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Prioritization of sustainable urban land use and transport policy measures for a small-town area in a developing country

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Abstract

A decision-making tool (DMT) combining the KonSULT knowledge base expert system (KBES), AHP, and TOPSIS is applied to create, rank, and select policy measure options for sustainable urban land use and transport development in Khon Kaen University (KKU) in Thailand. KKU represents a small-town area in a developing country. KonSULT KBES is used to create potential policy measure options and provide contribution scores of each option to all minor criteria. AHP is adopted to estimate the relative weights of all decision criteria. TOPSIS is subsequently utilized to determine the composite scores of all options. Such estimated composite scores are eventually used to disclose the prioritization of those options. It is found that 22 (81%) out of the total of 27 policy measure options proposed by DMT are in the completely implemented, the being implemented, and the planning stages in KKU. Therefore, DMT can be applied to generate, prioritize, and select suitable urban land use and transport options for a small-town area (KKU) in Thailand. The ranking order of the top 10 most suitable policy measure options in KKU is pedestrian areas and routes, accident remedial measures, segregated cycle facilities, land use to support public transport, cycle and pedestrian safety, cycle network, school travel plans, traffic calming measures, development density and mix, and promotional activities. Finally, DMT can be utilized to advise administrators and decision-makers to undertake appropriate actions and properly allocate a limited budget for the implementation of such options in any small-town area in any developing country.

Keywords: KonSULT, AHP, TOPSIS, MADM, Prioritization of policy measure options

1. Introduction

The global population dwelling in urban areas will continue to rise and is expected to reach 60% of the total population by 2030 [1]. Due to the rapid growth of population, residents' vehicle dependency and travel demand have also increased dramatically [2], resulting in adverse transport-related issues such as traffic congestion, road accidents, social inequality, excessive use of fuel and energy, environmental impacts, global warming, and climate change. Such issues strongly influence the quality of life and well-being of people in urban areas [3].

Recently, the United Nations Development Programme (UNDP) announced 17 sustainable development goals (SDGs) in association with 169 targets to stimulate an equilibrium among economic, social, and environmental elements of the sustainable development principle and encourage the execution of important actions in the future [1, 4]. Some examples of the targets associated with the SDGs closely involved with road safety, environmental impacts, and climate change issues are the Target 3.6 of the SDG 3 aimed to reduce the number of world fatalities and injuries from road crashes in half, Target 11.6 of SDG 11 proposed to diminish the adverse environmental consequences of cities, and Target 13.2 of SDG13 intended to combine the climate change measures into national policies, strategies, and planning [1].

Khon Kaen University (KKU) is located in Khon Kaen town area of Khon Kaen province in Thailand. The total KKU area covers approximately 900 hectares and has a total number of students, staff members, and visitors of more than 50,000 persons in 2021. In this study, KKU is considered as a small-town area in a developing country - having a total population of less than 100,000 persons [5]. It has been one of the largest and fastest growing regional universities in Thailand. In addition, it is becoming a medical hub in Southeastern Asian countries [6]. With the rapid increase of travel and freight demands, KKU has suffered from various traffic and transport-related problems such as traffic congestion, road accidents, adverse environmental impacts, inefficient consumption of energy, and greenhouse gas (GHG) emissions [7-11]. Consequently, KKU inevitably needs to create, rank, and implement the appropriate sustainable urban land use and transport policy measures to deal with such problems [9, 11]. The KKU master plan study in 2007 [12], the KKU action plans from 2017 to 2023 [13], the KKU administrative and strategic plans from 2010 to 2022 [14], and the KKU safety and security plans from 2015 to 2023 [15] could generally provide the recommendations of suitable urban land use

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and transport policy measures for KKU. Some of these policy measures were completely implemented, some are being implemented, while others are still on the planning stage. In practice, KKU has experienced difficulty in the generation, prioritization, and selection of the suitable policy measures. Based on direct interviews with some administrators and professional planners and engineers, KKU has rarely conducted the appropriate prioritization of all proposed land use and transport policy measures. The efficient and effective Decision-Making Tool (DMT) is inevitably needed to assist and facilitate in the creation, ranking, and selection of the suitable policy measures for KKU.

Based on the Procedures for Recommending Optimal Sustainable Planning of European City Transport System (PROSPECTS) project, a “Decision Maker’s Guidebook” (DMG) was developed to assist decision-makers in crafting sustainable urban land use and transport plans [16, 17]. Based on the logical structure proposed in DMG, one of the most important components is the generation and prioritization of sustainable urban land use and transport policy measure options for various urban area types [17]. A web-based knowledgebase expert system (KBES), namely, the knowledgebase on sustainable urban land use and transport (KonSULT) [18-23] was then developed in 2001. The knowledgebase contained in KonSULT can be used to generate and prioritize various potential policy measure options and to identify contribution performances (scores) of all potential policy measure options in association with all objectives and potential problem-resolving performances gathered from many human experts; thus, gaining the practical and professional experiences of these experts from various European countries [24]. While KonSULT has demonstrated satisfactory results in its ability to cover different area contexts such as in European cities and possibly in other developed worlds, future research on the development and testing of KonSULT in other areas such as in developing countries is essentially needed [24]. Furthermore, such KonSULT knowledgebase has rarely been applied to create and rank several policy measures in any towns or cities in developing countries. With the admirable merits and successful applications in several developed countries [24], the KonSULT web-based software [18] is consequently applied in the research.

The policy measure prioritization process is an ill-structured decision-making problem involving multiple decision criteria, group judgements and a definite number of policy measure options. Accordingly, the multiple attribute decision making (MADM) method well matches with the nature of the prioritization and evaluation of policy measure options [25, 26]. Numerous techniques, such as Simple Additive Weight (SAW), Analytic Hierarchy Process (AHP), VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR), and the Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) have been developed and applied to deal with MADM problems [25-28]. Each of these methods has distinct potential applicability, advantages, disadvantages, and limitations.

