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Abstract: Transport project selection is always critical in government planning due to limited resources and diverse demands. Project portfolio management (PPM) was proposed in this study to suggest an optimal set of projects under predetermined constraints. With multiple conflicting criteria, comprehensive steps of multi-criteria decision making (MCDM) procedures were proposed in this study. The process begins with a step of pre-screening the projects and selecting the criteria for project evaluation. Sequential steps of: 1) weight determination process using the proportion method; 2) MCDM process using preference ranking organisation method for enrichment evaluations (PROMETHEE) II; 3) constraint consideration process using PROMETHEE V, was proposed to evaluate and select an optimal project portfolio. The study showed that decision making could be successfully done for the transport infrastructure investment with minimal complex calculation steps and questionnaire input from experts.

Keywords: decision making; multi-criteria decision making; MCDM; portfolio management; proportion method; Thailand; transport infrastructure; transport project evaluation; PROMETHEE.

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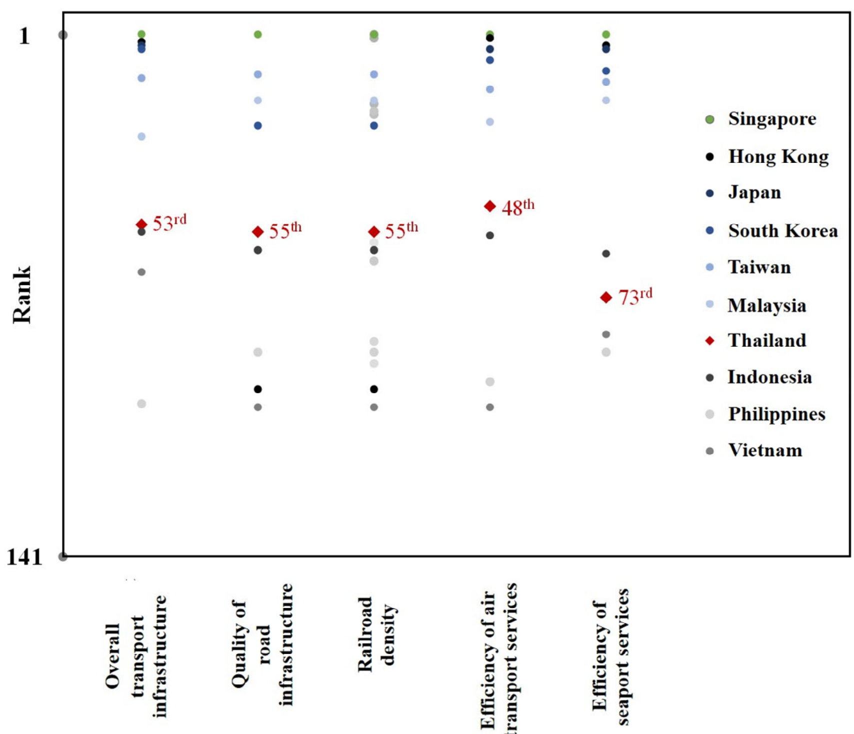
1 Introduction

The quality of transport infrastructure in Thailand is considered relatively poor by international rankings. In the Global Competitiveness Report 2019, Thailand was ranked 53rd out of 141 countries for overall transport infrastructure (Schwab, 2019). Figure 1 illustrates the ranks of Thailand compared to other countries in the region. When considering the rank of each mode of transportation separately, Thailand's efficiency of seaport services was ranked the lowest of all modes. Railroad density in Thailand was comparatively decent but the efficiency of train services (not shown) was ranked only 75th out of 141 countries which reflects an extreme weakness of the railway infrastructure. Because accessibility and connectivity of railway and waterway are very limited, freight transport still heavily relies on comparatively expensive roadways. The unnecessarily high cost of freight transport is one important factor that hinders the growth of the Thai economy. It is important to improve Thai transport infrastructure to shift the major modes of transportation to railway and waterway (International Monetary Fund, 2016). Energy Research Institute of Chulalongkorn University reported, in 2013, that road transport has the highest energy consumption among other modes of transportation and it can be concluded that this is the biggest source of energy consumption in Thailand (Rujikiatkumjorn and Wangjiranirun, 2013). Besides, based on statistical data from Thailand Department of Land Transport, an increase in the number of registered vehicles was observed annually and it negatively affects Thailand's domestic energy consumption situation (Pongthanaisawan and Sorapipatana, 2010). Air pollution and traffic accident are also critical issues in Thailand that are caused by massive use of roadways (Narita et al., 2019; Tanaboriboo and Satiennam, 2005).

Figure 1 Transport infrastructure ranks by World Economic Forum (see online version for colours)



Source: Schwab (2019)

Considering the problems mentioned earlier, the country must initiate a large-scale transport infrastructure investment. In January 2013, the Cabinet of Thailand decided to propose 70 new projects to improve transport infrastructure in five modes: railways, roadways, waterways, airways and cross-border facilities, as shown in Table 1. Those initiatives need to focus on capacity building in the transport system for the country's long-term competitiveness. To achieve the goal, the transport infrastructure investment needs to cover three main objectives:

1 Modal shift: To replace a mode of transport with another to reduce the overall transportation cost.

2 Transport connectivity: To facilitate regional transport connectivity and cross-border trade between cities in the sub-region and ASEAN Economic Community (AEC).

3 Urban mobility: To strategically implement public transport that improves the efficiency of city logistics.

Table 1 Transport projects proposed by the Cabinet of Thailand

Mode of transportation	*Number of projects*
Railways	37
Roadways	10
Waterways	5
Cross-border facilities	18

Development of transportation systems through the transport infrastructure projects is an important investment because it plays vital roles on financial, social, economic, environmental and political issues (Thacker et al., 2019; Wang et al., 2018; Yoshino and Nakahigashi, 2018). Government investment in infrastructure is a key factor in promoting modal shift (Kaack et al., 2018). However, prioritising the investment in the transport infrastructure projects is a common problem at all levels of local governments (Deluka-Tibljaš et al., 2013; Gühnemann et al., 2012; Schutte and Brits, 2013; Shang et al., 2004). It was also reported that the transport project selection is one of the most important planning activities encountered by the governments (Macharis and Bernardini, 2015; Schutte and Brits, 2013; Shang et al., 2004). Transport project evaluation is a decision making process that provides relevant information for policymakers to prioritise the projects to be invested in (Aldian, 2005; de Brucker et al., 2011; Jones et al., 2013; Joumard and Nicolas, 2010). Several studies were conducted to evaluate the impact of Thailand's infrastructure investment (De Groote et al., 2020; Limcharoen et al., 2017; Peetawan and Suthiwartnarueput, 2018; Sathirathai, 2013). However, there is still a lack of a comprehensive investigation to support Thai Government decision making in the future. This study proposed a set of tools for the Thai Government to effectively make an impactful investment on the country's transport infrastructure under conflicting criteria. Project portfolio management (PPM), a management tool used to strategically select one or more project portfolio from potential set of project proposals, is proposed to provide an evidence-based information for Thai Government investment decision. PPM can facilitate a decision making that achieves organisation's strategies and objectives under multiple constraints, such as critical budgets and resources. A comprehensive combination of methods is also proposed accordingly to calculate an optimal prioritisation of the project and a portfolio for the transport infrastructure development plan in Thailand.

