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CONSTRUCTION OF A KEY PERFORMANCE INDEX FOR ASPHALT PAVEMENT MATERIALS

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Abstract

Taiwan's nationwide road network has aimed to enhance its operational efficiency by adjusting to the region's topographical and weather conditions. Selecting the appropriate asphalt concrete can ensure long-lasting pavement construction, prolong the lifespan of highways, and enhance driving safety by facilitating swift water drainage and skid resistance. This investigation gathered significant elements for assessment through factor analysis and survey techniques, and validated the obtained factors in an effort to develop a crucial performance indicator (KPI). The study's outcomes were employed to suggest a performance evaluation factor framework for asphalt concrete pavement, which may serve as a guide for related public infrastructure services during the decision-making process.

Keywords: Pavement materials; KPI; Construction

Introduction

Taiwan experiences a predominantly hot, humid, and rainy climate. The island nation, with its limited landmass, dense population, rapid economic growth, and a rising number of vehicles on its roads, has witnessed a significant increase in traffic flow. Consequently, the issue of truck overloading has exacerbated, posing a grave challenge to the highway and road pavement technology in Taiwan. Over the past three decades, Taiwan has garnered extensive experience in road pavement technology, striving to adapt to the unique geographic features, climate conditions, environmental concerns, and traffic patterns that define the region. To enhance the engineering quality and standards of pavement construction in Taiwan, engineering units have imported drainage asphalt, a material extensively employed in the United States and European countries. The drainage asphalt is chosen in a bid to cater to the specific requirements posed by Taiwan's geographic and environmental factors. The primary aim of this study was to establish suitable criteria for evaluating the performance of asphalt pavement materials in the construction industry, which could serve as a reference point for relevant authorities when assessing the quality of asphalt pavement materials.

In light of these objectives, this study devised appropriate criteria for measuring the construction performance of domestic asphalt pavement materials and established a model to identify the key criteria for replacing traditional open-graded materials in the future. The findings of this research could serve as a valuable reference for planning and constructing future highway projects and drainage pavement systems in Taiwan. To arrive at these conclusions, the study reviewed relevant literature on asphalt concrete pavement materials and collected up-to-date data on the subject through interview methods. These efforts aimed to discern the performance evaluation aspects and criteria for asphalt pavement materials. Expert interviews were conducted with scholars and professionals who possess in-depth knowledge of asphalt concrete pavement materials. By employing factor analysis and questionnaire surveys, the study selected evaluation criteria specific to asphalt pavement in national highway projects. This process also involved eliminating unsuitable factors and constructing novel aspects for a more comprehensive understanding of the material's performance. Through this rigorous methodology, the study sought to establish a solid foundation for evaluating asphalt pavement materials in Taiwan, taking into consideration the unique challenges posed by the nation's climate, geography, and growing traffic demands.

This research highlights Taiwan's challenges in highway and road pavement technology due to its hot, humid, and rainy climate, limited land, dense population, rapid economic growth, and increasing traffic flow. The study aims to establish suitable criteria for evaluating the performance of asphalt pavement materials, considering Taiwan's unique characteristics. By importing drainage asphalt and devising appropriate criteria for measuring construction performance, the study seeks to provide valuable reference points for future highway projects and drainage pavement planning and construction in Taiwan.

Literature Review

In this section, a summary and analysis of the existing literature and research methods related to performance evaluation and asphalt pavement materials are provided, aiming to identify the most appropriate criteria. Evaluating any proposed technological solution comprehensively is a vital step in its development and optimization before it can be deployed on a large scale in real-life situations. The use of indicators is crucial for describing the distinct characteristics of a technological intervention and for facilitating comparisons with alternative solutions intended to fulfill similar objectives. Key Performance Indicators (KPIs) are metrics that assess the efficacy of a project or venture, as well as its suggested solutions, in achieving predetermined key goals [1]. The process of choosing KPIs also helps in determining the level of success for a project's objectives. These indicators should exhibit the following qualities [2]:

- Relevance: A KPI should be associated with one or more expected innovation impacts, making it pertinent as it can contribute to the realization of a program's overall objectives.
- Clarity: The definition of a KPI must be explicitly connected to the expected impacts of the innovation being studied.
- Measurability: Experimental values obtained from field testing at a suitable scale should be utilized to create customized simulation tools, which can subsequently be employed to estimate the anticipated innovation impacts.