The KonSULT knowledgebase in association with the MADM methods has never been applied to generate and prioritize the suitable sustainable urban land use and transport policy measure options in any developing country [24]. Consequently, the combination of the KonSULT web-based software and the selected MADM methods (AHP and TOPSIS) could potentially be utilized to recommend, rank, and select the suitable policy measure options for KKU in Thailand. Such combined framework could be developed further as a Decision-Making Tool (DMT) for the same purpose in other similar areas in developing countries. Accordingly, results of the prioritization of the policy measure options could be utilized to suitably allocate the limited budget for their implementation.

The key objective of this research is to apply the combination of KonSULT web-based software, AHP, and TOPSIS to generate and prioritize sustainable urban land use and transport policy measure options for a small-town area (KKU) in Thailand.

2. Literature review

KonSULT [18] can be applied in identifying the most suitable policy measures for different area types. Based on the KonSULT KBES, this study initially proposed a novel approach for prioritizing various sustainable urban land use and transport policy measures for Khon Kaen University (KKU) by employing appropriate MADM methods.

A literature review [29-32] provides some examples of previous applications of AHP and TOPSIS methods in prioritizing and evaluating transport policies and measures. The examples are the selection of suitable transport policies to deal with climate change issues in Italy by using AHP [29], the assessment of the effectiveness of sustainable mobility measures in Lithuania using TOPSIS [30], the evaluation and selection of the optimal routes for intermodal transportation in Thailand by utilizing both AHP and TOPSIS [31], and the selection of an urban mobility project in a medium-sized city in Brazil using both AHP and TOPSIS [32].

AHP and TOPSIS have been widely used in various prioritizations of suitable transport policy measure options. AHP, one of the most popular MADM methods, has been utilized to estimate the relative weights of several decision criteria because of its theoretical robustness, simplicity, promising accuracy, capability to directly measure the judgment consistency of each individual expert and a group of many experts, and its ability to handle both objective and subjective judgments [33, 34]. TOPSIS is one of the most notable MADM methods successfully applied in determining the prioritization and selection of sustainable transport policies and measures. This is because TOPSIS relies upon the reliable and well-accepted principles of ideal point methods and Euclidean distance [25, 27]. Based on a comprehensive literature review survey, Behzadian [35] found that TOPSIS has been successfully applied to a wide range of fields. Widianta [36] also concluded that TOPSIS could produce (approximately 95%) similar results to the results obtained from other methods adopted by 60 experts in prioritization tasks. In other words, TOPSIS is one of the most suitable methods for MADM approaches because of its accuracy and ability to handle multiple criteria.

Based on a literature review of the KKU master plan study [12] and three other KKU strategic, action, safety, and security plans [13-15], all proposed land use and transport policy measures were summarized and classified in accordance with the Policy Guidebook (PG) system presented in Table 1. In addition, three implementation stages (completely implemented, being implemented, and planning stages) of all policy measures were specified. As illustrated in Table 1, the identified implementation stages of some policy measures (including parking standards, pedestrian area and routes, conventional traffic management, accident remedial measures, and cycle and pedestrian safety) under different KKU plans are unique and distinct. For the sake of simplicity and ease of understanding, it was assumed that for any determined policy measure, its lowest degree in all implementation stages among different KKU plans was used to represent the implementation stage of such a measure.

Table 1 Land use and transport policy measures of KKU

KonSULT policy measures			KKU research study	KKU strategic and action projects			Combination of all KKU projects
Codes of policy measures	**Names of measures**	**Policy measure classifications**	**KKU master plan study (2007) [12]**	**KKU action plans (2017–2023) [13]**	**KKU administrative and strategic plans (2020–2023) [14]**	**KKU safety and security plans (2015–2023) [15]**	
A1	Development Density and Mix	LU	✓***	✓**	-	-	✓***
A2	Land Use to Support Public Transport	LU	-	✓**	-	-	✓**
A3	Parking Standards	LU	✓*	✓**	✓*	-	✓**
A4	Cycle Network	IF	✓*	-	-	-	✓*
A5	Pedestrian Area and Routes	IF	✓*	✓**	✓*	-	✓**
A6	Road Maintenance	MS	✓**	-	-	-	✓**
A7	Conventional Traffic Management	MS	✓*	✓**	✓**	✓*	✓**
A8	Accident Remedial Measures	MS	✓**	✓**	✓**	✓*	✓**
A9	Traffic Calming Measures	MS	✓*	-	✓*	✓*	✓*
A10	Bus Services	MS	✓*	-	✓*	-	✓*
A11	Demand Responsive Transport	MS	-	-	-	-	-
A12	Bus Regulation	MS	✓*	-	✓*	-	✓*
A13	Segregated Cycle Facilities	MS	-	-	✓*	-	✓*
A14	Cycle Parking and Storage	MS	-	-	✓*	-	✓*
A15	Cycle and Pedestrian Safety	MS	✓*	-	✓**	✓*	✓**
A16	Pedestrian Crossing Facilities	MS	✓*	-	✓*	-	✓*
A17	Promotional Activities	AB	-	-	✓*	-	✓*
A18	School Travel Plans	AB	-	-	-	-	-
A19	Promoting Low-carbon Vehicles	AB	-	-	✓*	-	✓*
A20	Bike Sharing	AB	-	✓ *	-	-	✓*
A21	Telecommunications	AB	-	-	✓*	✓*	✓*
A22	Conventional Signs and Markings	IP	✓*	-	✓*	✓*	✓*
A23	Conventional Timetable and Service Information	IP	✓*	-	✓*	-	✓*
A24	Trip Planning Systems	IP	-	-	-	-	-
A25	Crowdsourcing	IP	-	-	-	-	-
A26	Barrier-free Mobility	IP	✓*	-	✓*	-	✓*
A27	Fare Levels	P	-	-	-	-	-
	Total		**15**	**7**	**17**	**6**	**22**

Key: LU: Land use; IF: Infrastructure; MS: Management & service; AB: Attitudinal & behavioral; IP: Information provision; P: Pricing.
*Completely implemented; **Being implemented; ***Planning stage.