The structure of the paper is organised as follows: Section 2 describes literature survey and related approaches, Section 3 elaborates research methodology, Section 4 shows data preparation steps that leads to research findings are discussed, and Section 5 concludes the study with suggestions for future work.

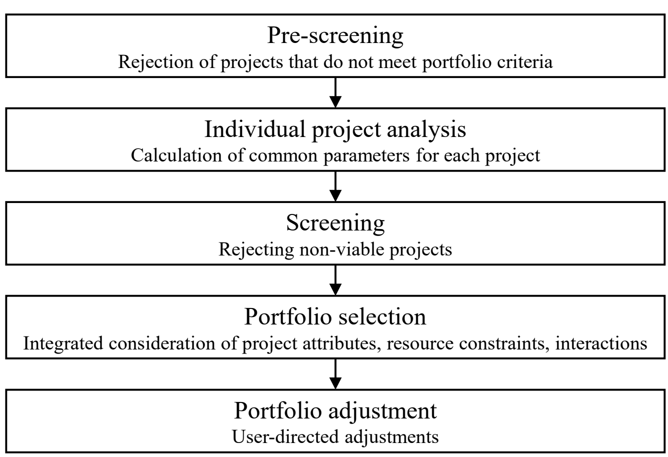
2 Literature review

2.1 Project portfolio management

PPM is a decision making tool that involved selecting project portfolio based on project prioritisation to achieve the organisation's strategies and objectives, given limited resources and other relevant constraints. PPM has gained increasing attention as a dynamic decision process because of several benefits (Cooper et al., 2002; LaBrosse, 2010). Applying PPM in decision making will benefit inefficient use of the limited resources, a powerful elimination of redundant projects, and a strategic alignment to the organisation's objectives. PPM is widely used by several governments, organisations, and private sectors, especially in the process of selecting a set of projects from project proposals (Martinsuo, 2013; Rajegopal et al., 2007; Yu et al., 2008). However, several cases failed to achieve their goals even with the implementation of PPM in their project selection processes, mainly because of a lack of an accurate understanding of the PPM fundamental framework.

The PPM fundamental framework can be summarised into five stages (Archer and Ghasemzadeh, 1999), as shown in Figure 2. Initially, a pre-screening step is done to ensure that the projects in consideration fit at least one of the organisation's goals and objectives. Next, an individual project analysis stage is conducted to evaluate each project individually based on pre-defined criteria. This is a quantitative data preparation for the rest of the selection process. Subsequently, a screening process is done to eliminate projects that do not meet pre-defined criteria to reduce the total number of projects before an actual selection process. In the next stage, a portfolio selection step is implemented. All projects are compared based on the quantitative data calculated in the previous stage using a selected technique to rank the projects by priorities. In the last step, constraints are considered to adjust the selected portfolio to appropriately fit the objectives of the organisation.

Figure 2 PPM fundamental framework



Source: Adapted from Archer and Ghasemzadeh (1999)

2.2 Transport project evaluation

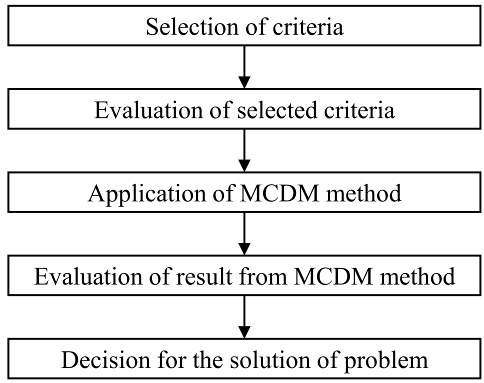
Several techniques have been developed to evaluate transport projects. One of the most common decision making tools is cost-benefit analysis (CBA) (Annema et al., 2017; Jones et al., 2018, 2013) which was also commonly conducted for decision making in transport infrastructure investment (Bhattarai et al., 2020; Chi and Bunker, 2020; Henke et al., 2020; Ustaoglu and Williams, 2020). CBA considers ranges of benefits and costs and expresses them in monetary terms using appropriate financial calculation obtained from actual cost or estimated willingness-to-pay (WTP) (Schutte and Brits, 2013). Then, these benefits and costs can be easily compared to common monetary measures. Examples of the CBA methods include calculation of net present value (NPV), benefits/costs ratio (B/C ratio), and economic internal rate of return (EIRR). However, some inaccuracies were reported in the estimation of NPV and NPV-cost ratio in the CBA of transportation projects because of an under-estimation in traffic levels (Odeck and Kjerkreit, 2019). Also, it has been criticised by transportation system professionals that these conventional methods have limitations in evaluating the transport projects because CBA can only deal with impacts that can be quantified as monetary values. Other concerns, such as social impact, political impact, environmental issues, and other qualitative matters are often difficult to be converted into the monetary terms (Aldian, 2005; Iniestra and Gutiérrez, 2009). Hence, CBA is considered incomplete for the decision making in transport project evaluation. It is required to introduce other qualitative aspects into consideration to justify the inclusiveness of the decision. A process of multi-criteria decision making (MCDM) will allow decision-makers to do so in the transport project evaluation and decision making (Beria et al., 2012; Macharis and Bernardini, 2015; Schutte and Brits, 2013).