KPI is a useful tool for construction companies to enhance their competence and improve their professional capabilities and construction standards. KPI can also be used to actively identify and solve problems to ensure the realization of project goals. Gaiss (1998) suggested that “performance” should include efficiency and effect.

Ferrell argued that performance includes the five aspects of innovation, conflict, effect, efficiency, and job satisfaction or staff morale. Performance evaluation is an important method for control management and is a professional and pragmatic discipline [3]. Babitsky and Brenner (1985) stressed that performance evaluation is a critical corporate indicator that quantifies the performance of in-process events or specific process output goals [4]. Robbins suggested that quantified expressions, such as performance evaluations, refer to a general description of an organization's process using words, functions, percentages, amounts, ratios, and indicators [5]. Chandler (1997) emphasized the significance of pinpointing an organization's or project's performance to secure future investment, boost share value, and attract top-tier employees. Thus, it becomes crucial to examine the ways in which an organization's performance is measured. The foundation for creating performance indicators has been operational since the early 2000s [6]. Neely (1999) investigated the criticisms surrounding these measures and concluded that they are "lagging metrics" based on past results and decisions, which offer limited utility in enhancing current performance. Essentially, they reflect an organization's previous performance rather than its present state. Furthermore, it is essential to continually identify not only an organization's performance but also the means through which it was achieved. By comprehending how an organization attains a specific performance level and designing metrics (leading instead of lagging), it can begin to improve and expand its market share [7].

Ghalayini & Noble (1996) compared conventional and unconventional assessment techniques. The development of performance indicators has been a topic of investigation for quite some time, with numerous research works highlighting the benefits and potential downsides of such indicators [8]. Letza (1996), among others, cautioned against the dangers of accurately measuring irrelevant factors when the primary goal of an exercise is to establish performance indicators, as these efforts may not align with the intended decision-making process [9]. Ghalayini & Noble (1996) contended that this is not only unneeded but also imposes considerable expenses on the organization regarding collecting and managing the necessary data [10]. Stemming from these studies, performance evaluation acts as a managerial control tool that utilizes objective and quantitative research methods for data gathering and analysis to quantify a project's expected outcomes or the efficacy of ongoing and completed projects as a numerical value or percentage. These results can aid decision-makers in administering projects more efficiently.

Asphalt concrete, commonly known simply as asphalt, is a composite material frequently used in constructing paved roads, highways, and parking lots. It comprises an asphalt binder and mineral aggregate, which are mixed, layered, and compacted. Lee and Kunhee (2005) suggested that new materials and engineering techniques for asphalt pavement are continually being developed and imported, with new construction technologies emerging to enhance material performance. However, application results have shown that although various improved materials and engineering techniques are gradually being adopted, most construction companies are unfamiliar with the specific performance of new materials and techniques and the initial construction technology and maintenance challenges. Consequently, the lifespans of these materials and techniques are reduced, resulting in increased costs and subpar outcomes [10].

Lee (2000) proposed that design engineers must promptly and effectively produce practical productivity estimations to evaluate and create construction options for paving endeavors. A feasible instrument accessible to engineers for examining construction alternatives is CA4PRS, a simulation model that calculates the quantity of lane miles a contractor can rebuild within a particular construction closure period, considering specified equipment and scheduling limitations [11]. Ibbs and Lee (2005) indicated that CA4PRS, designed and assessed in California, intends to support public transportation authorities in appraising construction choices by offering data on construction efficiency, related expenses, and traffic functioning [12].