3. Research methodology

A flow chart presenting the research methodology is shown in Figure 1. Each step is briefly described as follows:

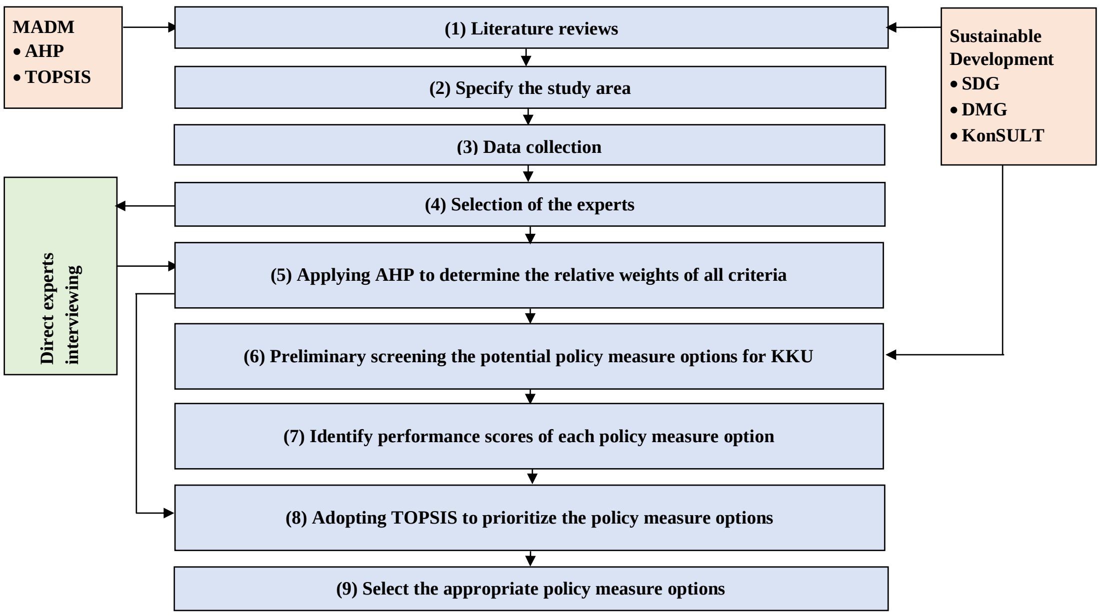

Figure 1 Research methodology

1. Literature reviews: We examined various relevant research articles and reports, such as sustainable urban mobility plans [37], the KonSULT website [38], and several MADM methods [25-36].
2. Specific study area: KKU, which represents a small-town area in Thailand.
3. Data collection: We collected basic information of the study area. The basic information includes things such as the type of area, size of the population, and existing traffic and transport management systems. In addition, key policy strategies and the policy measures achieved from important KKU land use and transport-related studies and plans were collected.
4. Selection of experts: We selected 18 experts and individually interviewed them to identify the relative weights of all decision criteria.
5. We used AHP to determine the relative weights of all decision criteria. These relative weights were obtained from direct interviews with all 18 selected experts.
6. We utilized KonSULT KBES for preliminary screening of all potential policy measure options based on the "small-town area type."
7. We identified performance scores (ranging from +1 to +11 on a rating scale) for all policy measure options under each decision criterion.
8. We adopted TOPSIS to estimate the composite scores adopted for prioritizing policy measure options.
9. We selected appropriate policy measure options based on composite scores.

4. Study area

The study area was KKU, representing a small-town area located in the Khon Kaen town plan area of Khon Kaen province in the northeastern region of Thailand. The total KKU area (as illustrated in Figure 2) covers approximately 900 ha, and it has a mixture of different types of land use, such as various faculties, colleges, research centers, KKU administration offices, medical hub facilities, and student and staff dormitories. The total number of students and staff members was approximately 40,651 and 11,235, respectively. The total number of academic faculties, colleges, residential houses, and dormitories were 19, 3, 2, 869, and 35, respectively. In the existing KKU Smart Transit system, 20 electric mini-buses provide services in 4 routes both inside and outside the KKU perimeter [7-11].

Figure 2 Location of KKU (Google Map. Accessed on 30th October 2022).

KKU can be represented as a small-town area in Thailand because of its considerable number of residents (including students and staff members) and its fast development [11, 39, 40]. People residing both within and outside KKU normally utilize the KKU road network as a shortcut to Mitrapharp Road (ASEAN Highway (AH 12)) and Maliwan Road (AH 16). The intrusion of traffic into KKU has been the main cause of traffic congestion, road accidents, adverse environmental impacts, inefficient consumption of energy, and greenhouse gas (GHG) emissions [7-11]. Hence, KKU urgently needs to generate and implement appropriate sustainable urban land use and transport policy measures to tackle this critical problem [9, 11].

5. Data collection

Basic information about KKU, including the area category, size of the population, existing land use and transport characteristics, and traffic management schemes was collected. In addition, the current KKU policies, strategies, and policy measures contained in the KKU master plan study [12] as well as other KKU strategic, action, safety, and security plans [13-15] were gathered.

