993) [15] and Melon et al. (2008) [16] suggested that a group of 5-7 experts can be considered reliable. In this study, the data was collected from interviews with 12 experts, who had comprehensive knowledge and experience in analyzing and considering the factors that can affect the selection of intersection designs. In this study, the proportions of experts were evenly distributed, with 4 experts from the field of traffic engineering, 4 from the field of economics, and 4 from the field of environmental impact. The scores of importance of the main criteria for the pairwise comparisons were then assessed in order to determine the weight of the criteria influencing the selection of intersection designs on a scale of 1–9.

The synthesis of the weights of importance involved applying the "Principle of Hierarchy Composition" to process the weights of importance of each criterion into comprehensive relative importance weights. These weights were then used to consider the best options for intersection design. The evaluation of the performance of each design option was based on the assessments made by the experts and the results obtained from microscopic simulation models, which are discussed in the next section.

2.3 Data Collection

Researchers collected physical intersection characteristics using UAV to capture current aerial photographs, which were used as a base map. Additionally, various physical intersection data was surveyed in the field, including lane width, the numbers of lanes, and median islands. This data was collected to ensure the accuracy and realism of the model created with the PTV VISSIM software.

The traffic volume related to the turning movement count was surveyed during the peak hours in the morning (07.00 - 09.00) and in the afternoon (15.00-17.00). This data was then classified into 5 vehicle types: motorcycles (MC), passenger cars (PC), light busses (LB), busses (BS), and trucks (TR). The example results of the survey are shown in Fig. 4.

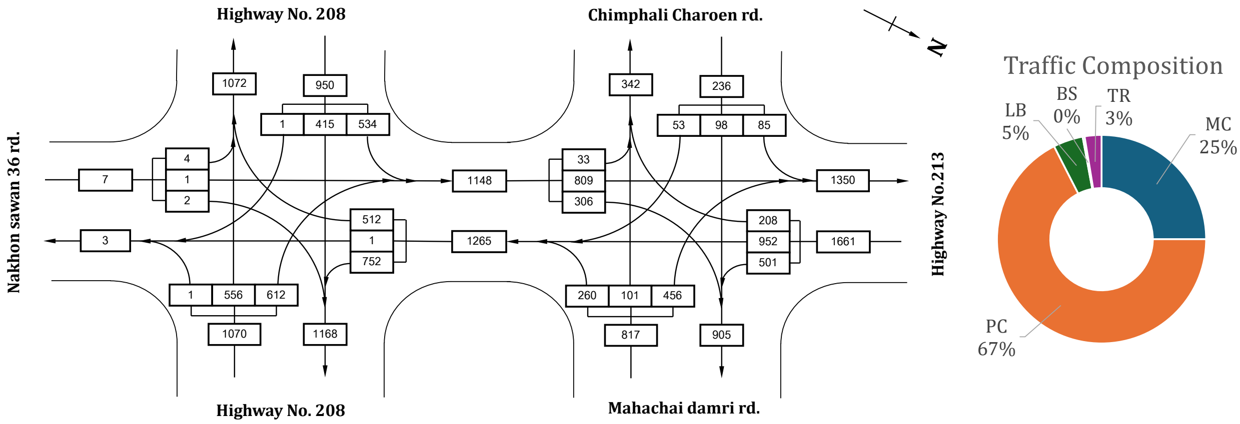

Fig. 4 *The results of the turning movement count (A.M. Peak)*

Spot speed refers to the speed of a vehicle passing a specific point on the road. Data collection involved surveying vehicles of three types: motorcycles (MC), passenger cars (PC), and heavy vehicles (HV). Radar speed guns were used to determine the desired speed. A suitable sample size for data collection is typically around 50 vehicles, although 100 vehicles can be commonly surveyed. Surveys should be conducted during periods unaffected by weather conditions, incidents, or other factors that may disrupt traffic flow [17]. In this study, spot speed was surveyed and categorized into two types: free flow speed and turning speed.