Park et al. (2009) showcased laboratory and comprehensive performance test outcomes for a high-durability asphalt binder (HDAB) and high- durability asphalt mixture (HDAM) appropriate for the wearing conditions of bridge deck systems. The HDAB was formulated using a styrene– butadiene–styrene (SBS) modifier and hydrocarbon to enhance construction manageability and fatigue crack resistance [14]. Huang et al. (2009) investigated pertinent global LCA sources, pinpointed the knowledge void in the road sector, and outlined the creation of an LCA model for pavement construction and upkeep that could incorporate recycling [15]. Qian et al. (2011)

presented a lightweight epoxy asphalt mixture (LEAM) for pavements on movable bridges, which could be evaluated using the Marshall test, indirect tensile test, wheel tracking test, and bending beam test [16]. Park et al. (2009) maintained that a bridge's construction procedure places its pavement in a crucial stress state that may diminish the bridge's lifespan since the pavement acts as an essential structural layer shielding the bridge deck from moisture and guaranteeing high service quality and skid resistance. Irrespective of explicit and particular effectiveness, an assessment system should enable construction firms to identify the unique benefits of novel materials and engineering techniques and differentiate them from conventional ones [17]. In this manner, innovative materials and construction technologies can achieve broader adoption, decrease construction and labor expenses, and enhance road construction quality and advantages.

Research Method

This section delves into the research methodology of the paper, concentrating on the examination of questionnaire data using factor analysis. Stemming from a literature review and theoretical discussion, this study aimed to develop preliminary criteria and factors for pavement material performance as the basis for the questionnaire design. Data collection was executed using a survey form, which was distributed randomly. The statistical analysis of the data gathered from the survey forms was conducted using SPSS. The implemented methodologies encompassed descriptive statistics, reliability analysis, factor analysis, and a non-parametric approach employing the Kruskal-Wallis test. McClave et al. portrayed descriptive statistics as the utilization of numerical and graphical techniques to discern patterns in a dataset, summarize the information revealed in the dataset, and present the information in a convenient manner [18]. Altman et al. expounded that a pilot study is a small-scale trial performed to test the logic and augment the quality and efficiency of the data collected from larger datasets [19]. Carver and Nash noted that the Kruskal-Wallis H test is a nonparametric substitute for the one-way analysis of variance (ANOVA) [20].

Research Factors

This study gathered reference criteria for decision making on asphalt concrete pavement material applied in highway construction and analyzed relevant factors of the implemented measures. However, due to various research limitations, including the inability to invite a large panel of experts from all fields, including construction companies and personnel from the Taiwan Area National Freeway Bureau at the same time, this study only invited a small number of experts, contractors, and governmental personnel for individual expert interviews. Based on the interview results, this study constructed a preliminary hierarchy structure of a key performance index. The factor screening criteria and objectivity of the criterion selection quantification were as follows. Firstly, according to the literature review, defining the threshold required an overall evaluation of the structure factor correctness and decision group selection appropriateness. Without the support of actual theories or formulas, the thresholds in this study were set based on expert opinions so as to prevent the influence of subjective thinking. Secondly, the evaluation criteria were defined in qualitative and quantitative aspects at the researcher’s discretion. In this study, the evaluation criteria had both quantitative and qualitative factors, however the latter was most common. Thus, instead of sensitivity analysis, this study used factor analysis and a questionnaire survey to screen aspects and factors more objectively. The quantitative analysis was conducted based on numerical calculations, while the qualitative analysis was conducted by rating the questionnaire results. Quantitative analysis methods are more objective due to rating and judging being based on numbers, while qualitative analysis is used when evaluation factors cannot be quantified. However, the disadvantages of common qualitative analysis are the risk of subjective judgment and the use of expert thumbnail rules. Especially when lacking evidence data, researchers often make judgments based on thumbnail rules, which are prone to doubt or misjudgment.

Therefore, according to the questionnaire method and given the first stage of the preliminary criterion hierarchy structure design, this study used factor analysis, a questionnaire survey, and analysis by SPSS 10 software to screen new and objective aspects and factors, regroup factors, and rename factor aspects.

