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Quantifying Impact Factors of Sustainable Road Planning in Taiwan

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Abstract: This research aims to identify both cost and benefit impact factors using quantitative techniques, and then to determine their corresponding weights for sustainable road engineering projects. The impact factors were initially gathered from literature review and expert interviews, resulting in a total of 10 factors for questionnaire development. A 5-scale Likert questionnaire was accordingly developed for a survey. Of the 120 questionnaires distributed to randomly selected practitioners in the Taiwan construction industry, 54 were returned for fulfillment of the statistical criteria. A reliability test was employed to examine sampling adequacy in the beginning stage of data analysis. Factor analysis was used to identify the impact factors. The weight of each factor was determined using principle component analysis combined with orthogonal rotation. The analysis shows nine factors categorized into three components of the cost aspect and six factors categorized into two components of the benefit aspect. Of both cost and benefit aspects, the "construction" component has the highest weights but contains slightly different factors. This indicates that the practical cost of using designs beneficial for sustainable road engineering may be high. Focusing on environmental concerns may be costly and provide limited benefits to the public.

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Key words*: Construction management; Factor analysis; Survey; Sustainable road planning.*

Introduction

Sustainable construction for road engineering has been a concern since the late 20th century. Sustainability has also become one of the most important issues for road engineering when environmental protection must be considered. In the past, roadway costs were the main concern. Examples can be seen in road projects awarded using the lowest bid method and budgeting in related public sectors. They mainly focus on economic costs and funding availability to determine its practicability. Under the lowest bidding process, cost is the only criterion to choose contractors for all phases of a project. Currently, over 80% of road projects in Taiwan are performed under such a circumstance. This focus on cost may provide equality for bidders, but may disregard environmental impact to a society. As a result, it is suggested that seeking solutions beyond the cheapest short term options can create environmental benefits for the public [1]. In other words, the effort to achieve such goals may be costly and not economically beneficial to engineering practitioners. Petkovic et al. (2004) stated that the abundance of high quality and low cost natural materials is considered to lower environmental impact [2]. Although quantifying the impact of the cost and benefit aspects may provide constructive suggestions for sustainable road projects, it is difficult to quantify the impact through project lifecycle time due to the variety of road types [3]. Given that the design and planning phase for all types of construction projects is the most critical throughout their project lifetime, quantifying such impact for road projects should be performed. However, how to rank and quantify the impact is still an intricate and subjective issue.

The purpose of this research was to identify the impact factors (both cost and benefit aspects) using quantitative techniques, and to determine their corresponding weights for sustainable road projects. Although the research starts with the concept of project lifecycle time, its scope only lies in the impact on sustainable road projects (either costs or benefits) based on the planning stage. Constructability, usability, operability, and maintainability of road projects are regarded as givens that fully meet general requirements in this research. The quantitative techniques adopted in this study were utilized to measure the impact based on the supposition that factors can affect both cost and benefit aspects, but that these effects are not necessarily equal. The next section states that quantification of impact factors begins with factor identification after literature review, followed by confirmation based on expert interviews. The third section shows that questionnaires are accordingly developed and distributed to experienced researchers, officials, and practitioners. The remaining sections discuss that the impact factors and their corresponding weights are determined through the use of factor analysis, and then conclude the research with findings.

Sustainable Road Engineering

The Taiwan government has taken steps to respond to the trend of sustainability since the 1990s, implementing numerous policies and strategies to ensure sustainable development in the national domain. For example, an official report has been published suggesting planning and design guidelines for sustainable roads [4]. Such guidelines present 10 viewpoints with which designers should be concerned in terms of cost and benefit aspects: urban planning, facility design, route selection, environment impact, road configuration, exclusive path setting, transit, society impact, alternative route, and interface structure. Other studies in the literature discussed numerous aspects for sustainable road engineering, detailing strategies to increase the acceptance and