KKU is the first regional university to be established in the Northeastern region of Thailand. KKU aims to create social stability and sustainability within communities and has undertaken many projects that are of great relevance to the 17 SDGs [39]. The action plan for the 2019 fiscal year aligned the strategic structure of KKU administration with the strategic plan for 2020–2023 [14] that declares: The vision of KKU is to be "*a world-leading research and development university*" [40]. The mission and policies of KKU are composed of three main components: (1) people, (2) ecological aspects, and (3) spiritual aspects [40]. One of the ecological policies most pertinent to sustainable urban land use and transport planning and development is the concept of a green university. The green university consists of two key components: (1) environmental protection and energy consumption efficiency and (2) effective resource utilization [40]. It should be noted that one of the most relevant KKU strategic goals of sustainable urban land use and transport planning and development is to become "*the best place to live*" [40]. This strategic goal consists of eight important strategies, namely, to (1) become a green university, (2) build up biodiversity and forest restoration, (3) build up an aesthetic zone in the university, (4) make residential restoration, (5) provide an efficient safety and security system using smart safety and security, (6) utilize novel traffic zoning systems, (7) energy and environment conservation, and (8) stabilize the public utility system [40]. For the sake of simplifying the comparative analysis, all the names and categories of the potential policy measures containing such KKU studies and plans [12-15] mentioned previously were consequently organized in accordance with the conceptual framework of the PG in KonSULT as illustrated in Table 1. Relying upon the KKU policies and strategies as well as the need to tackle the critical land use and transport problems facing KKU, both KKU research centers and external professional organizations were commissioned to conduct their research studies and other strategic action plans aimed at resolving the current KKU problems. In addition, some KKU organizations (e.g., the safety and security division and the building and construction division) might be requested to prepare special plans (involving building construction, transport infrastructure development, safety and security system installations, etc.) for inclusion in the annual strategic and action plans of KKU. In practice, KKU has rarely properly prioritized all proposed policy measures because it has experienced difficulty prioritizing the proposed policy measures and budget allocations for the implementation of those measures. A practical and efficient DMT is needed to deal with these important issues. Although KKU and other small-town areas might generally be similar, organizational structure, socio-economic levels, area context, nature of experienced problems, existing land use and transport characteristics and management systems, et cetera could be uniquely distinct. This circumstance may lead to a discrepancy in the recommended policy measures for both KKU and other small-town areas.

6. MADM Method

Two popular MADM methods, namely AHP and TOPSIS, were combined and used to resolve this complicated decision-making problem. AHP was utilized to estimate the relative weights of all decision criteria by directly interviewing a group of 18 selected experts. TOPSIS was subsequently utilized to determine the composite scores of all potential options. Then, these policy measure options were prioritized, evaluated, and selected based on the obtained composite scores.

6.1 AHP Method

AHP is a mathematical approach for estimating the relative weights of all determined criteria. The relative weights of each criterion can be achieved via the pairwise comparisons using the ratio scale [41]. AHP fundamentally consists of three main steps: (1) decomposition, (2) prioritization, and (3) synthesis [41, 42].

Step 1. Decomposition

Decision-makers need to divide a determined problem into detailed decision elements and subsequently create a hierarchical structure of all decision elements. This hierarchical structure is key to interrelating and linking all decision elements from the principal goal (at the top level) down to detailed decision elements (at the bottom) [41].

Step 2. Prioritization

When the hierarchical structure is created, the relative weights of all decision elements are explicitly derived through pairwise comparisons. Applying the ratio scale method, pairwise comparisons of these decision elements can be performed [43, 44]. The ratio scale and its definition used in the pairwise comparisons are ranged from 1 = equal importance to 9 = extreme importance [43-45]. If w_i and w_j represent the relative importance of the decision elements i and j, respectively. For each expert interviewed, the obtained pairwise comparisons of relative importance, $a_{ij} = w_i / w_j$, for all decision elements and their reciprocals, $a_{ji} = 1/a_{ij}$, are input into a reciprocal square matrix $\boldsymbol{A} = \{a_{ij}\}$. The normalized right eigenvector ($\boldsymbol{W}$) associated with the largest eigenvalue (λ_{max}) of the square matrix $\boldsymbol{A}$ (based on the equation $\boldsymbol{AW} = \lambda_{max} \boldsymbol{W}$) provide the relative weights of all determined decision elements [46]. According to the equation of consistency index (CI = $(\lambda_{max} - n)/(n - 1)$), the Consistency Index (CI) was computed to measure the consistency of the square matrix $\boldsymbol{A}$. The ratio of CI to RCI (shown in Table 2) is called the Consistency Ratio (CR). Generally, a CR less than or equal to 0.10 is considered acceptable; otherwise, the square matrix $\boldsymbol{A}$ will be revised to improve judgmental consistency [41].

Table 2 Random Consistency Index (RCI) [41]

n	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
RCI	0.00	0.00	0.52	0.89	1.11	1.25	1.35	1.40	1.45

For ease of numerical computations, the normalization of the geometric mean of the row was used to estimate relative weights of all considered decision elements and to calculate the largest eigenvalue (λmax) of the square matrix $\boldsymbol{A}$ [41]. The geometric mean method (GMM) was used to combine different individual judgments to obtain group judgment [47].

Step 3. Synthesis

AHP typically applies the "principle of hierarchic composition" to aggregate the local relative weights of all decision elements contained in all hierarchical levels to obtain the global relative weights of each decision element (alternative) at the lowest hierarchical level [41].

6.2 TOPSIS Method

TOPSIS was developed to determine the best option based on the concepts of the compromise solution [25]. The basic principle of TOPSIS is that the chosen option has the shortest Euclidean distance from the positive ideal solution and the farthest Euclidean distance from the negative ideal solution. The calculation procedure of TOPSIS is described in following steps [25].

Step 1: Estimate a normalized decision matrix, where the normalized value (r_{ij}) is computed as

$$r_{ij} = x_{ij} \Big/ \sqrt{\sum_{i}^{n} x_{ij}^2}\,; i = 1, 2, \ldots.n; j = 1,2, \ldots.m. \quad (1)$$

Where x_{ij} is performance rating of alternative *i* under criteria *j; i* is alternatives; *n* being the total number of alternatives to be analyzed; *j* is the criteria and *m* being the total number of determined criteria.