Factor Selection Principle

Based on the literature review and expert opinions, the preliminary factors were selected. Exploratory factor analysis (EFA) was then adopted to extract j latent factors (F1, F2,…Fj) from k behavioral variables (X1, X2,…Xk) by determining which factors had eigenvalues greater than 1.

Since the observable variables and extracted latent factors had certain theoretical structures, confirmatory factor analysis was performed to confirm the compatibility of the theoretical structure with actual history data.

Factor analysis is a type of multivariate statistical technique that was developed in the early 20th century. Its use was previously concentrated on human behavior, however this gradually expanded to sociology, meteorology, politics, pharmaceutics, geography, and management sciences.

Factor analysis is a statistical analysis method proposed by Charles Spearman in 1904 that is used for intelligent test scoring. Factor analysis has been successfully applied in psychology, sociology, economics, demographics, geology, physiology, and even chemistry and physics. After years of development, factor analysis is no longer a single technique but rather a collective name for a type of techniques, including space (or aspect) reduction techniques. It is a multivariate statistical method studying relations among a group of observable variables. Its main purpose is to express previous data structures using fewer dimensions, thereby not only solving collinear problems among independent variables but also reducing a group of related variables into a few independent factors while reserving most of the information provided by the primary data structure.

Research Object And Sampling Method

The focus of this investigation was on porous asphalt concrete drainage pavement techniques for the National Highway No. 6 Nantou Section Project. The research's participants included supervisory units and construction contractor engineers engaged in the National Highway No. 6 Nantou Section Project. To guarantee an acceptable response rate and reliability, the study aimed at experienced engineers from various bids of this project, as well as stakeholders from the Taiwan Area National Freeway Bureau, Sinotech Engineering Consultants Ltd., construction contractors, and other associated organizations to gather more objective viewpoints. The investigator personally distributed and retrieved a total of 50 questionnaires, with all of them returned. After discarding four invalid responses, there were 36 valid samples, resulting in a 90% effective return rate. The gathered data were analyzed using SPSS 10 software for reliability analysis, descriptive statistical analysis, factor extraction, and eigenvalue extraction. The data obtained in the second stage were entered into Microsoft Excel to create a pairwise comparison matrix and determine the relative weights.

Questionnaire Design and Results Analysis

This section outlines the research design concept and examines factors from the perspectives of experts, employers, consultant company personnel, and construction contractors. It also provides details on the questionnaire format, objective, structure, process, and content. The factor analysis employed both a Likert scale and nominal scale pairwise comparison methods to analyze the questionnaires and assess the weights, with the aim of selecting the best material for asphalt concrete pavement.

Preliminary Factor Extraction

To ensure a comprehensive selection process for the construction performance criteria of asphalt concrete pavement material, the researcher initially interviewed a section chief in a consulting firm with practical experience in pavement projects, the deputy director of the government authority responsible for asphalt material, colleagues in an engineering material laboratory, and the quality control supervisor of a leading asphalt manufacturer in Taiwan. This was done to gather opinions from both the industry and government viewpoints. Before the interviews, this study conducted a literature review and summarized the factors of the concrete pavement material screening criteria, which led to four aspects: cost, effectiveness, superiority, and characteristics (Figure 1). Using these four aspects as a basis, interviews were carried out to generate the factors for this study.

Introduction Of Preliminary Criterion At Each Hierarchy

In the asphalt pavement material priority selection model, the criteria of each hierarchy were divided into four preliminary aspect criteria:

1. Cost aspect
2. Effectiveness aspect
3. Superiority aspect
4. Characteristic aspect.

Under the four aspect criteria, there were 19 factor criteria in total:

1. Four factor criteria under the cost aspect:
    (1) Cost per meter (M)
    (2) Maintenance cost
    (3) Budgeted cost
    (4) Durable period.
2. Three factor criteria under the effectiveness aspect:

(1) Improved performance

(2) More significant surface course drainage function

(3) Response of each unit to the effectiveness of this new engineering method.