When comparing important variables in the VISSIM model for intersections within urban areas, the Wiedemann 74 Model Parameters are crucial. One significant variable is the Average Standstill Distance, which is sensitive and can affect the model's accuracy [18]. Researchers conducted a survey on the average standstill distance, which is the distance between the rear bumper of the front vehicle and the front bumper of the rear vehicle when they are at a standstill. There are two options for adjusting or determining of the CC0 value (Standstill Distance): (1) conducting surveys in the study area by recording videos at locations where the vehicles stop and move, and (2) measuring the distance between stopped vehicles, with a minimum of 100 samples [19]. The default value for the Average Standstill Distance was 2.0 meters, with the acceptable range being between 1.0 to 3.0 meters. Values lower or higher than this range were considered to be unreasonable. In this study, the surveyed average standstill distance was determined at 1.85 meters.

2.4 Microscopic Model

The process of creating a microscopic simulation model involves eight important steps as follows: (1) Building the road network in the model: This includes defining road segments, lanes, intersections, and other relevant infrastructure; (2) Setting vehicle speeds: The speed distributions for different road segments and types of vehicles are determined; (3) Input traffic volume: The data on traffic volume is incorporated, including the number of vehicles and their distribution over time; (4) Defining vehicle trajectories: The paths that vehicles will follow within the model are established by considering factors like turning movements and lane changes; (5) Creating speed reduction areas: Areas are designated where vehicles are expected to slow down, such as curves, intersections, or areas with congestion; (6) Designing conflict areas: Areas where conflicts between vehicles may occur are identified and modeled, such as merging lanes or intersections; (7) Installing traffic signal systems: Traffic signal control systems are implemented to regulate the flow of vehicles at intersections; and (8) Setting performance criteria: The specific parameters or metrics that will be used to evaluate the model's results are established, such as travel times, delays, or queue lengths. The simulation was run based on the stochastic principle [20], which had shown over 95 % of confidential level as seen in formula (1). Additionally, the simulation result was carried out over 11 times as E (Standard Error of the Mean), S (Standard deviation), and n (number of sample) [21].

$$E = \frac{s}{\sqrt{n}} \tag{1}$$

Model calibration and validation involve the process of adjusting certain parameters in the model in order to ensure that the results will closely match real-world conditions. The obtained results must meet acceptable criteria. In this study, traffic volume was used as an indicator to calibrate and validate the model. The process of calibration involved adjusting the parameters by using data from the morning rush hour (07:30-08:30) and validating the model's accuracy by using data from the evening rush hour (15:30-16:30). Twelve points were examined, and each point was required to pass the calibration criteria according to the recommended guidelines established by the Design Manual for Roads and Bridges (DMRB) [17]. Comprehensive with GEH Statistic as seen in formula (2), M represents the hourly traffic volume from the traffic model and C represents the real-world hourly traffic count. Between the modelled and observed hourly volumes, a GEH value of less than 5.0 is considered properly good. Thus, the GEH was computed under 0.53 – 4.83 for this research.

$$GEH = \sqrt{\frac{2(M - C)^2}{M + C}} \tag{2}$$

2.5 Alternatives

Under the conditions and limitations of the study area, and to avoid impacts on surrounding communities, alternatives have been proposed for improvement in three main groups: 1. Improving the traffic signal system, 2. Enhancing the physical characteristics of the intersection, and 3. Integrating groups 1 and 2. Each option is considered suitable and adequate for addressing urgent traffic management and alleviating issues, in accordance with the warrant for intersection and interchange design [22] as depicted in Fig. 5.