2.3 Multi-criteria decision making

MCDM often deals with prioritising alternatives based on multiple conflicting criteria (Behzadian et al., 2010; Taheri-Moghadam et al., 2019a, 2019b). Not only a single criterion, which is normally economic-related, is considered, but also other quantitative criteria, as well as qualitative criteria in social, environmental, and political dimensions, can be taken into account. MCDM is growing rapidly in the field of operational research (OR) and also common to the decision making problems related to the transport planning processes (Jones et al., 2013; Macharis and Bernardini, 2015). The fundamental framework of MCDM process implementation is proposed by Pohekar and Ramachandran (2004). The steps of MCDM can be simply illustrated in Figure 3.

In the criteria selection step, it is important to decide the total number of criteria and their definitions. The number of criteria usually varies from 3 to 25, but it will become extremely complex as the number of criteria increases and it is usually practical that the number of criteria ranges between 7 and 10 (LaBrosse, 2010). Regarding the definitions of criteria, it was suggested that the criteria which are related to economic, environmental, social, technical, and political aspect should be taken into consideration for the transport project evaluation (Jain et al., 2014; Shang et al., 2004; Yedla and Shrestha, 2003). Besides, a set of criteria should be selected based on the availability of related information, the priority of rejecting redundancy, and the importance of inclusiveness.

Figure 3 MCDM process fundamental framework



An economic-related criterion can be chosen from the monetary value of the projects, including project costs and economic return, such as NPV, IRR and B/C ratio. Energy consumption is one of the most straightforward environmental-related criteria which can be readily converted into the monetary term (Joumard and Nicolas, 2010). Social-related criterion, which involves transportation quality, should be included to indicate the quality of connectivity of the system. Accessibility in transportation reflects community quality of life, which is directly related to social benefits. Also, risks from economic, social, and technical problems should be considered as well (Mavi et al., 2018; Shang et al., 2004). Budget overrun is one common example of economic risk. Social risk can be related to problems from negative community feedback. The technology risk will include the assessment of the project implementation complexity. Besides, the time required to implement the projects should be introduced as one of the evaluating criteria.

2.4 Criteria weight determination process

When implementing MCDM, all of the criteria must be considered, but not equally as important. Criteria weights should be assigned to indicate a level of influence each criterion has on the decision making (Aldian, 2005; LaBrosse, 2010; Sadasivuni et al., 2009). Criteria weight determination can be considered as one of the most important processes in the MCDM problem. There are two main approaches to determine criteria weights: objective and subjective approaches. For the objective approach, the criteria weight is derived from available data of each criterion using mathematical models. On the other hand, the subjective approach derives criteria weights based on input from experts and stakeholders. Questionnaires are needed to be carefully designed to ask those experts to state their priorities (Cheung et al., 2002; Geneletti, 2010; Kodikara et al., 2010). Though it is a time-consuming process for the experts, the criteria weights acquired from this approach is generally applied in several MCDM processes for transport project evaluation and other cases (Aldian, 2005; Costa and Correa, 2010; Deluka-Tibljaš et al., 2013; Macharis and Bernardini, 2015). Quantification of the qualitative criteria can be successfully performed based on an extensive stakeholder survey for several fields of application, such as manufacturing systems prioritisation (Gothwal and Raj, 2019), organisational performance assessment (Kaur et al., 2015) and port performance evaluation (Rezaei et al., 2019).

There are several methods for criteria weight calculation based on the stakeholder input and the most common ones are analytic hierarchy process (AHP) and proportion method (Gothwal and Raj, 2018; Kumar et al., 2020). AHP is a tool that widely used in MCDM which is based on three principles: construction of a hierarchy, priority setting, and logical consistency (Gothwal and Raj, 2018; Macharis et al., 2004; Vaidya and Kumar, 2006; Wan and Kang, 1994). However, the proportion method is a consistent and flexible criteria weight determination method that is found more applicable for most cases in developing countries (Aldian, 2005). Both methods are similar in most of the implementation procedures and the difference will be explained as follows. Questionnaires are carefully designed in both methods and the stakeholders are to be asked to state relative priority for each pair of criteria on a scale of importance. The difference between the two methods is the scale of importance that the stakeholders used in the questionnaires. AHP uses Saaty's 1–9 scale of pairwise comparison which is based on psychological observations (Franek and Kresta, 2014; Harker and Vargas, 1987; Saaty, 1988). Proportion method, instead, ranks the relative importance for each pair of the criteria in percentage, such as 50% meaning the two criteria are equally important and 60% meaning the first criteria is moderately more important than the other. Interpreting into percentage allows stakeholders and experts to understand and respond to the questionnaires easier than the Saaty's 1–9 scale (Aldian, 2005).

After the questionnaire responses are collected, the relative importance will be used for the weight calculation. In AHP, eigenvalue problem calculation in matrix form must be solved to obtain criteria weights; whereas proportion method has an advantage in using questionnaire responses directly and the criteria weights can be simply calculated by basic mathematics. Judgement bias and inconsistency are undesirable; therefore, a consistency check process can be implemented using eigenvalue to calculate the consistency. However, only AHP benefits the process of inconsistency check (Macharis et al., 2004).

2.5 PROMETHEE

It was reported that AHP with modifications, including preference ranking organisation method for enrichment evaluations (PROMETHEE), was widely used to solve multi-criteria decision problems in the field of transport (Broniewicz and Ogrodnik, 2020). PROMETHEE is an outranking technique developed by Brans in 1982 and extended by Brans and Vincke in 1985 (Brans and De Smet, 2016; Macharis et al., 2004; Pohekar and Ramachandran, 2004). It is a tool that ranks and selects alternatives among multiple conflicting criteria to find a solution in portfolio problems (Behzadian et al., 2010; Vetschera and De Almeida, 2012). Comparison of strengths and weaknesses of PROMETHEE and AHP were briefly summarised in Macharis et al. (2004). Considering an amount of evaluating alternatives, AHP has a major disadvantage in a large number of pairwise comparisons needed to be completed, while PROMETHEE needs much less input for evaluation. Using the nine-point scale is another important disadvantage of AHP because it cannot handle a wide range of degree of importance between criteria. PROMETHEE can also provide better result visualisation using graphical analysis for interactive aid (GAIA), in addition to numerical results. Moreover, PROMETHEE is much more flexible than AHP, especially when new projects are added into consideration.