Step 2: Estimate a weighted normalized decision matrix, where the weighted normalized value (v_{ij}) is calculated as

$$v_{ij} = w_j * r_{ij} \quad (2)$$

where w_j is the relative weight of criteria *j*

Step 3: Determine the positive ideal solution (V_j^+) and negative ideal solution (V_j^-):

$$V_j^+ = \{\max v_{ij} \big| \, j \in J_1), (\min v_{ij} \big| \, j \in J_2)\}; i = 1,2, \ldots n; j = 1,2, \ldots m \quad (3)$$

$$V_j^- = \{\min v_{ij} \big| \, j \in J_1), (\max v_{ij} \big| \, j \in J_2)\}; i = 1,2, \ldots n; j = 1,2, \ldots m \quad (4)$$

Where, J_1 is associated with beneficial attributes (i.e. the higher values the better performance) and J_2 is associated with the non-beneficial attributes (i.e. the smaller values the better performance).

Step 4: Calculate the separation from either the positive ideal solution or the negative ideal solution to each alternative. Separation values can be determined as Euclidean distance:

The separation of each alternative from the positive ideal solution is calculated by

$$S_i^+ = \sqrt{\sum_{j=1}^{m} (v_{ij} - V_j^+)^2}\,; i = 1,2, \ldots.n; j = 1,2, \ldots.m \quad (5)$$

Similarly, the separation from the negative ideal solution is computed by:

$$S_i^- = \sqrt{\sum_{j=1}^{m} (v_{ij} - V_j^-)^2}\,; i = 1,2, \ldots.n; j = 1,2, \ldots.m \quad (6)$$

Step 5: A calculation of the relative closeness to the ideal solution can be derived as:

$$P_i = \frac{S_i^-}{S_i^+ + S_i^-}\,, i = 1,2,3, \ldots \ldots \ldots.., n \quad (7)$$

Step 6: The ranking orders of all determined options can be obtained according to the relative closeness to the ideal solution in descending order to find the best option. The best option will have the shortest distance from the positive ideal solution and the longest distance from the negative ideal solution [27].

6.3 Selection of experts

In this research, 18 human experts were equally divided into 2 groups: (1) “urban transport planners” and (2) “town planners and urban designers.” These experts were chosen based on the following criteria: (1) direct involvement with important urban land use and transport projects for town plan areas in regional cities of Thailand and (2) professional experience and expertise related to sustainable urban transport planning, town planning, and urban design.

7. Organizing of decision elements into a hierarchical structure

In this study, the prioritization of policy measure options was conducted based on the principle of sustainable development with an aim to create a systematic balance among three main criteria, namely, (1) economic development, (2) social responsibility, and (3) environmental protection [17]. The seven principal objectives of sustainable urban land use and transport development [17], videlicet, (1) economic efficiency, (2) economic growth, (3) finance, (4) a livable street and neighborhood, (5) equity and social inclusion, (6) safety, and (7) protection of the environment were also adopted as seven minor criteria in association with the three main criteria previously mentioned. Subsequently, the three main criteria and the other seven minor criteria were hierarchically organized as a hierarchy structure as illustrated in Figure 3.

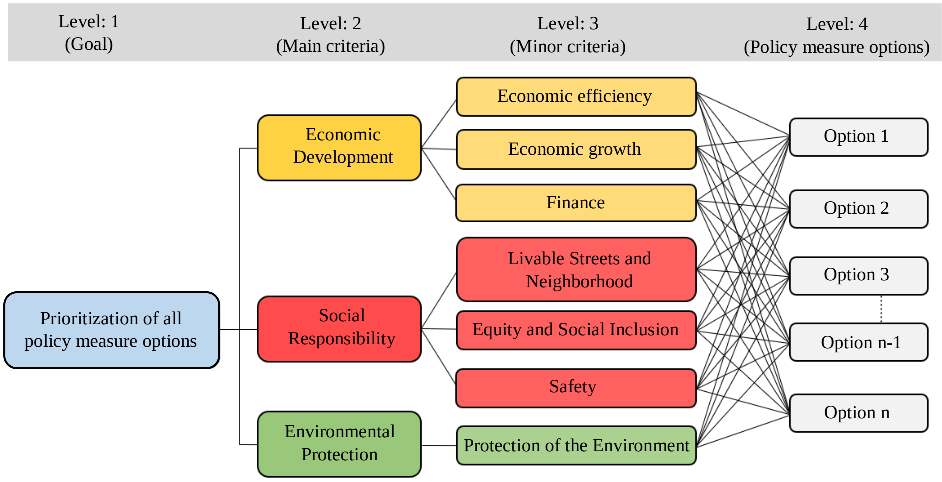

Figure 3 Hierarchical structure of all decision elements.

8. Estimations of relative weights of both main and minor criteria

The relative weights of all decision criteria were obtained by directly interviewing 18 selected experts. Based on the principle of hierarchic composition in the AHP synthesis step [41] and the GMM method for group judgments [47], the estimated group relative weights of those main and minor criteria are presented in Figure 4 and Figure 5, respectively. It was found that all computed CR values obtained from each individual expert and the estimated GCR values obtained from a group of 18 experts were all less than 0.10. This means that the judgments of each individual expert and group of 18 experts were acceptably consistent and reliable. In Figure 4 and Figure 5, it was found that the main criterion having the highest relative weight among the 3 main criteria is social responsibility (0.5211), followed by environmental protection (0.3534), and economic development (0.1255), respectively. In addition, the minor criterion possessing the greatest relative weight among the seven minor criteria is the protection of the environment (0.3534), followed by safety (0.3034), livable streets and neighborhood (0.1369), equity and social inclusion (0.0808), economic efficiency (0.0594), finance (0.0439), and economic growth (0.0222), respectively.