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sustainability of regulations by maximizing the potential benefits and minimizing negative impact [5]. Studies suggested four factors that influence road pavement: permeable pavement, osmosis pavement, pavement retention, and slope design [3, 6, 7]. Furthermore, four factors regarding a green environment were summarized in three studies [8-10]. They are plant covering rate, native species, carbon sequestration, and stepping stone setting. For all other factors in relation to sustainable road design, Thenoux et al. compared energy consumption for different forms of pavement rehabilitation. They provided a framework for energy saving that could be applied to road construction [11]. A model was created for the prediction of long-term leaching of contaminants during road construction based on waste management [12]. Intelligent transport systems have also been developed for sustainable road construction. Adopting such systems in the design phase might save on maintenance costs in the operating phase [13, 14]. In addition, an analysis showed there were significant travel-time benefits to passengers [15]. Numerous studies pointed out that attributes based on eco-considerations need to be considered in the planning stage of road construction projects [16-22]. A total of 37 initial impact factors are obtained from the literature review and are shown on the left hand side of Fig. 1.

Survey and Data Analysis

Expertise gained from interviews was adopted to examine the applicability of the factors listed on the left hand side of Fig. 1. This study targeted road engineering professionals, with over 10 years of practical experience, or 5 year experience in academia. As a result, there could be hundreds of professionals in Taiwan. Starting with large-sized companies and government agencies, we randomly selected experts and performed interviews one by one. A total of 16 experts were randomly interrogated, and their feedback was used to modify and restructure the factors. These 16 experts have similar backgrounds. For example, five or more experts have work experience for road engineering and serve in public sectors currently. Before his or her interview each interviewee received either by email or mail the initial summary of factors shown on the left hand side of Fig. 1. Given that the aspects of cost and benefit sharing for the same sets of factors are feasible, each interview was recorded and took at least one hour, depending on availability of the interviewee. Samples of interview questions can be briefly summarized as follows: “Would these factors be classified?”, “If yes, please classify them in the most proper way based on your experience”, and If no, please specify your comments.” What experts suggests is to re-group these 37 factors based on their characteristics. In other words, these 10 terms chosen according to experts are representative of the original 37 factors. The difference between these 37 and 10 factors can be ignored or insignificant. For example, the box on the upper left corner contains four factors (permeable pavement, osmosis pavement, pavement retention, and slope design), and their matching term is pavement configuration. Experts suggest that pavement configuration conclude the meanings and also be represented. “Pavement configuration,” therefore, involves the first four attributes directly related to pavement design. Similarly, the term green environment represents activities directly in relation to project