PROMETHEE II is a member of the PROMETHEE family. It is an outranking method that derives the full ranking of the alternatives (Athawale et al., 2012; Brans and De Smet, 2016). A structure of PROMETHEE II is fundamentally based on a pairwise comparison of alternatives along with each predefined criterion. Alternatives are systematically evaluated according to those criteria, considering that some are to be maximised and the rest are to be minimised. A preference function in PROMETHEE II translates the difference between the two projects into a unique degree of preference ranging from zero to one. Frequently, the preference function is considered practical for qualitative criteria that have limited levels of evaluation scale, while a linear preference function is the best fitting for quantitative criteria. Without additional constraints, it seems logical to select the projects that are ranked highest in PROMETHEE II. However, it is not always the case that project with the highest rank is the most financially efficient. PROMETHEE V is another member of the PROMETHEE family that was developed to include constraints for alternative or project selection (Brans and De Smet, 2016). It uses net outranking flow from PROMETHEE II as an input for further evaluation.

3 Methodology

Based on the above-mentioned literature survey, Thailand transport project evaluation can be implemented using a combination of PPM and MCDM. In this study, a comprehensive combination of MCDM tools was proposed. A research framework, as shown in Figure 4, includes the complete steps of PPM. As a pre-screening step, a set of available investment projects and investment objectives were identified. The projects that do not align with at least one of the objectives are omitted from the study. In the step of the individual project analysis in PPM, relevant criteria for the decision making in the transport project evaluation were defined and data of each project was calculated for the study. Subsequently, the screening and portfolio selection procedures were conducted in the following steps:

1. weight determination process using proportion method
2. MCDM using PROMETHEE II
3. constraint consideration step using PROMETHEE V, to evaluate, prioritise, and select the appropriate project portfolio.

Each step is thoroughly explained in the following sections.

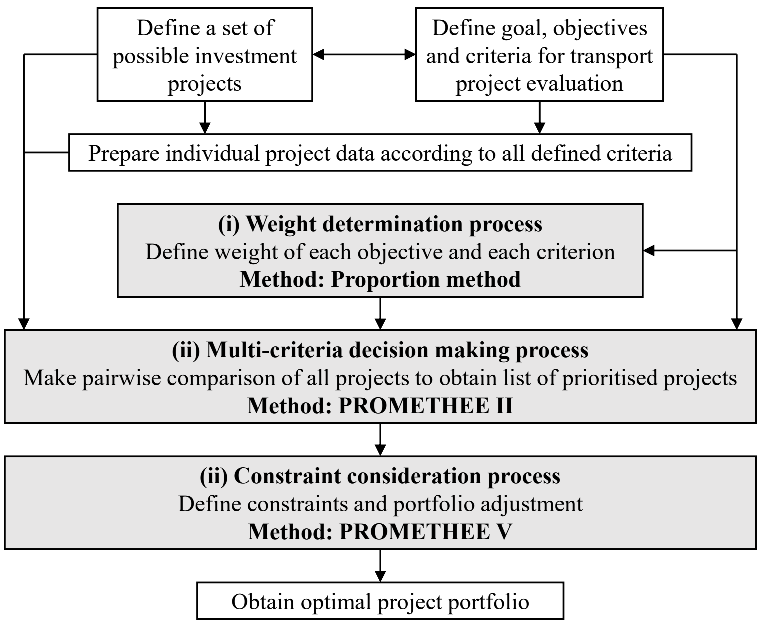
3.1 Weight determination process using proportion method

In this study, the proportion method was implemented in the criteria weight calculation. The questionnaire was designed with questions that ask the respondent to rank the importance of each criterion and make a pairwise comparison for each pair of criteria. Stakeholders, including three experts from the government sector and five experts from the academic sector, were asked to complete the questionnaires before the criteria weights were calculated. In the questionnaire, the pairwise comparison between criteria i and criteria j was evaluated as a proportion, for example, 50% if they are equally meaningful and 60% if i is moderately more meaningful than j. The criteria weights were then calculated using equation (1).

$$w_i = \frac{\sum_{j=1}^{n} a_{ij}}{\left(n \times \left(\frac{n-1}{2}\right)\right)} \quad (1)$$

where w_i is the weight of criterion i, n is the total number of criteria, and a_{ij} is the proportion of criterion i to j from the questionnaire input.

Figure 4 Research framework



3.2 MCDM process using PROMETHEE II

Visual PROMETHEE, a user-interactive software, was used to solve the problem in this study. First, the evaluative differences between each pair of projects were calculated using equation (2). Next, the preference function was applied using equation (3).

$$d_j(a, b) = g_j(a) - g_j(b) \quad (2)$$

$$P_j(a, b) = F_j\left[d_j(a, b)\right] \quad (3)$$

where $d_j(a, b)$ is the deviations of between evaluated performance values of the project a and b on each criterion j, $P_j(a, b)$ is preference value of project a to b, and F_j is the preference function.

Then, a global preference index and positive and negative outranking flow of alternative a can be calculated by equations (4), (5) and (6), respectively. The positive outranking flow indicates how much project a is preferred over the rest of the projects. The larger the positive outranking flow is, the more attractive is the project. On the other hand, the negative outranking flow indicates how much the rest of the projects are preferred over the project *a*. The smaller the negative outranking flow is, the better it is to invest in the project.

$$\pi(a, b) = \sum_{j=1}^{k} P_j(a, b) w_j \tag{4}$$

$$\varnothing^{+}(a) = \sum_{x \in A} \pi(a, x) / (n-1) \tag{5}$$

$$\varnothing^{-}(a) = \sum_{x \in A} \pi(x, a) / (n-1) \tag{6}$$

where $\pi(a, b)$ is the global preference index of the project *a* over *b* for all criteria, w_j is the weight of criterion *j*, and $\varnothing^{+}(a)$ and $\varnothing^{-}(a)$ are the positive and negative outranking flows of the project *a*, respectively.

Finally, a net outranking flow of each project can be derived using equation (7). This net outranking flow is the ultimate indicator in PROMETHEE II that represents the performance and priorities of the projects. The projects that are higher in priority will have higher values of the net outranking flow.

$$\varnothing(a) = \varnothing^{+}(a) - \varnothing^{-}(a) \tag{7}$$

where $\varnothing(a)$ is the net outranking flow of project *a*.

3.3 Constraint consideration process using PROMETHEE V

After the pairwise comparison was implemented by PROMETHEE II, PROMETHEE V considers optimal selection condition and project constraints with zero-to-one linear programming, using equation (8).

$$\text{Max } Z = \sum_{a \in A} \varnothing(a) X_a \tag{8}$$

where *Z* is an indicator of optimal selection, *A* is a set of all projects, X_a is a binary variable of the project *a* and it equals to 1 if the project is selected and 0 otherwise.

