# QUANTIFYING IMPACT FACTORS FOR SUSTAINABLE ROAD ENGINEERING

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**ABSTRACT**: This research is to identify impact factors in both cost and benefit aspects using quantitative techniques and then to determine their corresponding weights for sustainable road engineering projects. The impact factors are initially gathered from literature review and expert interviews, resulting in a total of 10 factors for questionnaire development. A 5-scale Likert questionnaire is accordingly developed for a survey. With the fulfillment of statistical criteria, 54 of 120 questionnaires are returned and a reliability test is employed to examine sampling adequacy in the beginning stage of data analysis. Therefore, we are able to identify the impact factors by the use of eight tests of missing value, mean, standard deviation, skewness, t-testing, correlation coefficients, factor loading, and measures of sampling adequacy (MSA). To determine the weight of each factor, the principle component analysis combined with orthogonal rotation best fit this research. Therefore, the analysis yields the results showing that 3 components include 9 factors in the cost aspect and 2 components include 6 factors in the benefit aspect. The finding is anticipated to benefit practitioners in the designing, planning, budgeting, and controlling phases of road engineering projects.

***Keywords****: Sustainable Road Project, Impact Factor, Factor Analysis, Survey, Construction Management*

## 1. INTRODUCTION

Sustainability has become one of most important issues for road engineering in considering environment protection. However, the effort to achieve such work may be costly, not economically beneficial to engineering practitioners. With the consideration of cost and benefit aspects, this research is to identify the impact factors for the aspects of cost and benefit using quantitative techniques, and to determine of their corresponding weights for road engineering projects.

Sustainable construction for road engineering has been notices since late 20$^{th}$ century. Education always plays an important role here [1]. Literature discusses numerous aspects for sustainable road engineering. A study provided strategies to increase the acceptance and sustainability of regulations by maximizing the potential benefits and negative impacts [2]. Scholars suggested four factors that influences road pavement [3-5]. Another four factors regarding green environment are summarized [6-8]. The work of Thenoux et al. showed that energy consumption comparison for pavement rehabilitation. It provided a framework of energy saving applied into road construction [9]. A model was created to predict long-term leaching of contaminants in road construction based on waste management [10]. Intelligent transport systems have been brought into attention for sustainable road construction. Adopting such systems in the design phase may save maintenance fee in the operating phase [11,12]. Numerous studies pointed out those factors based on eco-considerations need to be involved in the planning stage of road construction projects [13-19]. A total of 22 factors were concluded from literature review.

## 2. SURVEY AND BASIC DATA ANALYSIS

Using these 22 impact factors gathered from the previous work as the basis, we carry out expert interviews to examine the applicability of the factors. Experts suggest that the aspects of cost and benefit share the same sets of factors. Expertise from 30 expert interviews modifies and restructures the factors. The number of the factors is reduced from 38 to 10 which are pavement configuration, green environment, soil reservation, route selection, material, facility, structure, construction method, waste reduction, and intelligent transit. A questionnaire, accordingly, is developed using these factors as the stems. The survey aims at practitioners with 3 or more year experience regarding road engineering. With the random selection from either public or private sectors, a total of 120 questionnaires are distributed and then 54 are returned within a month. Respondents from academic institutes make up the major proportion at 46%. The rest returned questionnaires are from public sectors and private sectors at 33% and 21% of the total, respectively. 54% of the total respondents have over 10 year experience. Among them, the positions of two-third respondents are division heads or above.

## 3. FACTOR ANALYSIS

It is necessary to meet the criterion of sample size greater than 200 or greater than 5 times more than the stem number before conducting the factor analysis [20,21]. The survey with 54 returned questionnaires satisfies the requirement. Tables 1 and 2 demonstrate the test results for the factors in the cost and benefit aspects, respectively. The reliability analysis is carried out to examine whether the returned questionnaires are valid. It is generally accepted that the Cronbach's α values for the factors are greater than 0.7 for high reliability and less than 0.3 for low reliability. The Cronbach's α values are all between 0.6 and 0.8, representing a meddling to high reliability. The Kaier-Meyer-Olkin (KMO) measure of sampling adequacy (MSA) is used to evaluate the appropriateness of factor analysis. The KMO values for both cost and benefit aspects are between 0.6 and 0.7. The appropriateness of conducting factor analysis is meddling; therefore, the feature reduction can be carried out based on the suggested thresholds [22].

Table 1 Test results (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 reservation | 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 | 2.1255~4.5525 | >0.75 | -0.7~0.7 | ＜0.05 | ＞0.3 | ＞0.3 | ＞0.7 | ≦0.712 |

Table 2 Test results (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 reservation | 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 |

Eight statistical tests are suggested for feature reduction: missing value, mean, standard deviation, skewness, t-testing, correlation coefficients, factor loading, and measures of sampling adequacy (MSA). Any factor with over 2 test results out of the threshold ranges is subject to removal [22]. Factor No. 3, soil reservation, in the cost aspect is suggested to be removed. Factor Nos. 2, 3, and 4 (green environment, soil reservation, and route selection) in the benefit aspect are removed. As a result, there are 9 and 7 factors remaining in the cost and benefit aspects, correspondingly.