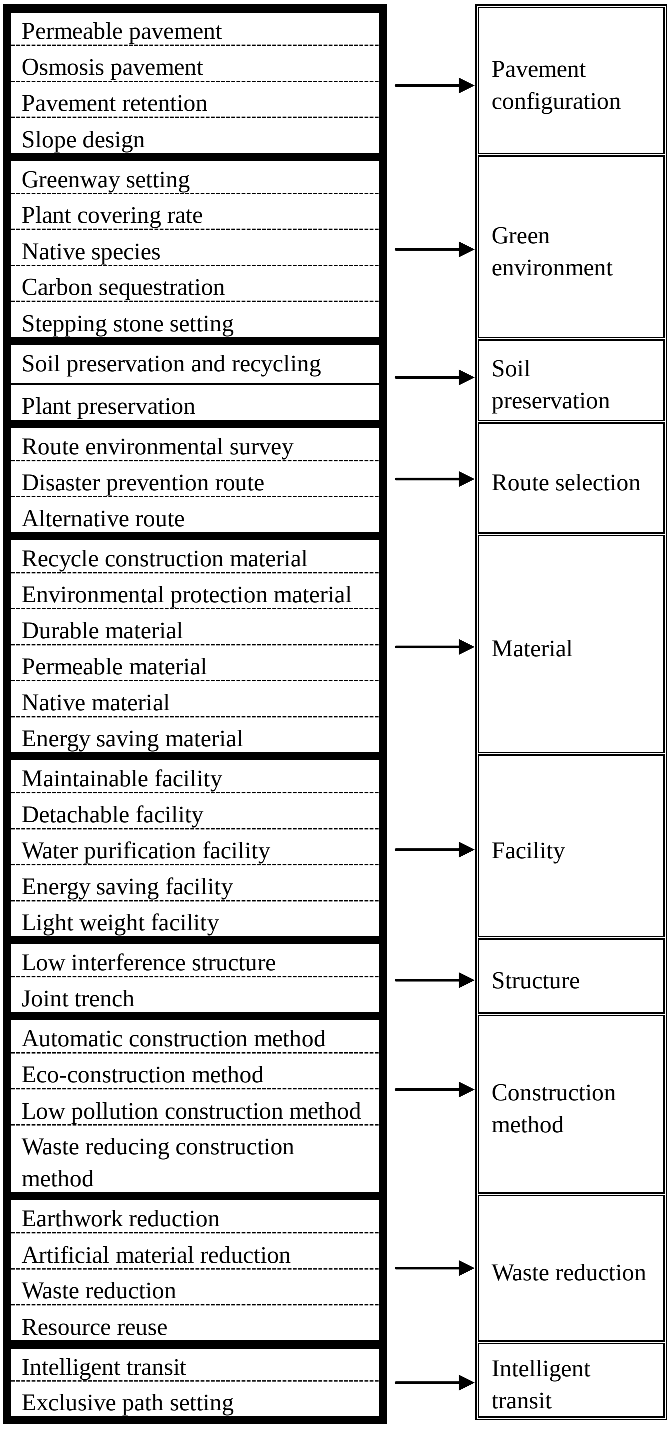

Fig. 1. Introduction of Impact Factors for Sustainable Roads

surroundings. “Green environment” is composed of greenway setting, plant covering rate, native species, carbon sequestration, and stepping stone setting according to the standards of environmental protection. The factors are introduced in Fig. 1, including pavement configuration, green environment, soil reservation, route selection, material, facility, structure, construction method, waste reduction, and intelligent transit.

A questionnaire was developed using these 10 factors listed in the right hand side of Fig. 1 as the stems. The questionnaire was designed using the widely accepted Likert 5-scale measurement and

Table 1. Questionnaire Sample.

If Applying the Sustainable Concept Into the Planning and Design Phase of Road Engineering, What is the Impact Level in Terms of Considering Cost and Benefit Aspects for each Following Factor?

Factor No.	Factor Name	Cost Impact Level					Benefit Impact level				
		1	2	3	4	5	1	2	3	4	5
1	Pavement Configuration	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
2	Green Environment	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
3	Soil Preservation	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
4	Route Selection	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
5	Material	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
6	Facility	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
7	Structure	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
8	Construction Method	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
9	Waste Reduction	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
10	Intelligent Transit	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

is shown in Table 1. Since the standard scheme for sustainable road planning and design has been in existence for less than a decade [4], it is difficult to find a large number of professionals experienced in relation to sustainable road development. The survey is aimed at practitioners with 3 or more years of experience regarding sustainable roads, or 10 or more years of experience regarding regular road engineering. An effective sample size for a survey is suggested to be greater than 200 returned questionnaires or greater than the number of stems multiplied by five [23-25]. Thus, 50 or more effective questionnaire responses are required. With random selection from either public or private sectors, 80 questionnaires were initially distributed. Unfortunately, the threshold of 50 effective questionnaire responses was not met in the first round of distribution. A second round of 40 questionnaires was then distributed to meet the minimum requirement. Within two months, a total of 54 questionnaires were returned.

The basic information of the respondents is duplicated, as shown in Fig. 2. Respondents from academic institutes and public sectors make up the majority at 82%, which may show that practitioners serving in private companies are less likely to respond to questionnaires. They could have gained enough experience from past cases, but might simply be too busy to respond. Even though the majority of the respondents have fewer than 10 years' experience, 56% of respondents did have work experience of over 10 years. These professionals are most likely to be section chiefs or division heads, as can be observed by looking at "position title" for the pie chart in Fig. 2.