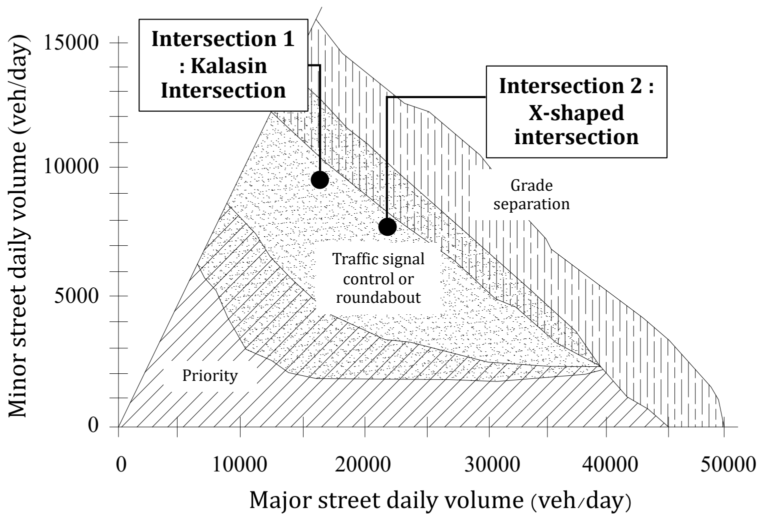

Fig. 5 *Intersections control type analysis using graphical method*

To create alternatives for intersection management and control, the researchers applied the microscopic models that had been adjusted, calibrated, and validated. As shown in Table 1, a total of 3 groups and 10 intersection options were proposed.

Table 1 *The proposed intersection management and control options*

Group	Traffic Micoscopic Models	Alternatives
Group 1 : Improve the traffic signal control system		Alternative 1.1 : The new Vehicle Actuation (VA) traffic signal at Kalasin intersection Alternative 1.2 : The new VA traffic signal at the X-shaped intersection Alternative 1.3 : The new VA traffic signal at both intersections
Group 2 : Implement roundabouts at intersections		Alternative 2.1 : The new roundabouts at both intersections Alternative 2.2 : The new roundabouts at both intersections with a bypass left lane
Group 3 : Integrating options for improvement in Groups 1 and 2		Alternative 3.1 : The new roundabouts at both intersections and fixed time traffic signal at the Kalasin intersection Alternative 3.2 : The new roundabouts at both intersections and VA traffic signal at the Kalasin intersection Alternative 3.3 : The new roundabouts at both intersections and VA traffic signal with a bypass left lane at the Kalasin intersection Alternative 3.4 : The new VA traffic signal at Kalasin intersection and new roundabout at the X-shaped intersection Alternative 3.5 : The new roundabouts with VA traffic signal at the Kalasin intersection and new VA traffic signal at the X-shaped intersection

2.6 SAW, WASPAS, TOPSIS, VIKOR, and PROMETHEE Methods

The framework of this study was also extended toward giving an explanation of the influence of deciding the weights that could affect other emerging alternatives [23]. The results proposed an approach that could be used to prioritize and select the intersection model that simplified data collection through a microscopic simulation model, and the process of decision-making via real practice. The comparative MCDA techniques are shown in Table 2.