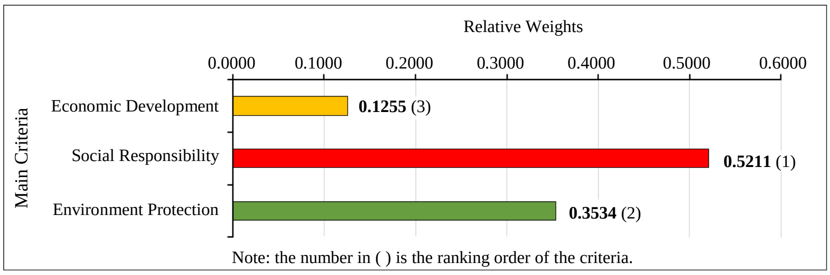

Figure 4 Group relative weights of main criteria from all 18 experts.

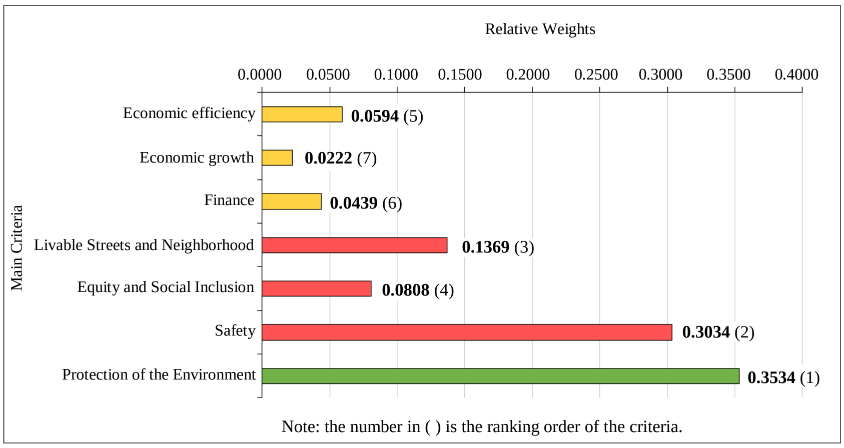

Figure 5 Group relative weights of minor criteria from all 18 experts.

9. Determine contribution scores

9.1 Preliminary Screening of Potential Policy Measure Options for KKU

Preliminary screening of potential policy measure options could be achieved by utilizing KonSULT knowledgebase. Based on the “small town area type,” 27 potential policy measures were finally selected and adopted as potential policy measure options for KKU, as shown in Table 3. Suitability scores of these policy measure options must be equal to or greater than 3 (meaning moderately suitable).

9.2 Contribution Score of the 27 Selected Policy Measure Options to All Minor Criteria

Contribution scores contained in the KonSULT knowledgebase of each policy measure option to the 7 minor (objectives) criteria were determined using values of the original 11-point scale, ranging from -5 (strongest possible negative contribution) to +5 (strongest possible positive contribution), with 0 representing the midpoint (no contribution). In this research, such a rating scale was systematically converted to a positive 11-positive integer scale, ranging from +1 (strongest possible negative contribution) to +11 (strongest possible positive contribution), with 6 representing the midpoint (neutral contribution). Such a conversion could eliminate the misleading effects of both negative and positive scores to the composite score of each policy measure option. For example, the summation of -3 score for one objective and +3 for the other objective of any policy measures is becoming zero which means that such measure has no influence on these two determined objectives.

Table 3 Contribution scores of the 27 potential policy measure options associated with the 7 main criteria.

Policy measure options (A_i)	Minor criteria (C_j : objectives of sustainable urban land use and transport development)						
	Economic efficiency (C1)	Livable streets and neighborhood (C2)	Protection of the environment (C3)	Equity and social inclusion (C4)	Safety (C5)	Economic growth (C6)	Finance (C7)
Development Density and Mix (A1)	+ 9	+ 10	+ 8	+ 10	+ 9	+ 9	+ 6
Land Use to Support Public Transport (A2)	+ 9	+ 10	+ 10	+ 8	+ 9	+ 8	+ 8
Parking Standards (A3)	+ 8	+ 9	+ 8	+ 9	+ 8	+ 8	+ 7
Cycle Network (A4)	+ 8	+ 9	+ 9	+ 9	+ 9	+ 7	+ 5
Pedestrian Area and Routes (A5)	+ 9	+ 11	+ 10	+ 11	+ 10	+ 9	+ 6
Road Maintenance (A6)	+ 8	+ 7	+ 8	+ 6	+ 8	+ 6	+ 7
Conventional Traffic Management (A7)	+ 7	+ 6	+ 6	+ 5	+ 7	+ 6	+ 5
Accident Remedial Measures (A8)	+ 9	+ 9	+ 9	+ 9	+ 11	+ 6	+ 6
Traffic Calming Measures (A9)	+ 9	+ 9	+ 8	+ 8	+ 10	+ 8	+ 5
Bus Services (A10)	+ 7	+ 7	+ 8	+ 9	+ 7	+ 6	+ 5
Demand Responsive Transport (A11)	+ 6	+ 6	+ 7	+ 10	+ 6	+ 6	+ 3
Bus Regulation (A12)	+ 8	+ 7	+ 7	+ 9	+ 8	+ 8	+ 7
Segregated Cycle Facilities (A13)	+ 8	+ 9	+ 9	+ 9	+ 10	+ 6	+ 4
Cycle Parking and Storage (A14)	+ 8	+ 9	+ 8	+ 8	+ 6	+ 7	+ 4
Cycle and Pedestrian Safety (A15)	+ 6	+ 10	+ 8	+ 9	+ 11	+ 8	+ 4
Pedestrian Crossing Facilities (A16)	+ 6	+ 9	+ 6	+ 9	+ 8	+ 9	+ 4
Promotional Activities (A17)	+ 8	+ 8	+ 10	+ 8	+ 7	+ 6	+ 5
School Travel Plans (A18)	+ 8	+ 9	+ 9	+ 7	+ 9	+ 7	+ 5
Promoting Low Carbon Vehicles (A19)	+ 6	+ 8	+ 10	+ 5	+ 5	+ 7	+ 5
Bike Sharing (A20)	+ 8	+ 8	+ 8	+ 7	+ 8	+ 8	+ 7
Telecommunications (A21)	+ 8	+ 6	+ 7	+ 6	+ 6	+ 6	+ 5
Conventional Signs and Markings (A22)	+ 8	+ 6	+ 7	+ 6	+ 8	+ 6	+ 6
Conventional Timetable & Service Information (A23)	+ 8	+ 7	+ 7	+ 8	+ 7	+ 6	+ 7
Trip Planning Systems (A24)	+ 8	+ 7	+ 6	+ 8	+ 7	+ 6	+ 7
Crowd Sourcing (A25)	+ 9	+ 6	+ 6	+ 5	+ 7	+ 6	+ 8
Barrier-Free Mobility (A26)	+ 6	+ 6	+ 6	+ 10	+ 9	+ 6	+ 6
Fare Levels (A27)	+ 8	+ 8	+ 8	+ 9	+ 7	+ 7	+ 4