Factor Analysis

Reliability analysis was first performed to examine if the returned questionnaires are valid. It is generally accepted that any Cronbach's α value greater than 0.7 indicates a high level of reliability, and that a value of less than 0.3 is a sign of low reliability. The Cronbach's α values are all between 0.6 and 0.8, representing a medium to high level of reliability. Although the survey is reliable, it is necessary to examine its appropriateness before using factor analysis; therefore, Kaier-Meyer-Olkin (KMO) was adopted to measure sampling adequacy (MSA). The KMO values always fall in the range from 0 to 1, where 1 stands for complete sampling adequacy and 0 means the opposite. Kaier suggests that the total KMO be equal to or greater than 0.6 for factor analysis. The overall KMO values for both cost and benefit aspects are all greater than 0.6 (Table 2), which indicates appropriateness for conducting factor analysis. The thresholds suggested by Chen and Hsu in their work are used [25]. Tables 3 and 4 demonstrate the results for the cost and benefit aspects of the factors, respectively.

Feature reduction was conducted next based on the suggested thresholds. Tables 3 and 4 show the results for the eight statistical tests carried out for feature reduction: missing value, mean, standard deviation, skewness, t-testing, correlation coefficients, factor loading, and MSA. Any factor with over two test results out of the threshold ranges was removed [25]. Factor No. 3, soil preservation of the cost aspect, was suggested to be removed. Factor Nos. 2, 3, and 4 (green environment, soil preservation, and route selection) of the benefit aspect could be deleted. As a result, there are 9 and 7 factors remaining in the cost and benefit aspects, respectively. They are pavement configuration, green environment, route selection, material, facility, structure, construction method, waste reduction, and intelligent transit of the cost aspect; pavement configuration, material facility, structure, construction method, waste reduction,

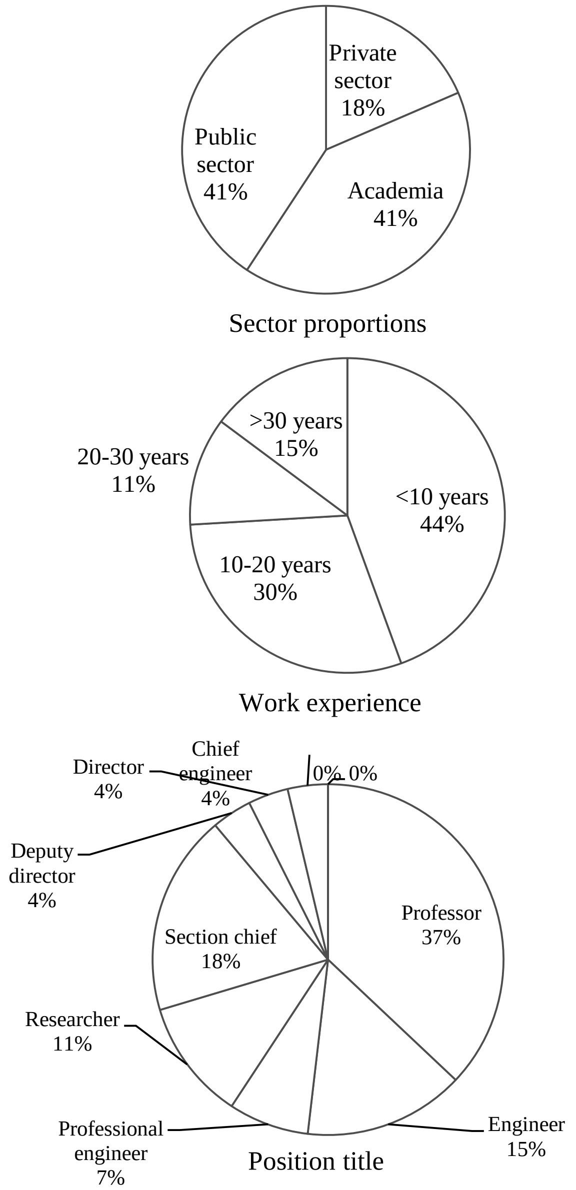

Fig. 2. Basic Analysis for Interviewees.