Table 2 *Comparison of the SAW, WASPAS, TOPSIS, VIKOR and PROMETHEE methods*

Decision Structure		MCDA techniques				
		SAW	WASPAS	TOPSIS	VIKOR	PROMETHEE
Objectives and Criteria (C_n)	Criteria	√	√	√	√	√
	Sub-criteria	√	√	√	√	√
	Weight (AHP)	√	√	√	√	√
Collective data	Micro - simulation	√	√	√	√	√
	Normalization	$R_{ij} = [x_{ij} - \max x_{ij}] / [\max x_{ij} - \min x_{ij}]$, (while i = 1, 2, . . . , n, j = 1, 2, . . . ,m)				
The application an aggregation method	Formula	• $R_{ij} = x_{ij} / x_j$ *, if the j^{th} criteria is a benefit criterion, and • $R_{ij} = x_j$ - / x_{ij} , if the j^{th} is the cost criterion	$Q_i^{(1)} = \sum_{j=1}^{n} \bar{x}_{ij} w_j,$ $Q_i^{(2)} = \prod_{j=1}^{n} (\bar{x}_{ij})^{W_j},$ $Q_i = \lambda \sum_{j=1}^{n} \bar{x}_{ij} w_j + (1-\lambda) \prod_{j=1}^{n} (\bar{x}_{ij})^{W_j},$ $\bar{x}_{ij} = \begin{cases} \frac{x_{ij}}{max\ x_{ij}} & \text{if max } x_{ij} \text{ is preferable} \\ \frac{min\ x_{ij}}{x_{ij}} & \text{if max } x_{ij} \text{ is preferable} \end{cases}$ $\lambda = 0, 0.1, 0.2, \ldots, 1.0$	• R , $r_{ij} = x_{ij}$ / sq root (sum, i = … m of x_{ij}2) • Si* = Sq root (sum of squares for j = 1 ….., n) of ($V_{ij} - V_j$*) • Si- = Sq root (sum of squares for j = 1 …., n) of ($V_{ij} - V_j$-) (Ci*, i = ,. . . . , m) as C_i* = S_i- / (S_i* + S_i-)	$L_{p,j} = \sum_{i=1}^{n}[w_i (f_i^* - f_{ij}) / (f_i^* - f_i^-)]^{1/p}$, 1 < p < ∞; j = 1,2, ... , j $S_j = L_{p,j} = \sum_{i=1}^{n} w_i (f_i^* - f_{ij}) / (f_i^* f_i^-)$ $R_j = L_{p,j} = max_j [\sum_{i=1}^{n} w_i (f_i^* - f_{ij}) / (f_i^* f_i^-)]$ • Qj = v (Sj – S*) / (S- - S*) + (1 - v) (Rj – R*) / (R- - R*) • *while v is introduced as weight of strategy of Sj and Rj*	• P_j (*i, i* ‘) =0 if R_{ij} $R_{i'j}$ • P_j (*i, i* ‘) = (R_{ij} - $R_{i'j}$) if R_{ij} $R_{i'j}$ $\varphi^+(i) = \frac{1}{n-1} \sum_{i'=1}^{n} \pi(i', i), i' \neq i$ $\varphi^-(i) = \frac{1}{n-1} \sum_{i'=1}^{n} \pi(i', i), i' \neq i$ $\pi(i, i\_) = (\sum_{j=1}^{m} W_j$ x $P_j((i, i')) / \sum_{j=1}^{m} wj$ • $\phi+(i) = \phi+(i) - \phi-(i)$
	Prioritization	√	√	√	√	√
	Compared Best / Worst	×	×	√	√	√
	Compared Best by attribution	×	×	×	√	√
	Pairwise comparison	×	×	×	×	√
	Sensitivity Analysis	×	√ (Option)	√ (Option)	√ (Option)	√ (Option)
Attribution		Alt.1.1, Alt.1.2, …. Alt.3.5 , According to shown in Table 1				

3. Results & Discussion

3.1 The Results of AHP and Weight Variation

Interviews were conducted with all 12 experts, who provided the weights of importance for each criterion using the AHP method as well as verified the consistency with the Consistency Ratio (C.R.), which was to be less than 0.10, and the group consistency with the Geometric Consistency Ratio (G.C.R.), which was also to be less than 0.10. After the interviews, the next step was to proceed with calculating the scores for the subsequent intersection design selection process. This involved assigning the weights of importance to the dimensions, main criteria, and sub-criteria, as shown in Table 3.

Table 3 *The results of AHP and weight variation*

Main criteria	Weight (W1)	Sub-criteria	Weight (W2)	Sub-criteria Groups	Weight (W3)
(1) Eng	0.489	(1.1) Traffic efficiency	0.306	(1.1.1) Delay	0.364
				(1.1.2) Number of stops	0.301
				(1.1.3) Travel time	0.335
		(1.2) User understanding	0.153		
		(1.3) Safety	0.542		
(2) Econ	0.188	(2.1) Construction costs	0.324		
		(2.2) Impact on surrounding businesses	0.193		
		(2.3) Electricity, labor, and maintenance costs	0.212		
		(2.4) Economic transportation index	0.271	(2.4.1) VHT	0.462
				(2.4.2) Fuel consumption	0.538
(3) Envi	0.322	(3.1) Environmental impact during construction	0.381		
		(3.2) Aesthetic impact	0.232		
		(3.3) Air and noise pollution post-project	0.387	(3.3.1) CO	0.344
				(3.3.2) CO_2	0.304
				(3.3.3) PM 2.5	0.352