Decision making constraints were included in this step. These constraints will be considered along with equation (8) and the optimal selections were suggested in the Visual PROMETHEE software for the investment of Thai transport infrastructure projects.

3.4 Comparison of conventional AHP and proposed method

In the conventional decision making process, the steps of weight determination process and MCDM can also be done simply by AHP. However, in this study, sequential steps of:

1 proportion method

2 PROMETHEE II

3 PROMETHEE V was proposed to evaluate the project performance and suggest the optimal transportation project portfolio, as shown in Figure 4.

To justify the effectiveness of the proposed method, both methods were compared in Table 2. The weight determination in conventional AHP method is more complicated because it involves a complex calculation to solve the eigenvalue problem for an *n* by *n* matrix, while the method proposed in this study simply needs basic arithmetic calculation. Also, no pairwise comparison questions are required to evaluate the projects in the step of decision making which significantly simplifies the step of questionnaire design and survey.

Table 2 Comparison of conventional AHP and proposed methods

	Conventional method	*Proposed method*
Weight calculation	*Complicated* Solve eigenvalue problem with $n \times n$ matrix	*Simple* Solve arithmetic calculation
Number of questions in the questionnaire	*Large* 108 questions for weight determination and 259 questions for project evaluation	*Small* 108 questions for weight determination and no questions for project evaluation

4 Results and discussion

4.1 Data preparation and pre-screening

4.1.1 Objective selection and project pre-screening

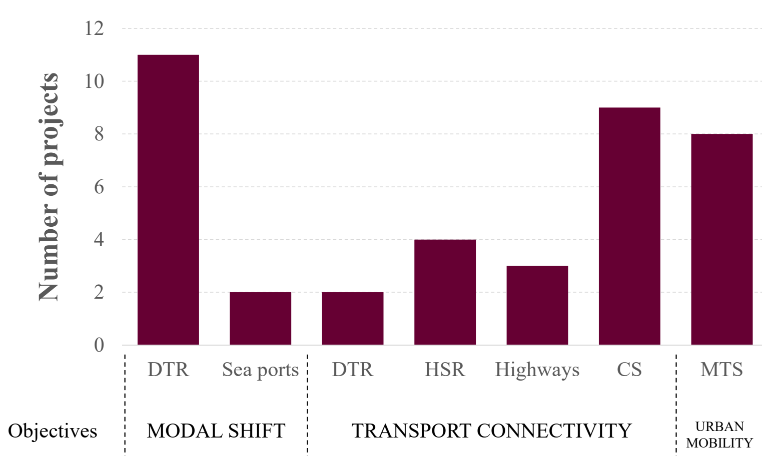
The Ministry of Transport evaluated the projects and selected 53 out of 70 projects that align with at least one of those three objectives mentioned in the introduction:

1 modal shift

2 transport connectivity

3 urban mobility.

Figure 5 Pre-screened projects (see online version for colours)



Among the pre-screened projects, 16 projects focus on the modal shift, 28 projects that promote the transport connectivity, and nine projects that benefit urban mobility. However, due to the limited availability of information for some projects, only 39 projects have sufficient information for the decision making process, which will be considered in this study. Those projects include construction projects of double-track railways (DTR), seaports, high-speed railways (HSR), highways, cross-border stations (CS) and mass transit systems (MTS), as shown in Figure 5.

4.1.2 Criteria selection

Nine criteria were carefully selected to include the aspects of economic, environmental, social, technical and political impacts. The first eight criteria are:

1. project cost
2. project duration
3. EIRR
4. energy cost reduction
5. technology risk
6. operational risk
7. community risk
8. financial risk.

The ninth criterion is different between each group of projects. Logistics cost reduction, level of connectivity, and commuting time reduction was designed for the projects on modal shift, the projects on connectivity, and the projects on urban mobility, respectively. Definitions of the criteria are listed in Table 3.

Based on the available project information, most of the criteria can be evaluated, except the energy cost reduction, the logistics cost reduction, the quality of connectivity, and the commuting time reduction. These four criteria have to be evaluated based on theoretical assumptions and opinions from the experts in the questionnaires. The energy costs can be calculated by equation (9) for passenger commuting trips and equation (10) for freight transportation trips. The total energy costs were calculated based on the estimated number of passengers, freight volume, and travel distance. For each project, the energy cost reduction was then evaluated by the difference between the total energy costs before and after the project implementation.

$$\textit{Energy cost}\ (\text{USD/person}\cdot\text{km}) = \frac{\textit{Energy cost}\ (\text{USD/MJ}) \times \textit{Energy consumption rate}\ (\text{MJ/km})}{\textit{Number of estimated passengers}\ (\text{person})} \tag{9}$$

$$\textit{Energy cost}\ (\text{USD/ton}\cdot\text{km}) = \frac{\textit{Energy cost}\ (\text{USD/MJ}) \times \textit{Energy consumption rate}\ (\text{MJ/km})}{\textit{Estimated freight}\ (\text{ton})} \tag{10}$$

Table 3 Descriptions of criteria for transport project evaluation

No.	*Criteria*	*Type*	*Description*	*Unit*	*Preference*
1	Project costs	Quantitative	Financial investment	USD	Min.
2	Project duration	Quantitative	Time required to complete the project	Year	Min.
3	EIRR	Quantitative	Economic internal rate of return	%	Max.
4	Energy cost reduction	Quantitative	Reduction in monetary value of energy consumption rate (MJ/person·km or MJ/ton·km)	USD/year	Max.
5	Technology risk	Qualitative	Uncertainty in technical aspects	Score 1–3	Min. risk (max. score)
6	Operational risk	Qualitative	Administrative bottlenecks	Score 1–3	Min. risk (max. score)
7	Community risk	Qualitative	Risks of resistance from local communities and NGOs	Score 1–3	Min. risk (max. score)
8	Financial risk	Qualitative	Uncertainty in ownership and financial structure	Score 1–3	Min. risk (max. score)
9	Logistics cost reduction	Quantitative	Reduction in freight cost by roadways and railways	USD/year	Max.
9	Level of connectivity	Qualitative	These criteria include: • Connectivity within country • Connectivity within the region • Location in AEC	Score 1–3	Max.
10	Commuting time reduction	Quantitative	Reduction in commuting time by MRT instead of car	Minute	Max.