Table 2. KMO Measure and Bartlett's Test.

Aspect	Test Name		Value
Cost	KMO Measure		0.612
	Bartlett's Test		
		Chi-square Distribution	104.361
		Degrees of Freedom	45.000
		Significance	0.000
Benefit	KMO Measure		0.655
	Bartlett's Test		
		Chi-square Distribution	103.495
		Degrees of Freedom	45.000
		Significance	0.000

and intelligent transit of the benefit aspect.

Factor extraction was then utilized to divide the factors into a few sets. The results, according to the threshold for the eigen value > 1, appear in scree plots in Figs. 3 and 4. It can be seen that the factors of the cost and benefit aspects can be classified into 3 and 2 groups, respectively. The weight of each factor is determined using principal component analysis combined with orthogonal rotation, as shown Tables 5 and 6. Factor facility for the benefit aspect was subject to deletion because the threshold > 0.5 [25]. There were three components obtained for the cost aspect based on transformation convergence: planning, construction, and facility. For the benefit aspect, the two components were named construction and planning.

Discussion

The results obtained from the principal component analysis depict the essentials for sustainable road engineering. The considerations for the cost aspect lie in three components of planning, construction, and facility. The construction component has the largest weight at 40.81%, which suggests that practitioners should pay the most attention to the three factors of waste reduction, material, and green environment. This implies that lifecycle costs may be raised as a result of lack of consideration on how to handle waste, how to select proper material, and how to protect the surrounding environment. The Planning component has a weight of 35.34%, and it is agreed

Table 3. Test Results for Cost Aspect.

Factor	Missing Value	Mean	Standard Deviation	Skewness	t-test	Correlation Coefficient	Factor Loading	MSA	Cronbach's α
Pavement Configuration	0.00	3.33	0.85	-0.323	0.002	0.384	0.686	**0.691**	0.688
Green Environment	0.00	3.17	0.80	0.156	0.004	0.375	0.690	**0.554**	0.689
Soil Preservation	0.00	3.02	**0.71**	-0.351	0.032	**0.246**	0.853	**0.472**	0.709
Route Selection	0.00	3.15	0.83	0.320	0.003	0.365	0.809	**0.536**	0.691
Material	0.00	3.33	**0.70**	-0.570	0.044	0.301	0.594	**0.510**	0.701
Facility	0.00	3.57	**0.69**	-0.276	0.015	0.399	0.639	0.738	0.687
Structure	0.00	3.46	0.91	-0.282	0	0.455	0.653	**0.648**	0.675
Construction Method	0.00	3.61	0.79	-0.382	0	0.475	0.572	0.737	0.673
Waste Reduction	0.00	3.06	0.90	0.212	0.029	**0.271**	0.583	**0.478**	0.709
Intelligent Transit	0.00	3.69	0.91	-0.422	0	0.442	0.618	0.730	0.677
Thresholds	0	2.13~ 4.55	>0.75	-0.7~0.7	＜0.05	＞0.3	＞0.3	＞0.7	≦0.712

Table 4. Test Results for Benefit Aspect.

Factor	Missing Value	Mean	Standard Deviation	Skewness	t-test	Correlation Coefficient	Factor Loading	MSA	Cronbach's α
Pavement Configuration	0.00	3.69	**0.67**	0.461	0.000	0.548	0.635	0.796	0.612
Green Environment	0.00	3.85	**0.68**	-0.538	0.046	**0.047**	0.751	**0.386**	0.705
Soil Preservation	0.00	3.78	**0.60**	**-0.935**	0.005	**0.219**	0.740	**0.567**	0.673
Route Selection	0.00	4.07	**0.70**	-0.449	**0.401**	**0.070**	0.626	**0.463**	0.702
Material	0.00	3.83	**0.72**	-0.682	0.000	0.586	0.751	**0.654**	0.601
Facility	0.00	3.80	**0.74**	-0.244	0.001	0.360	0.499	**0.694**	0.649
Structure	0.00	4.00	**0.61**	0.000	0.000	0.347	0.754	**0.614**	0.652
Construction Method	0.00	3.74	**0.71**	-0.589	0.001	0.379	0.653	**0.659**	0.645
Waste Reduction	0.00	3.80	**0.59**	-0.473	0.004	0.366	0.471	0.727	0.649
Intelligent Transit	0.00	4.13	0.78	-0.482	0.000	0.494	0.713	**0.635**	0.619
Thresholds	0	2.849~ 4.889	>0.75	-0.7~0.7	＜0.05	＞0.3	＞0.3	＞0.7	≦0.677