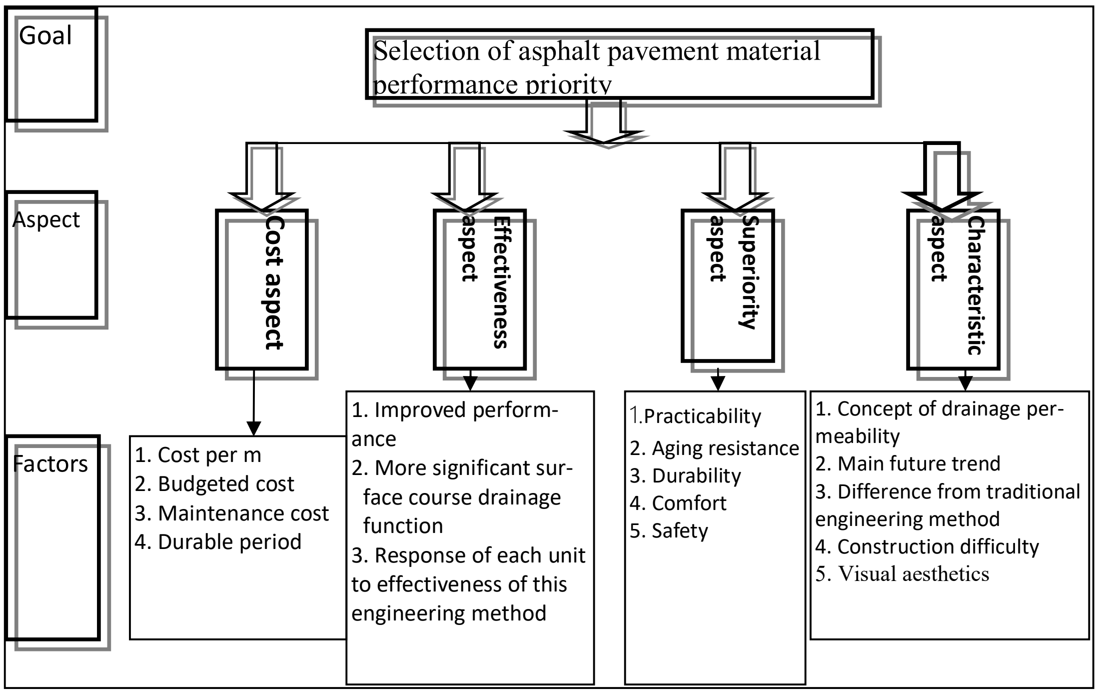

Figure 1. Preliminary pavement asphalt concrete material construction performance precedence selection

3. Five factor criteria under the superiority aspect:

(1) Practicability

(2) Aging resistance

(3) Durability

(4) Comfort

(5) Safety

4. Five factor criteria under the characteristic aspect:

(1) Concept of drainage permeability

(2) Mainstream trend in the future

(3) Comparison with traditional engineering methods

(4) Construction difficulty

(5) Visual aesthetic

The aspect criteria and underlying factor criteria were as follows:

1. Cost

Whether due to construction costs or maintenance costs, national highway projects can cost a lot; thus, proper budgeting is the utmost consideration. Four important cost criteria were generalized in this study, namely, cost/meter, maintenance cost, budgeted cost, and durable period, which are described below.

(1) Cost/meter (Cost/M)

Cost is one of most important factors for engineering construction, and it is the most significant external quantitative attribute from an economic perspective. Hence, in the feasibility analysis of an engineering construction project, the construction unit price should be estimated, even during the contract bidding procedure, as the bid will be awarded according to the bid price. Construction standards may differ with the building materials, therefore building material costs may vary. Even for the same project, there may be different cost quotations from different builders. Therefore, to achieve cost minimization, building the best quality facility with a lower cost is the preferred result.

(2) Maintenance cost

High maintenance costs follow the completion of national highway construction. Besides regular repair and replacement, there must be a long-term monitoring and maintenance mechanism, which will increase the maintenance difficulty, as well as labor dispatches and maintenance costs.