The results of assigning weights to the main factors revealed that the experts had assigned the highest importance weight to the criteria related to engineering, accounting for 48.9% of the total weight. Following that, the criteria related to the environmental factors had been ranked second in importance, with a weight of 32.2%. Lastly, the criteria related to economic factors had revealed the lowest weight, accounting for 18.8% of the total weight.

When considering the importance weights of the sub-criteria, it was found that safety in operation, construction cost, air and noise pollution after projects had been the sub-criteria with the highest importance weights for the Engineering, Economic, and Environmental criteria, respectively. Meanwhile, the results of assigning weights of importance to the sub-criteria revealed that delay, fuel consumption rate, and traffic-generated noise pollution had been the sub-criteria with the highest importance weights in each respective category.

3.2 Analysis of Multiplier Values

In the process of analyzing the multiplier values in this study, they were divided into 2 groups: (1) qualitative multiplier values and (2) numerical multiplier values ; The analysis of the qualitative multiplier values was conducted based on 6 sub-criteria (excluding construction costs). This analysis involved assessments from 3 experts, each representing the fields of engineering, economics, and the environment, respectively. The assessment was converted into numerical values ranging from 1 to 5, with 1 indicating an extremely negative evaluation and 5 indicating the highest positive evaluation. Each alternative had expressed its own strengths and weaknesses. Upon averaging the scores from the 6 sub-criteria, Alternative 2.2 had shown the highest average multiplier value (4.00), followed by Alternatives 3.2 and 3.3 (3.83). Alternative 1.2 had demonstrated the lowest average multiplier value (2.67).

The researchers derived the multiplier values from traffic microscopic model using PTV VISSIM to evaluate all the numerical multiplier values for each sub-criterion (except for construction costs, which were estimated separately, but still yielded numerical multiplier values). The analysis revealed that, overall, Alternative 1.1 and alternative 1.3 had been the options with the lowest delay, total numbers of stops, and travel time, with delay values of 33.2 and 34.7 seconds, total numbers of stop values of 6377.0 and 6132.0 times, and travel time values of 73.2 and 74.5 seconds, respectively. However, Alternative 3.1 had exhibited the highest delays and maximum travel times at 112.8 seconds and 162.2 seconds, respectively, while Alternative 2.2 had had the highest total stops at 14,301 times.

Regarding the secondary economic transportation index, Alternative 3.4 had shown the lowest Vehicle Hours Traveled (VHT) value of 472,524 veh-hr, while Alternative 1.3 had exhibited the lowest fuel consumption rate of

472,524 gallons. Conversely, Alternative 2.2 remained the option with the worst economic transportation index multiplier values, with VHT and fuel consumption rate values of 741,259 veh-hr and 157.5 gallons, respectively.

With reference to the secondary air and noise pollution criterion, it was observed that all options had exhibited similar CO_2 and PM2.5 emission levels. Alternative 3.1 had demonstrated the lowest CO_2 emission analysis value at 1.62 grams/s, while Alternative 1.1 had shown the lowest PM2.5 emission analysis value at 1.37 kg/km. However, upon analyzing the CO emission levels, Alternative 1.3 emerged as the most outstanding option, with the lowest CO emission analysis value at 4864.22 grams. The results of the qualitative and numerical multiplier value analyses are presented in Table 4.