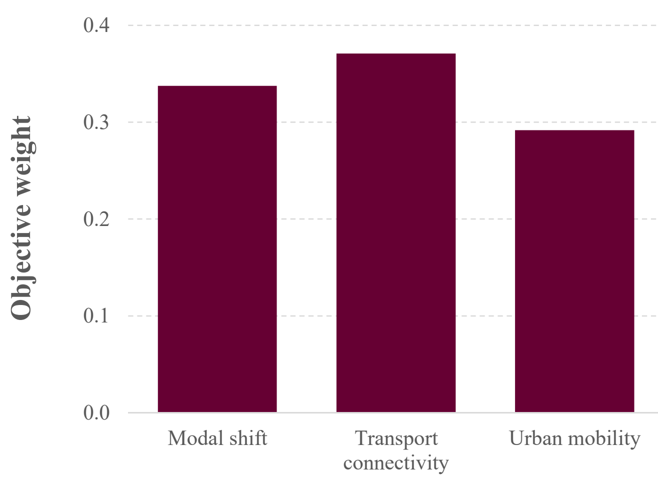
The logistics cost reduction and the commuting time reduction can be calculated based on average speeds, predicted freight volume and costs provided by the Office of Transport and Traffic Policy and Planning. The criteria relate to the risks were previously assessed by Sathirathai (2013). The data from the report was used in this study with the scoring of 1 to 3 (1 being high and 3 being low.)

This research shows how the combination of methods was used in the process of project portfolio selection for the transport project investment. After the projects were pre-screened and selected by the Ministry of Transport, the criteria were identified for project evaluation. In this section, the proportion method was implemented to prioritise the criteria based on the pairwise comparison. The criteria weights and the list of pre-screened projects were entered in the Visual PROMETHEE software to implement PROMETHEE II and PROMETHEE V for the MCDM and constraint consideration process, respectively. This section concludes with results that can assist the policymakers to systematically assess and select the projects based on the multi-criteria information.

4.2 Objective and criteria weight determination

All objectives and criteria were included in the weight determination process using the proportion method. Questionnaire responses were used in the calculation to prioritise the objectives and criteria based on the experts' subjective judgements. The weights are shown in Figure 6 and Table 4 to Table 6. Based on the calculated criteria weights, the weights that are related to financial measures, the project cost, EIRR, and financial risk, are always one of the most important criteria. The ninth weight, which was specifically assigned to each group of projects, is also ranked among the top ones.

Figure 6 Objective weights for Thai transport project evaluation (see online version for colours)



4.3 MCDM process

The project information, the list of criteria, the criteria weights, and the preference functions were entered into the Visual PROMETHEE software and the net outranking flows were calculated as shown in Figure 5 to Figure 7. The projects in each group were listed by the value of their net outranking flows (∅). Projects with a higher value of ∅ will be higher in ranks.

Table 4 Criteria weight for projects on modal shift

	Criteria	*Weight*
1	Project cost	0.1347
2	Project duration	0.1038
3	EIRR	0.1278
4	Energy cost reduction	0.1132
5	Technology risk	0.0913
6	Operational risk	0.1017
7	Community risk	0.0938
8	Financial risk	0.1049
9	Logistics cost reduction	0.1288

Table 5 Criteria weight for projects on transport connectivity

	Criteria	*Weight*
1	Project cost	0.1333
2	Project duration	0.1063
3	EIRR	0.1278
4	Energy cost reduction	0.0927
5	Technology risk	0.1000
6	Operational risk	0.0920
7	Community risk	0.0979
8	Financial risk	0.1226
9	Level of connectivity	0.1274

Table 6 Criteria weight for projects on urban mobility

	Criteria	*Weight*
1	Project cost	0.1247
2	Project duration	0.1035
3	EIRR	0.1299
4	Energy cost reduction	0.1160
5	Technology risk	0.0844
6	Operational risk	0.0948
7	Community risk	0.0885
8	Financial risk	0.1205
9	Commuting time reduction	0.1378

Among the projects on modal shift, two projects on deep-sea ports were ranked as the most important ones, while the rest of the projects are double-track rail network construction that covers most parts of the country. Considering the projects on transport connectivity, the ones proposed for custom stations have a positive value of ∅.

Construction projects for motorways are among the lower-ranking projects and the high-speed rail construction projects were the one with the lowest priorities. Those MRT projects for urban mobility objectives were also ranked by ∅.

Figure 7 Ranks of projects on modal shift (see online version for colours)

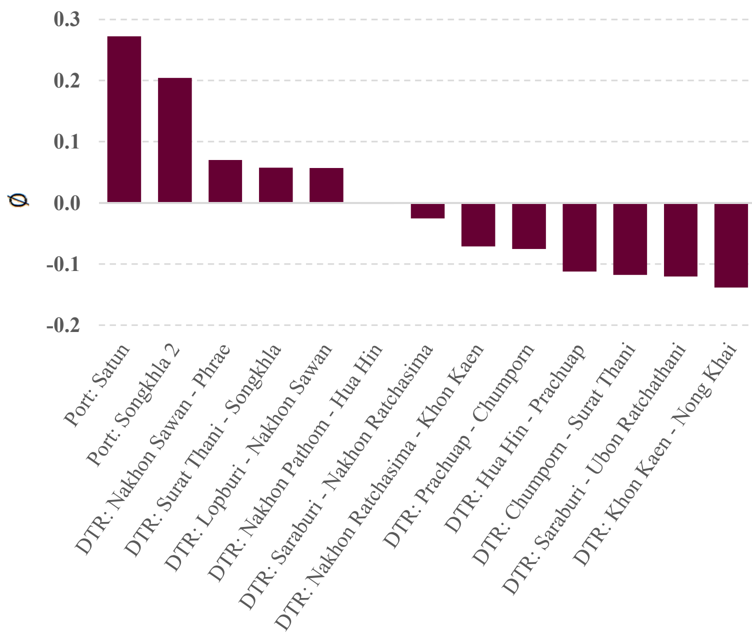


Figure 8 Ranks of projects on transport connectivity (see online version for colours)