(3) Budget

The cost of national highway construction is high; thus, the government will appropriate a fixed budget to every administrative department each year. However, due to accounting and statistic systems, government authorities cannot spend more than the total budget or leave much surplus, either. Otherwise, the responsible unit will be inspected by the government for the unsuccessful execution of the budget. As a result, government authorities appear less flexible than private companies in terms of the fixed budget; therefore, the responsible unit will measure the ratio of project cost to budgeted cost.

(4) Durable period

The durable period refers to the service life of the pavement structure itself and is also one of the decision factors. The authorities responsible for the highway administration should consider the intended purpose and repair policy of the pavement structures, as well as probable factors that may occur after such structures become obsolete. Otherwise, the shorter the pavement structure life, the higher the actual amortized cost will be, as well as the labor assignment cost and maintenance cost.

2. Effectiveness

As national highway construction pursues traffic convenience and further improvements to the competitive edge of a country, effectiveness is the most direct requirement of national highway construction. Additionally, this study considered indirect effectiveness and identified four crucial effectiveness criteria, which include enhanced performance, reduced maintenance costs, increased surface course drainage functions, and the response of each unit to the effectiveness of the engineering method. These criteria are detailed below.

(1) Improved performance

The purpose of the asphalt pavement material applied in national highway construction is to serve the road users while presenting drainage and durability functions, as well as an efficient and safe traffic environment.

(2) More significant surface course drainage functions

As asphalt concrete pavement material engineering methods are applied in national highway construction, road drainage performance is required to improve, thus improving the benefits of these engineering methods.

(3) Response of each unit to the effectiveness of the engineering method

There are numerous engineering methods and materials that have not been used in practical applications for quite some time. Thus, it was hard for the experts, scholars and engineering pioneers to make precise predictions of their benefits. This study could only refer to literature and trial pavement experiments. Hence, if experts, scholars, and engineering pioneers can determine the effectiveness of new engineering methods or materials before and after application, then it will serve as good criteria for the feasibility evaluations of new material engineering methods applied in national highway construction.

3. Superiority

Six important factors were generalized, namely, practicability, aging resistance, durability, comfort, drainage, and safety, detailed as follows.

(1) Practicability

Practicability is the most important component of a road. If the road itself cannot provide the loading function, its value will be greatly reduced.

(2) Aging resistance

Asphalt pavement material must have the capability to resist rainwater, sunlight, and aging.

(3) Durability

Poor quality road construction

material leads to a shorter durable period, accelerated road repairs, and increasing repair-derived social costs.

(4) Comfort

Compared with cement concrete roads, asphalt concrete pavement can provide a comfortable and smooth road with low vibration.

(5) Safety

A proper road design should provide drivers with good vision, prevent injuries or inconvenience due to wavy or steep roads, and enable fast traffic. The road slope should allow vehicles to move rapidly and safely, without traffic jams. In addition, systematic design and supervision, as well as quality control of construction processes and materials, should be performed to ensure a road has a rough course so as to prevent skidding on rainy days and prevent the road course from rutting and cracking under external forces. Therefore, the safety aspect means that the road design should avoid various tangible and intangible risks.

4. Characteristics

Before deciding to adopt an engineering method, the competent authorities will consider the economy-benefit factor and further compare characteristics of the engineering method itself; therefore, this study generalized five important factors which include drainage permeability, mainstream trend in the future, comparison with traditional engineering methods, construction difficulty, and visual aesthetic, detailed as follows.

(1) Drainage permeability

The main adoption principle is whether the drainage permeability of asphalt concrete pavement is superior to that of traditional pavement materials.

(2) Mainstream trend in the future

If asphalt concrete pavement material is superior to traditional asphalt material according to various indicators, this engineering method will become the mainstream trend in the future and will influence employer decisions to some extent.

(3) Comparison with traditional engineering methods

Constructing the same type of pavement using traditional open-grade engineering methods and porous asphalt concrete pavement engineering methods and then comparing them in terms of the construction cost, life span, and maintenance difficulty, can allow for a more significant and objective comparison.