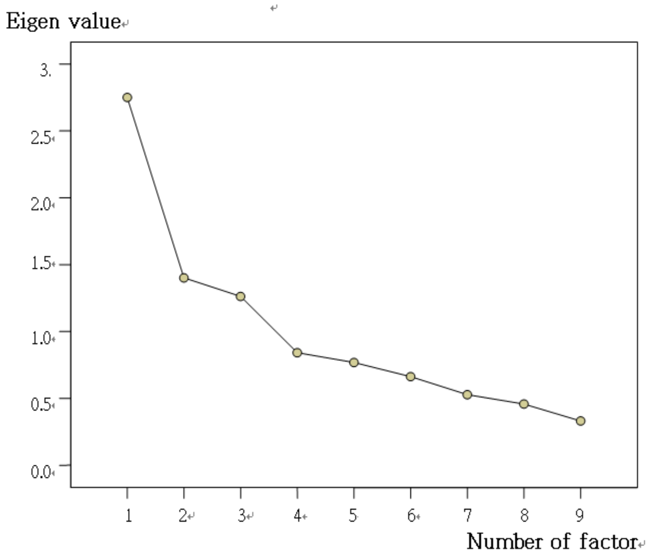

Fig. 3. Scree Plot for Cost Aspect.

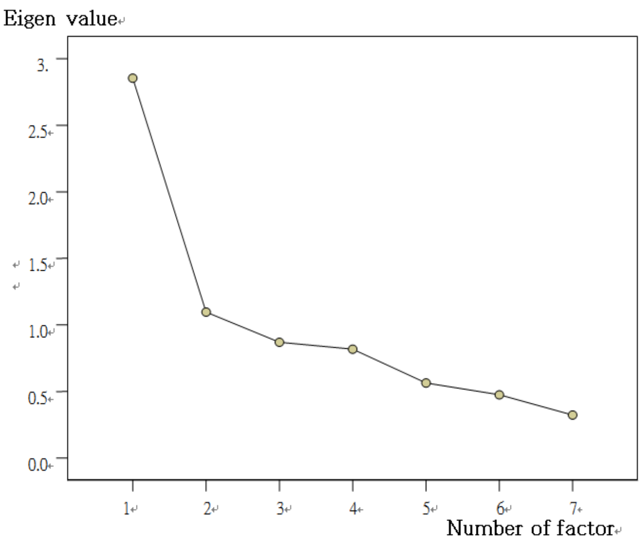

Fig. 4. Scree Plot for Benefit Aspect.

Table 5. Weights for Factors and Components (Cost Aspect).

Component	Factor	Extraction Value (Factor Loading)	Factor Weight (%)	Component Weight (%)
Planning	Route Selection	0.836	13.08	35.34
	Structure	0.741	11.60	
	Intelligent Transit	0.681	10.66	
Construction	Waste Reduction	0.695	10.88	40.81
	Material	0.694	10.86	
	Green Environment	0.660	10.33	
	Construction Method	0.558	8.74	
Facility	Pavement Configuration	0.801	12.54	23.85
	Facility	0.723	11.31	

Table 6. Weights for Factors and Components (Benefit Aspect).