Table 4 *The results of the analysis according to the factors in the model and the alternatives*

Main Criteria	Sub-criteria	Sub-criteria Groups	Alternatives				
			1.1	1.2	1.3	2.1	2.2
(1) Eng	(1.1) Traffic efficiency	(1.1.1) Delay (s)	33.2	60.9	34.7	52.2	69.1
		(1.1.2) Numbers of stops (times)	6,377	6,534	6,132	13,136	14,301
		(1.1.3) Travel time (s)	73.2	100.0	74.5	99.7	114.8
	(1.2) User understanding		5.00	4.00	5.00	2.00	4.00
	(1.3) Safety		2.00	1.00	2.00	4.00	4.00
(2) Econ	(2.1) Construction cost (in millions of baht)		3.00	3.50	6.00	6.00	7.50
	(2.2) Impact to surrounding businesses		3.00	3.00	4.00	4.00	4.00
	(2.3) Electricity, labor, and maintenance costs		1.00	1.00	1.00	5.00	3.00
	(2.4) Economic transportation index	(2.4.1) VHT (veh-hr)	547,739	647,637	492,990	523,008	741,259
		(2.4.2) Fuel consumption (gal.)	83.0	90.1	69.6	94.9	157.5
(3) Envi	(3.1) Environmental impact during construction		5.00	5.00	5.00	3.00	3.00
	(3.2) Aesthetic impact		2.00	2.00	2.00	4.00	4.00
	(3.3) Air and noise pollution post-project	(3.3.1) CO (gram)	5,799	6,300	4,864	6,634	11,011
		(3.3.2) CO_2 (gram/s)	2.36	2.00	2.19	1.87	2.17
		(3.3.3) PM 2.5 (kg/km)	1.37	1.44	1.42	1.49	1.39

Main Criteria	Sub-criteria	Sub-criteria Groups	Alternatives				
			3.1	3.2	3.3	3.4	3.5
(1) Eng	(1.1) Traffic efficiency	(1.1.1) Delay (s)	112.8	55.4	44.0	40.9	45.5
		(1.1.2) Numbers of stops (times)	12,972	12,038	11,285	9,693	7,669
		(1.1.3) Travel time (s)	162.2	100.3	88.4	83.4	86.6
	(1.2) User understanding		3.00	4.00	4.00	4.00	3.00
	(1.3) Safety		5.00	5.00	5.00	3.00	3.00
(2) Econ	(2.1) Construction cost (in millions of baht)		6.50	8.00	8.50	5.00	8.00
	(2.2) Impact to surrounding businesses		4.00	4.00	4.00	4.00	3.00
	(2.3) Electricity, labor, and maintenance costs		5.00	3.00	3.00	2.00	2.00
	(2.4) Economic transportation index	(2.4.1) VHT (veh-hr)	652,583	650,374	581,613	472,524	571,430
		(2.4.2) Fuel consumption (gal.)	116.8	106.8	93.5	77.0	85.5
(3) Envi	(3.1) Environmental impact during construction		3.00	3.00	3.00	4.00	3.00
	(3.2) Aesthetic impact		4.00	4.00	4.00	3.00	4.00
		(3.3.1) CO (gram)	8,167	7,464	6,535	5,385	5,973
		(3.3.2) CO2 (gram/s)	1.62	2.03	2.16	2.15	2.08

(3.3) Air and noise pollution post-project	(3.3.3) PM 2.5 (kg/km)	1.58	1.45	1.41	1.44	1.44

3.3 The MCDA Analysis

Factor weighting focused on the Engineering dimension at 48.92%, followed by the Environmental and Economic dimensions at 32.24% and 18.84%, respectively. After consideration together with the 5 MCDA tools, (SAW, WASPAS, TOPSIS, VIKOR, and PROMETHEE), it was found that each tool had proposed Alternative 3.3: The new roundabouts at both intersections and VA traffic signal with a bypass left lane at the Kalasin intersection as the best option, and Alternative 3.2: The new roundabouts at both intersections and VA traffic signal at the Kalasin intersection as the second-best alternative. However, based on the analysis in Table 5, there were differences in Alternatives 3.2 and 2.2.