(4) Constructability

The workability problems inherent to asphalt concrete pavement material should be overcome; otherwise, advantageous as it is, the later repair and maintenance and durability of the paved road course will be affected significantly.

(5) Visual aesthetic

Besides functionality, the visual appearance should be noted, as pavement with a better visual aesthetic not only beautifies the road but also brings the road users a better visual experience.

This study generalized the reference evaluation criteria and descriptions as shown in Table 1.

Table 1. Preliminary Reference Evaluation Criteria

Aspect	Preliminary evaluation criteria	Description
Cost aspect	1. Cost/M	Total of unit price of pavement plus construction cost.
	2. Maintenance cost	Repair cost of regular maintenance and rutting from pavement damage.
	3. Budgeted cost	Balance between project budget and budgeted cost.
	4. Durable period	Durable period of road surface course under external loading.
Effectiveness aspect	1. Improved performance	The most direct influence on the effectiveness of national highway pavement projects.
	2. More significant improvement of surface course drainage functions	Does the engineering method improve the drainage function significantly?
	3. Response of each unit to effectiveness of the engineering method	Comments of other related road administrative authorities about adopting the engineering method.
Superiority aspect	1. Practicability	If the road itself cannot provide the premium loading function then its value will diminish greatly.
	2. Aging resistance	Can modified asphalt mortar and lime in the pavement prevent the asphalt from aging?

	3. Durability	After using the engineering method, can the pavement prolong the road service life?
	4. Comfort	After using the engineering method, can the pavement feel smooth and comfortable to users while driving?
	5. Safety	Making sure the road surface is protected from rutting and cracking under external forces that can endanger driving safety.
Characteristic aspect	1. Concept of drainage permeability	Based on the drainage properties, can the materials better comply with drainage concepts?
	2. Mainstream trend in the future	In terms of engineering characteristics, will the material be widely applied in future?
	3. Comparison with traditional engineering methods	Multiple-aspect comparisons of the engineering method regarding benefits, functions, or characteristics.
	4. Construction difficulty	Construction difficulty of using the engineering method.
	5. Visual aesthetic	Besides functionality, the cosmetic beauty of the pavement must also be noted.

Summary

As the accuracy and reliability of the questionnaire data considerably impacted the selection of asphalt pavement material performance criteria, this study interviewed experts in asphalt concrete material to construct an evaluation criteria hierarchy and gather suitable criteria, aiming to develop and outline a framework for asphalt pavement priority criteria. The initial evaluation criteria framework consisted of three hierarchies. Under the ultimate goal (Hierarchy 1), there were four aspects (Hierarchy 2): cost, effectiveness, superiority, and characteristics. Between four and seven criteria (Hierarchy 3) were then established under each aspect, totaling 19 factors. To avoid an unmanageable questionnaire response rate, the questionnaires were distributed to 50 experts. After conducting pairwise comparisons of the importance of each criterion and analyzing the data, a preliminary design was completed to support subsequent research.

Results And Analysis Of The Questionnaire Survey

Based on the factor analysis, the questionnaires were collected in two stages. New aspects were assigned new names, factor criteria were refined, a pairwise comparison matrix was constructed, and the eigenvector method was employed to determine the weights among aspects. Factor criteria under each aspect from questionnaires that passed the homogeneity test were selected as the foundation for asphalt concrete material construction priority criteria modeling.

Data Processing And Analysis

1. Questionnaire sample

This study investigated the asphalt concrete material engineering priorities on national highways. Questionnaires were released to the Second Section of the Taiwan Area National Freeway Bureau, Sinotech Engineering Consultants Ltd., and the construction contractors involved in bidding. The recovered questionnaires were analyzed twice, as shown below.

(1) Questionnaire recovery

A total of 50 questionnaires were released, and 40 were recovered. After eliminating four ineffective copies (incorrect or incomplete questionnaires), there were 36 effective copies. The respondents had about 15 years of experience on average. The valid questionnaire was calculated as shown below, and the questionnaire response units and questionnaire analysis are shown in Table 2.