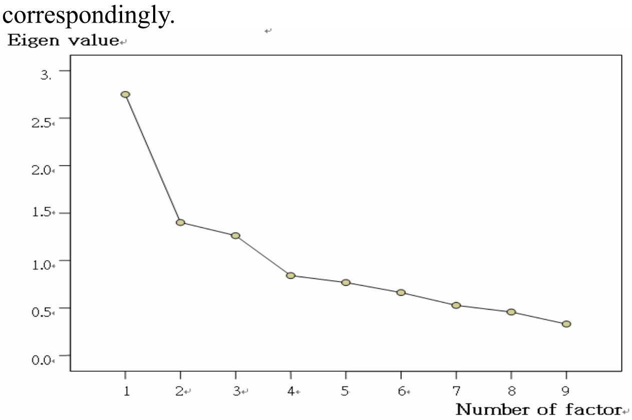


Figure 1 Scree plot (cost aspect)

Factor extraction is carried out to divide the factors into few sets. According to the threshold of eigenvalue > 1, Figures 1 and 2 are the scree plots showing that the factors in the cost and benefit aspects can be classified into 3 and 2 groups, respectively. The weight of each factor is, thus, determined and shown in Tables 3 and 4 using the principal component analysis combined with orthogonal rotation. Meanwhile, Factor facility is subject to deletion due to the threshold > 0.5 [22]. The three components obtained for the cost aspect based on transformation convergence are the: sustainable planning, construction method, and sustainable facility. For the benefit aspect, these two components can be named: construction method and sustainable facility.

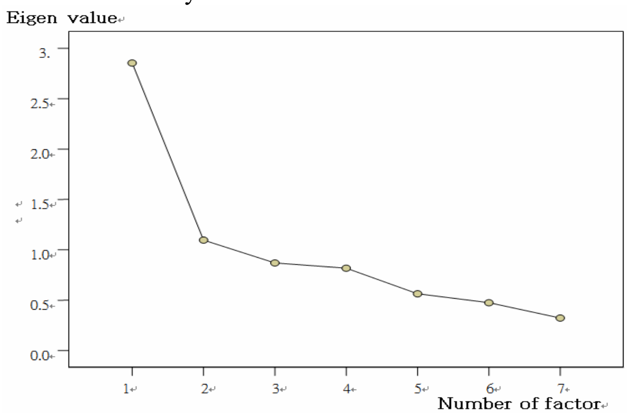


Figure 2 Scree plot (benefit aspect)

Table 3 Weights for factors and components (cost aspect)

| Component | Factor | Extraction value (Factor loading) | Factor weight (%) | Component weight (%) |
|---|---|---|---|---|
| Sustainable planning | Route selection | 0.836 | 13.08 | 35.34 |
| | Structure | 0.741 | 11.60 | |
| | Intelligent transit | 0.681 | 10.66 | |
| Construction method | 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 | |
| Sustainable facility | Pavement configuration | 0.801 | 12.54 | 23.85 |
| | Facility | 0.723 | 11.31 | |

The results obtained from the principal component analysis depict essence for sustainable road engineering. The considerations for the cost aspect lie in three components of sustainable planning, construction method, and sustainable facility. Component sustainable planning holds the largest weight and suggests practitioners paying attention in the planning phase the most, especially for route selection. This is consistent with common understanding. The results also suggest that the adoption of eco-structure and intelligent transit in the initial stage ensure a road project sustainable. Their corresponding costs need to be budgeted. For Component construction method, practitioners may focus on waste reduction, eco-material, environment and efficient construction method to achieve sustainability for roads projects.

Table 4 Weights for factors and components (benefit aspect)

| Component | Factor | Extraction value (Factor loading) | Factor weight (%) | Component weight (%) |
|---|---|---|---|---|
| Construction method | 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 | |
| Sustainable planning | Structure | 0.881 | 19.87 | 37.25 |
| | Intelligent transit | 0.771 | 17.38 | |

Besides difference in the numbers of component and factor, there are some similarity and dissimilarity between the aspects of cost and benefit. Component sustainable planning remains the same but slightly different between both aspect. Factor route selection is removed in the benefit aspect. Route selection originally including site investigation, alternative route selection, and emergency route selection, is however significant for the cost aspect. It is explicable that construction cost can vary dramatically based on above mentioned selections. Yet, these selections limits benefit to the public unless extreme cases such as urban vs. suburban route, mountain vs. plain route, terrain vs. marine route, etc. Alone with waste reduction, construction method, and material, the factors included in Components construction method for cost and benefit aspects are also slightly divergent. For the cost aspect, it is costly that a road project enhances green environment. On the other hand, it may be not beneficial for a long run especially under global climate change. For the benefit aspect, pavement configuration becomes one of the factors. This may explain that a well-designed or constructed pavement has a positive impact to a sustainable road project. It is commonly accepted that lower maintenance cost and longer duration increase workability for roads.

## 4. CONCLUSION

It is essential to revisit impact factors for sustainable road engineering especially under global climate change. The objective of this research is to identify impact factors in both cost and benefit aspects. With the gathering from comprehensive literature review and expertise, a questionnaire is developed with 10 stems in each aspect. A total of 120 questionnaires are distributed and then 54 returned questionnaires are effective. Feature reduction is carried out to eliminate one factor from the cost aspect and four from the benefit aspect. Using principal component analysis combined with orthogonal rotation, three and two components for the cost and benefit aspects are obtained, respectively. Therefore, identifying the impact factors and ascertaining their corresponding weights are achieved.

There are numerous types of road construction projects, which have various conditions. It is encouraged that the survey can aim at more specific road construction project. Succeeding studies may develop evaluation models, decision models, or other advanced systems to facilitate practitioners in determining sustainability of road projects. It is always hoped that increased sustainable project will create more win-win situations for mankind.

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