Table 5 *The analyses using MCDA (SAW, WASPAS, TOPSIS, VIKOR, and PROMETHEE)*

Alternatives	MCDA calculation scores				
	SAW	WASPAS ($\lambda = 0.5$)	TOPSIS	VIKOR ($v = 0.5$)	PROMETHEE (ϕ+(i))
Alternative 1.1 : The new Vehicle Actuation (VA) traffic signal at Kalasin intersection	0.734 (6)	7.6819 (6)	0.4294 (7)	0.6758 (5)	0.533 (5)
Alternative 1.2 : The new VA traffic signal at the X-shaped intersection	0.613 (10)	7.5151 (10)	0.2465 (10)	0.0000 (10)	-0.626 (8)
Alternative 1.3 : The new VA traffic signal at both intersections	0.726 (7)	7.6694 (7)	0.4244 (8)	0.7573 (4)	0.634 (3)
Alternative 2.1 : The new roundabouts at both intersections	0.736 (5)	7.7017 (5)	0.6516 (4)	0.5799 (6)	0.064 (7)
Alternative 2.2 : The new roundabouts at both intersections with a bypass left lane	0.758 (3)	7.7179 (3)	0.7581 (3)	0.5587 (7)	0.090 (6)
Alternative 3.1 : The new roundabouts at both intersections and fixed time traffic signal at the Kalasin intersection	0.700 (8)	7.6520 (8)	0.6108 (5)	0.1206 (9)	-0.746 (10)
Alternative 3.2 : The new roundabouts at both intersections and VA traffic signal at the Kalasin intersection	0.783 (2)	7.7531 (2)	0.7901 (2)	0.8515 (2)	0.711 (2)
Alternative 3.3 : The new roundabouts at both intersections and VA traffic signal with a bypass left lane at the Kalasin intersection	0.805 (1)	7.7781 (1)	0.7951 (1)	1.0000 (1)	1.065 (1)
Alternative 3.4 : The new VA traffic signal at Kalasin intersection and new roundabout at the X-shaped intersection	0.736 (4)	7.7100 (4)	0.5687 (6)	0.7704 (3)	0.615 (4)
Alternative 3.5 : The new roundabouts with VA traffic signal at the Kalasin intersection and new VA traffic	0.685 (9)	7.6448 (9)	0.4201 (9)	0.1817 (8)	-0.655 (9)

signal at the X-shaped intersection

3.4 Sensitivity Analysis

The Sensitivity Analysis (SA) investigates the role of sensitivity in Multi-Criteria Decision Analysis (MCDA) techniques. The sensitivity analysis of each technique identifies which MCDA method offers the most robust ranking of alternatives in the face of potential data or weight variations.

Fig. 6 illustrates changes in the rankings of all options in different scenarios for methods such as SAW, WASPAS, TOPSIS, VIKOR, and PROMETHEE. The results demonstrate that changes in rankings occur when different weights are assigned to factors, illustrating sensitivity to variations in factor weights. Methods that exhibit minimal or no change in ranking when weights are adjusted are considered to be less sensitive. Based on the vulnerability analysis of different methods overall, Alternative 3.3 consistently remains the best option.