Color shading: +1 +2 +3 +4 +5 +6 +7 +8 +9 +10 +11

Remarks:
+ 1 = Strongest possible negative contribution
+ 2 = Strong possible negative contribution
+ 3 = Medium possible negative contribution
+ 4 = Weak possible negative contribution
+ 5 = Weakest possible negative contribution
+ 6 = No contribution
+ 7 = Weakest possible positive contribution
+ 8 = Weak possible positive contribution
+ 9 = Medium possible positive contribution
+ 10 = Strong possible positive contribution
+ 11 = Strongest possible positive contribution

10. Prioritization of potential policy measure options

The next step was to prioritize potential policy measure options through the use of TOPSIS. The brief calculation procedure of TOPSIS summarized in section 5.2 was followed.

The values of relative closeness to the ideal solution (P_i) achieved from TOPSIS were utilized to prioritize all the 27 potential policy measure options shown in Figure 6.

The prioritization of the top 10 most suitable policy measure options for KKU is pedestrian areas and routes (A5), accident remedial measures (A8), segregated cycle facilities (A13), land use to support public transport (A2), cycle and pedestrian safety (A15), cycle network (A4), school travel plans (A18), traffic calming measures (A9), development density and mix (A1), and promotional activities (A17) in that order.

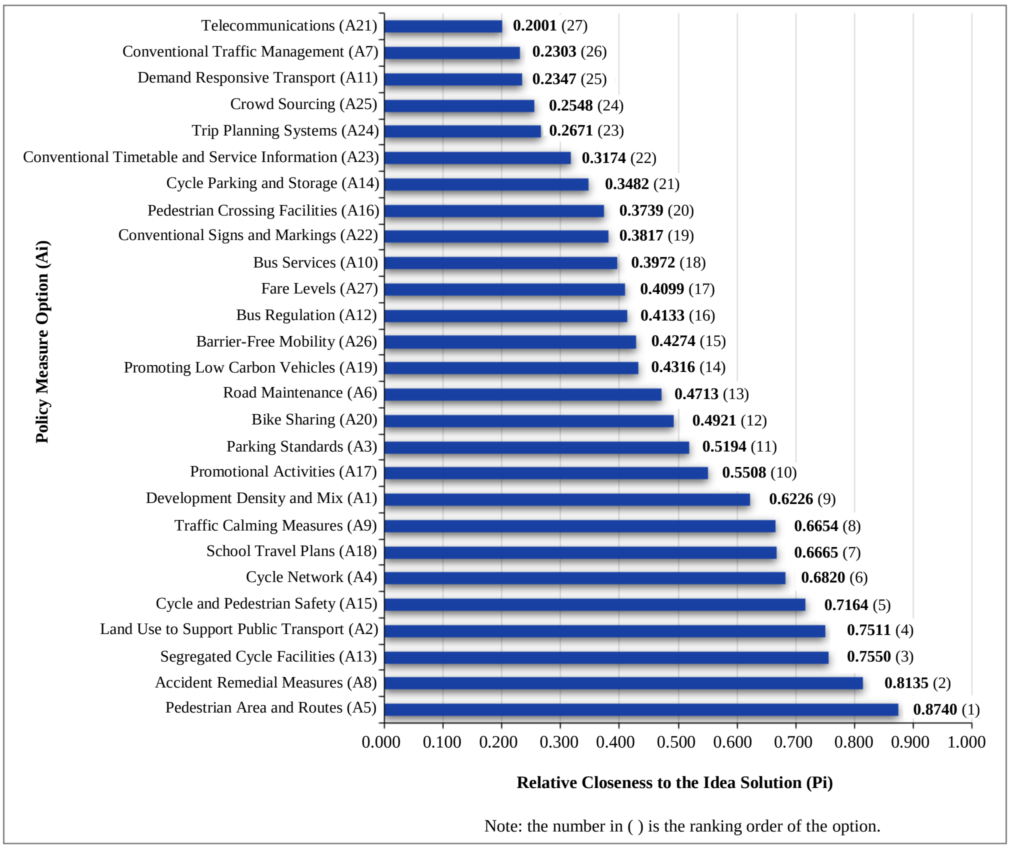

Figure 6 Prioritization of policy measure options derived from TOPSIS.