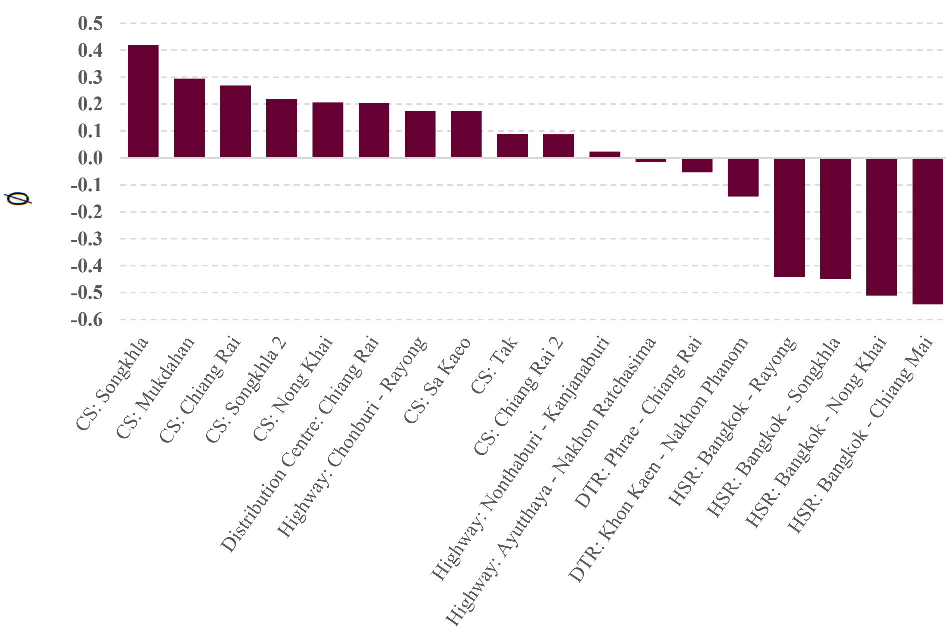
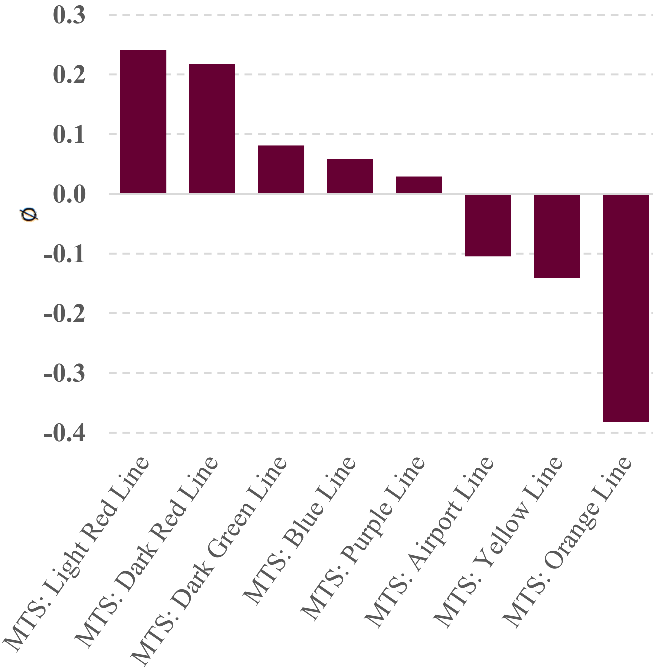


Figure 9 Ranks of projects on urban mobility (see online version for colours)



4.4 Constraints consideration process

In the last step of this study, the constraint consideration process was systematically conducted. Fundamentally, three constraints were selected:

1. Meeting budget limit: An investment for each project group must be less than or equal to the objective weight times the allocated budget.
2. Satisfying basic objectives: All of the predefined objectives must be satisfied by the combination of the projects in the optimal portfolio.
3. Including mandatory projects: All of the mandatory projects which were defined by the Thai Government, listed in Table 7, must be included in the optimal portfolio.

Under the constraint of budget limit, the amount of total investment should not exceed the standard national budget allocated for the development of the transport infrastructure. In this case, the total budget equals to the accumulating budget of seven consecutive years. The total budget was then allocated to each group of projects based on their objective weights in Figure 6 and the calculation is shown in equation (11)

$$\textit{Group budget} \le \textit{Objective weight} \times \textit{seven year budget} \tag{11}$$

In PROMETHEE V, four scenarios were setup with different combinations of constraints, as shown in Table 8, and the optimal project portfolios were suggested as shown in Table 9.

Table 7 List of mandatory projects

Projects on modal shift	DTR: Lopburi – Nakhon Sawan
	DTR: Nakhon Pathom – Hua Hin
	DTR: Saraburi – Nakhon Ratchasima
	DTR: Nakhon Ratchasima – Khon Kaen
	DTR: Prachuap – Chumporn
Projects on transport connectivity	Distribution centre: Chiang Rai
	Highway: Chonburi – Rayong
	DTR: Phrae – Chiang Rai
Projects on urban mobility	MTS: dark green line
	MTS: blue line
	MTS: purple line

Table 8 Combination of constraints in each scenario

Scenario	*Constraint 1: meeting budget limit*	*Constraint 2: satisfying all objectives*	*Constraint 3: including mandatory projects*
1	✓	✓	✓
2	✓	✓	
3	✓		✓
4		✓	✓

Table 9 Optimal project portfolio suggested by PROMETHEE V

Scenario	*Projects on modal shift*	*Projects on transport connectivity*	*Projects on urban mobility*
1 26 projects	9 projects Project with ranks 1, 2, 3, 4, 5, 6, 7, 8 9	12 projects Projects with ranks 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 13	5 projects Projects with ranks 1, 2, 3, 4, 5
2 21 projects	5 projects Project with ranks 1, 2, 3, 4, 5	11 projects Projects with ranks 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11	5 projects Projects with ranks 1, 2, 3, 4, 5
3 26 projects	9 projects Project with ranks 1, 2, 3, 4, 5, 6, 7, 8, 9	12 projects Projects with ranks 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 13	5 projects Projects with ranks 1, 2, 3, 4, 5
4 26 projects	9 projects Project with ranks 1, 2, 3, 4, 5, 6, 7, 8, 9	12 projects Projects with ranks 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 13	5 projects Projects with ranks 1, 2, 3, 4, 5

4.5 Optimal project portfolio

It was found that most of the projects that were selected in the project portfolio, according to the optimal selection in PROMETHEE V, were the ones with positive values of ∅. Scenarios 1 and 4 had the same combination on projects selected regardless of the budget limit constraint. This is evidence that ∅ in PROMETHEE II project evaluation with multiple criteria has already considered an efficiency in budget utilisation. However, when excluding the constraint of mandatory projects in Scenario 2, the decision making process eliminated projects with the negative value of ∅. It can be concluded this constraint has a high influence on the decision making in this study and the list of the mandatory projects is needed to be carefully selected.