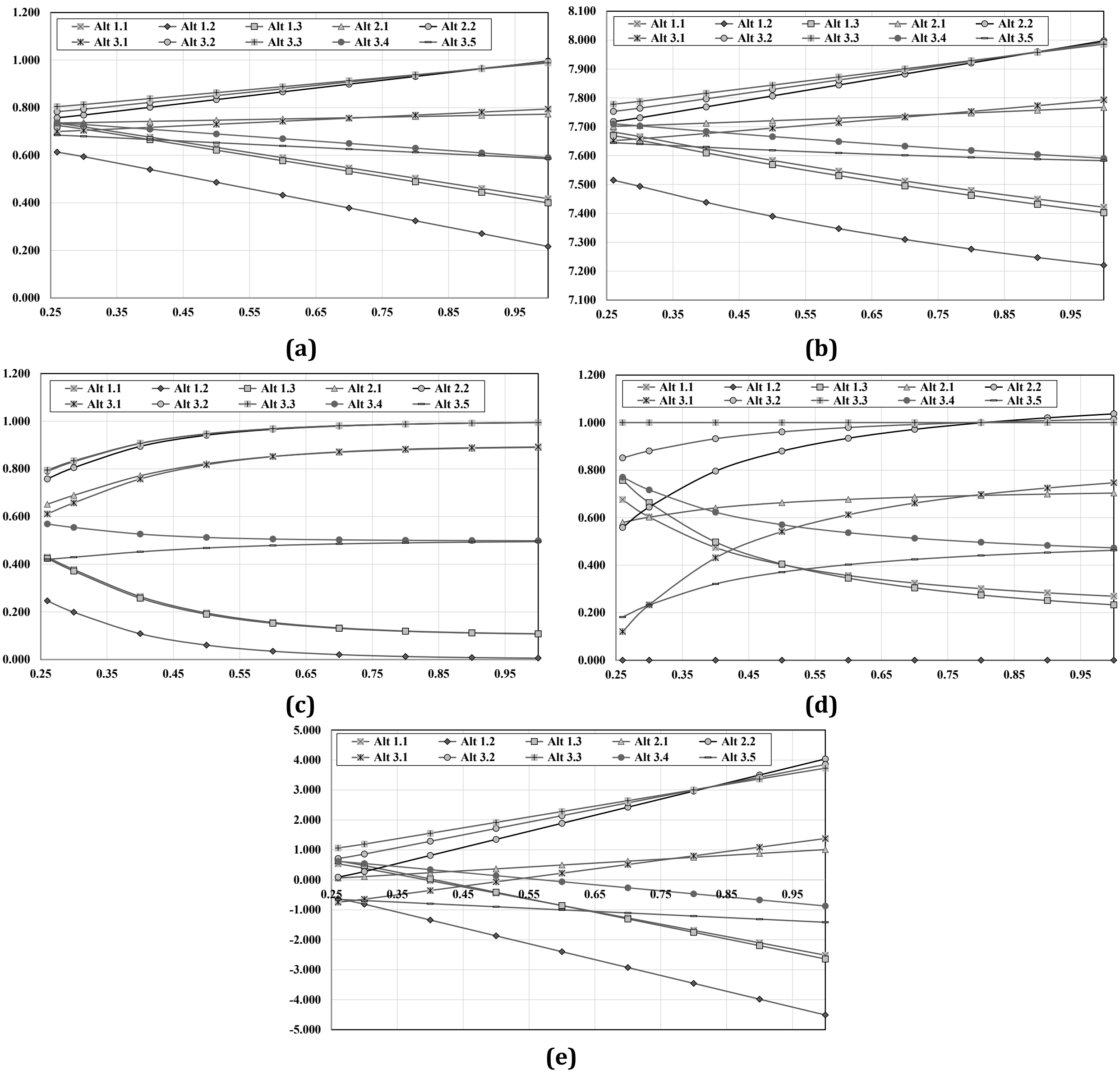

Fig. 6 *Sensitivity analysis of MCDA tools by safety sub criteria (a) SAW; (b) WASPAS; (c) TOPSIS; (d) VIKOR; (e) PROMMETHEE*

4. Conclusions

The application of MCDA is a cutting-edge discipline that is extensively utilized in engineering to achieve objectives via decision-making through a process of prioritization, which is distinct from the traditional optimization approach. In the context of five decision-making tools with varying complexity rankings, (SAW, WASPAS, TOPSIS, VIKOR, and PROMETHEE) and screen the most efficient intersection management and control alternatives. The study confirmed the selection of Alternative 3.3: The new roundabouts at both intersections and VA traffic signal with a bypass left lane at the Kalasin intersection, as the optimal option across all decision-making tools and sensitivity analyses. This research placed emphasis on the development of efficient decision-support frameworks in traffic engineering.

Ethical Approval

The study was conducted under the approval of the Ethics Committee for Research Involving Human Subjects, Mahasarakham University, Thailand (210-212/2023).

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

All authors equally contributed to this manuscript.

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