It was found that 9 (90%) out of the top 10 policy measure options recommended by DMT were proposed in a small-town area (KKU). Of the 9 policy measure options, 4 (A4, A9, A13, and A17) are in the completely implemented stage, 4 (A2, A5, A8, and A15) are in the being implemented stage, and 1 (A1) is in the planning stages. Only A18 (school travel plans) has never been proposed in KKU. The details of the 9 options recommended in KKU according to their ranking order are: pedestrian areas and routes (A5) (e.g., pedestrian area and car-free zone in the faculty of engineering), accident remedial measures (A8) (e.g., road safety audits based on a safe system approach and black spot treatment), segregated cycle facilities (A13) (e.g., a separated cycle lane network), land use to support public transport (A2) (e.g., locating trip origins (residential facilities for staff and students) and destinations (natural history museum, agricultural park, and a medical hub) close to electric shuttle bus stations, cycle and pedestrian safety (A15) (e.g., many pedestrian crossings, two pedestrian crossings with traffic lights, and a few grade-separated pedestrian crossing facilities), a cycle network (A4) (e.g., implementation of KKU cycle networks), traffic calming measures (A9) (e.g., nine roundabout constructions, six traffic signal installations, numerous speed humps and speed table installations), development density and mix (A1) (e.g., residential housing relocation projects from the southern part to the northern part near academic zones and a commercial area development project for academic institutes), and promotional activities (A17) (e.g., the development of KKU Transit app to promote the use of the electric shuttle bus service and reduce environmental impacts and GHG emissions generated by road traffic). Although the development density and mix (A1) option is ranked 9th among the top 10 options, it is still in the planning stage. Hence, it is highly recommended that KKU administrators or decision-makers undertake urgent actions to accelerate A1's actual implementation. Four options (A5, A8, A2, and A15) are in the being implemented stage. Pedestrian areas and routes (A5), accident remedial measures (A8), land use to support public transport (A2), and cycle and pedestrian safety (A15) have 1st, 2nd, 4th, and 5th ranks in the top 10 options, respectively. Consequently, the KKU administrative and strategic bodies and decision-makers are urged to expedite the implementation of such options.

As shown in the last column of Table 1, 22 (approximately 81%) out of all 27 options suggested by DMT were proposed in KKU. Based on these 22 options, 14 (A4, A9, A10, A12, A13, A14, A16, A17, A19, A20, A21, A22, A23, and A26) are in the completely implemented stage, 7 (A2, A3, A5, A6, A7, A8, and A15) are in the being implemented stage, and only 1 (A1) is in the planning stages in KKU. Only 5 options (A11, A18, A24, A25, and A27) have never been proposed in a small-town area (KKU). Based on careful considerations of the applicability and practicality of such 5 options suggested by DMT for KKU, the school travel plan (A18) option—ranked 7th among the top 10 options—is highly recommended for implementation in KKU. The other 4 options (A11, A24, A25, and A27) will not be proposed for KKU because the main area context of KKU (i.e., an education-oriented institute, relatively small size, provision of electric shuttle bus services free of charge for everyone, etc.) may be unique and differ from a typical small-town area in any developing country. In addition, fare levels (A27), trip planning systems (A24), crowdsourcing (A25), and demand-responsive transport (A11) are considered as low priority options because options A11, A24, A25, and A27 are ranked 17th, 23rd, 24th, and 25th in priority, respectively, among the 27 options.

11. Conclusions

Based on the principle of sustainable development, this research aimed to generate, prioritize, and select the policy measure options for sustainable urban land use and transport development in KKU, which represents a "small-town area" in Thailand, by applying DMT—a combination of the KonSULT KBES—and two powerful MADM methods, namely AHP and TOPSIS. The PG module of

KonSULT KBES was used to create potential policy measure options and distribute the contribution scores of each option to all minor criteria (seven KonSULT objectives). Subsequently, AHP was adopted to estimate the relative weights of all decision criteria by directly interviewing a group of 18 selected experts. All the judgments of each individual expert and the entire group were acceptably consistent. TOPSIS was then used to determine the composite scores of all potential policy measure options. Such estimated composite scores were eventually employed to prioritize all policy measure options.

The ranking order of the top 10 most suitable policy measure options proposed by DMT for KKU is: pedestrian areas and routes (A5), accident remedial measures (A8), segregated cycle facilities (A13), land use to support public transport (A2), cycle and pedestrian safety (A15), cycle network (A4), school travel plans (A18), traffic calming measures (A9), development density and mix (A1), and promotional activities (A17). It was found that 9 (90%) out of the top 10 policy measure options were in the completely implemented, the being implemented, and the planning stages in KKU. The development density and mix (A1) option, one of the top 10 options, remained in the planning stage; an acceleration of its actual implementation in KKU is strongly recommended. The other four being implemented options, namely, pedestrian areas and routes (A5), accident remedial measures (A8), land use to support public transport (A2), and cycle and pedestrian safety (A15), were ranked as one of the top 5 options. The KKU administrative and strategic bodies and decision-makers are consequently urged to expedite the ongoing implementations of these four options.

In addition, 22 (81%) out of all 27 policy measure options were in the completely implemented, the being implemented, and the on-planning stages in KKU. Only the remaining 5 options (A11, A18, A24, A25, and A27) have never been recommended in KKU. Based on a scrutiny of the applicability and practicality of 5 such options, school travel plans (A18), which are 1 of the top 10 options, is strongly recommended for implementation in KKU. However, the other 4 options, namely, demand-responsive transport (A11), trip planning systems (A24), crowdsourcing (A25), and fare level (A27) will not be recommended for KKU because the area context and the nature of underlying problems in KKU may be different from that of a typical small-town area in any developing country. Consequently, DMT can be utilized to create, rank, and select suitable urban land use and transport policy measures for a small-town area (KKU) in Thailand. DMT can also be applied to advise administrative and strategic planners and decision-makers to undertake and adapt appropriate actions in the implementation of urban land use and transport policy measures in a small-town area in any developing country. In addition, DMT is beneficial in public consultations with various groups of stakeholders and the general public in the decision-making process at KKU. The prioritization of the policy measure options proposed by DMT can be used to properly allocate a limited budget for the implementation of such options in KKU. In this way, the vision, goals, objectives, strategies, and policies under the sustainable development principle of any small-town area in any developing country can efficiently and successfully be achieved through the assistance and contribution of the DMT framework.

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