Table 10 Proposed project portfolio for Scenarios 1, 3 and 4

Objective	*Rank*	*Description*
Modal shift	1	Port: Satun
	2	Port: Songkhla 2
	3	DTR: Nakhon Sawan – Phrae
	4	DTR: Surat Thani – Songkhla
	5	DTR: Lopburi – Nakhon Sawan
	6	DTR: Nakhon Pathom – Hua Hin
	7	DTR: Saraburi – Nakhon Ratchasima
	8	DTR: Nakhon Ratchasima – Khon Kaen
	9	DTR: Prachuap – Chumporn
Transport connectivity	1	CS: Songkhla
	2	CS: Mukdahan
	3	CS: Chiang Rai
	4	CS: Songkhla 2
	5	CS: Nong Khai
	6	Distribution centre: Chiang Rai
	7	Highway: Chonburi – Rayong
	8	CS: Sa Kaeo
	9	CS: Tak
	10	CS: Chiang Rai 2
	11	Highway: Nonthaburi – Kanjanaburi
Urban mobility	1	MTS: light red line
	2	MTS: dark red line
	3	MTS: dark green line
	4	MTS: blue line
	5	MTS: purple line

Table 10 shows a detailed list of proposed project portfolio under Scenarios 1, 3 and 4 which included the constraint of mandatory projects. The mandatory projects on modal shift are the double-track rail network projects which were selected by the State Railway of Thailand. The decision was made based on station locations, routes, capacities and logistics. There is also one motorway project included which is constructed to connect Chonburi and Mabtapud. This project is requested to be a mandatory project by the Department of Highway because it connects the most important industrial areas in Thailand. Other two mandatory projects are the double-track rail network in the northern part of Thailand from Denchai to Chiang Kong and construction of Chiang Kong distribution centre. These two projects are considered mandatory because they can efficiently connect Thailand to Laos which is one of the most attractive partners. For the projects on urban mobility, those mandatory projects were selected because they were undergoing projects.

The suggested set of optimal project portfolio reflects the needs of the country to improve its transport infrastructure to satisfy all three objectives. Technically, improving transport connectivity and infrastructure is the key goal in transport strategies for Thailand, which was also suggested by Bakker et al. (2017). It was also reported that the Thai Government should consider not only freight transport but also passenger services when investing in a large-scale integrative rail master plan (Peetawan and Suthiwartnarueput, 2018). Eventually, the investment will benefits in capacity building in the transport infrastructure for country's long-term competitiveness as it was suggested that there was a strong relationship between economic growth and transport infrastructure development (Skorobogatova and Kuzmina-Merlino, 2017). Government investment in upgrading the network of railway transportation was found to be useful in promoting long-run economic growth in the country (Sungkaew et al., 2018). Currently, some of the suggested projects are being implemented. For example, the double-track rail networks for the modal shift with the rank of 5 to 10 are under construction and expected to be completed by 2023. To monitor and assess the proposed project portfolio, the ongoing transport infrastructure development performance can be evaluated by the global competitiveness index (GCI) and the logistics performance index (LPI) in future work (Limcharoen et al., 2017; Skorobogatova and Kuzmina-Merlino, 2017). The indices will eventually contribute to an improvement of the world ranking of transport infrastructure in Thailand.

5 Conclusions

Transport project selection generally involves a complex decision making process with a wide range of alternatives. Given that the transport infrastructure in Thailand is considered inadequate and inefficient, the Thai Government must initiate a large-scale investment to improve the quality of overall transport infrastructure. Those initiatives were based on three objectives: modal shift, transport connectivity and urban mobility. This study addressed a concern that Thai Government needs to strategically evaluate and select a set of projects to invest in and the study can contribute to filling the lack of the comprehensive investigation to support Thai Government decision in future transport infrastructure investment. The PPM was proposed because it allows the policymakers to decide on a project portfolio investment. PPM can effectively deal with critical decision making that involves limited resources and the large number of project to implement. A process of MCDM, one of the most common appraisal tools in transport policymaking, was used to prioritise alternatives based on multiple conflicting criteria. The transport infrastructure projects were pre-screened by the Ministry of Transport based on the predefined objectives. The criteria were selected to include the aspects of economic, environmental, social, technical and political impacts.

A combination of methods, introduced in this study, consists of:

1 the weight determination process using proportion method

2 the MCDM process using PROMETHEE II

3 the consideration of the constraints process using PROMETHEE V.

The weight determination process was considered a formal procedure to identify the importance of each objective and criterion. The proportion method was implemented to assign the criteria weights based on the questionnaire input from the stakeholders. The PROMETHEE II method was used to derive the full ranking of the projects based on a pairwise comparison of the projects in each criterion. The preference function in PROMETHEE II translated the difference in the performance of a pair of projects into a preference degree with a value that ranges from zero to one, called net outranking flows (∅). Projects with a higher value of ∅ were considered more attractive for investors. PROMETHEE V was used to consider the effects of constraints for the project selection. Those constraints were:

1 meeting budget limit

2 satisfying all objectives

3 including mandatory projects.

Four scenarios were setup with different combinations of constraints and the optimal project portfolios were suggested using Visual PROMETHEE software.

It was found that the carefully selected criteria and method were suitable and adequate because ∅ could perfectly reflect the overall attractiveness of the projects. The scenarios proposed investment in the projects with a positive value of ∅ and the budget constraint was satisfied even though it was not included in the scenario. The mandatory projects had a strong influence on the portfolio selection and resulted in a portfolio that consisted of the projects with a negative value of ∅. It can be concluded that the proposed steps of decision making were appropriate to comprehensively evaluate and select the alternatives. The advantages of the proposed methodology emphasise the simple calculation procedure in the step of weight determination. The transport infrastructure projects can be assessed based on the multi-criteria evaluation with a relatively smaller amount of questionnaire input from the experts. The project portfolio can successfully suggest an optimal set of projects to be implemented under the predetermined constraints. Limitations of the study include the lack of available project confidential information and the drawbacks of the methodology, i.e., the lack of the consistency check procedure and the lengthy calculation time in the step of criteria data evaluation. However, the advantages of this methodology outweigh its disadvantages. The results also agree with previous studies that encouraged the development of transport connectivity and infrastructure for the long-run economic growth. In short, the proposed combination of methods shows a great potential to support and provide information for the Thai Government to make an effective investment decision which can be extended to other types of investment. The future work of this research can also include a monitoring process and a revision of the decision making steps that are based on the progress of the on-going project performance evaluated by the GCI and the LPI.

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