Component	Factor	Extraction Value (Factor Loading)	Factor Weight (%)	Component Weight (%)
Construction	Material	0.858	19.35	62.75
	Construction Method	0.759	17.11	
	Waste Reduction	0.585	13.19	
	Pavement Configuration	0.581	13.1	
Planning	Structure	0.881	19.87	37.25
	Intelligent Transit	0.771	17.38	

that route selection is the most significant factor among all factors. This viewpoint is consistent with the general understanding according to expert opinions. An appropriate route is always the key. The results also suggest that the adoption of eco-structure and intelligent transit in the initial stage ensures a sustainable road project. The facility component contains only two factors, but they outweigh the factors in the other components. For example, pavement configuration has a weighting of 12.54%, comprising one of major parts of road lifecycle costs, especially in the maintenance phase. Experts agree that pavement configuration can cause substantial costs to sustainable road projects.

In the benefit aspect, all factors are categorized into two components. The construction component overwhelmingly outweighs the other one. This is similar to the cost aspect, but slight divergence exists. From the viewpoint of benefits, the green environment is replaced by the pavement configuration in the construction component. This is indicative of differences in thinking based on different viewpoints. Constructing green road environments as well as utilizing the proper pavement configuration is usually costly to practitioners. The green environment factor would not create a significant benefit for users. Measuring the benefits of a green environment for a road project depends on various factors and is utterly difficult. In addition, the green environment may not have long term benefits, especially under the influence of global climate change. It is, however, relatively easy to measure user satisfaction with a well-paved road. This may explain why well-designed or well-constructed pavement has a positive impact on a sustainable road project. It is commonly favored for roads to have lower maintenance cost and longer duration. The other component has the same factors as those for the cost aspect. A basic comparison indicates that the more beneficial considerations accounted for when planning a sustainable road, the more costly the project will be. The factor of route selection is removed from the benefit aspect. Route selection, originally including site investigation, alternative route selection, and emergency route selection, is significant in terms of the cost aspect. Construction costs can vary dramatically based on the above-mentioned decisions. Yet, these selections have limited benefits for the public except in extreme cases, such as the choice of an urban vs. suburban route, mountain vs. plain route, terrestrial vs. marine route, etc. The above findings provide a guideline for practitioners to design sustainable roads.

This study also found that the construction component in both cost and benefit aspects has the highest weight, but contains slightly different factors from each other. This indicates that the practical cost of using designs beneficial for sustainable road engineering may be high. Creating a green environment for road projects may be not only costly, but less beneficial to the public. Similar findings can be seen for the factors of route selection and facilities. Route selection is usually significant regarding cost consideration to a road project, and this study also supports such facts. However, a comparison for the impact factors between Table 4 and Table 5 shows that route selection barely brings benefits to users. Further exploration would be needed to explain such controversy. Well-designed facilities selected and installed for a highway are possibly beneficial to users, but the aforementioned comparison does not verify it. An advanced discussion on the subject of what kinds of facilities are needed or how those facilities operate would provide answers. These findings should be useful to both the public and private sectors.

Conclusion

It is essential to revisit the impact factors for sustainable road engineering, especially with global climate change. The major contributions of this study are to identify and rank impact factors in terms of both cost and benefit aspects, and to explore the difference of impact between these two viewpoints. Information was gathered from a comprehensive literature review and expert interviews, based on which a questionnaire was developed with 10 stems in each aspect. A total of 120 questionnaires were distributed, and 54 effective responses were returned. Factor reduction was carried out to eliminate one factor in the cost aspect and four in the benefit aspect. Using factor analysis and principal component analysis combined with orthogonal rotation, three and two components for the cost and benefit aspects were obtained, respectively. Therefore, impact factors and their corresponding weights were identified. The weight of each component and its influence on the cost and benefit of a sustainable road project was also determined.

There are numerous types of road construction projects whose conditions vary considerably. It is advisable to conduct a survey aimed at more specific road construction projects. Adopting sustainable thinking in other phases could be discussed and potential contributions explored. Succeeding studies may develop evaluation models, decision models, or other advanced systems to help practitioners in determining the sustainability of road projects.

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