Questionnaire response rate = 40 ÷ 50 = 80%

Ratio of valid questionnaires = 36 ÷ 40= 90%

Questionnaire survey analysis

The first stage of this study was to construct four assumptive aspects and 19 factors from the experts, employers, and the literature. The collected data were analyzed using SPSS 10.0 based on factor analysis. The statistical methods were as follows:

Table 2. Questionnaire analysis

Questionnaires	Copies released	Copies received	Number of valid copies
Related Arranging Authoritues	5	3	3
Engineering Con-	25	20	19

sultant Companies			
Construction contractors	20	17	14
Subtotal	50	40	36

1. Reliability analysis

The homogeneity of each measured item of the recovered questionnaires was measured and represented by Cronbach's α coefficient.

2. Factor Analysis (FA)

Exploratory factor analysis was conducted to test the classification of the variables (cost, effectiveness, superiority, and characteristics), so as to facilitate later confirmatory factor analysis.

3. Factor naming

Exploratory factor analysis was utilized to test the correlations among the observable variables and latent variables and check the fitness between each questionnaire item with the measured model so as to conform to the construct validity and find new aspects and factors.

Questionnaire Reliability And Validity

1. Reliability test

For the reliability test after data collection, Cronbach's α coefficient was used to measure the homogeneity of the answers to the test questions, as shown in Table 3. A Cronbach's α>0.7 is considered to indicated good reliability (Nunnally, 1978). Wortzel (1979) suggested that a Cronbach's α between 0.7 and 0.98 represents high reliability, while a value lower than 0.35 represents that an item should be rejected or adjusted. After deleting some items, a reliability test was performed on the scale. In this study, the Cronbach's α coefficient was 0.70-0.84 (Table 3), indicating good reliability.

Exploratory Factor Analysis (EFA)

This study used SPSS 10.0 to conduct exploratory factor analysis (EFA) of the scale, in order to explore the factors attributed to each observable variable. Hence, factor analysis was performed respectively in terms of pavement usability, material superiority, construction effectiveness, construction cost, and adoption principle, in order to check for probable classification problems, and the results are shown below.

Exploratory factor analysis: Principal component analysis and varimax were used for rotation, in which factors with eigenvalues greater than 1 were chosen. The Kaiser-Meyer-Olkin sampling adequacy measure (KMO) was 0.619 (Table 5), which was greater than 0.5, indicating the data of questionnaires was suitable for factor analysis.

Table 3. Questionnaire Reliability Analysis

Factor	Cronbach α
More significant improvement of surface course drainage function Concept of drainage permeability Improved performance Durable Period Mainstream trend in the future	0.837
Aging resistance Safety Durability Maintenance Cost Comfort	0.851
Budgeted Cost Visual aesthetic Response of each unit to effectiveness of this engineering method	0.776
Construction difficulty Cost/M	0.728
Practicability Comparison with traditional engineering method	0.897

As shown in Table 8, Part 1 was renamed "pavement usability" and included five items. The explainable variance was 26.167% and the factor loadings were 0.82-0.62. Part 2 was "material superiority" and included five items. The explainable variance was 16.129%, the factor loadings were 0.76-0.57, and the total explainable variance was 38.296%. Part 3 was "construction effectiveness" and included three items. The explainable variance was 15.827%, the factor loadings were 0.87-0.54, and the total explainable variance was 54.124%. Part 4 was "construction cost" and included two items. The explainable variance was 11.79%, the factor loadings were 0.88-0.83, and the total explainable variance was 65.913%. Part 5 was "adoption principle" and included two items. The explainable variance was 8.407%, the factor loadings were 0.83-0.74, and the total explainable variance was 74.315%. The results proved that there should be five factors which include pavement usability, material superiority, construction effectiveness, construction cost, and adoption principle. Based on the factor analysis results, this study carried out an empirical discussion and analysis of these five aspects.

1. Coefficient of variance

Coefficient of variance (CV) is used to measure the differences among subjects. CV can standardize units in cases where differences cannot be compared due to the use of different data units (Table 4).

Table 4. Descriptive Statistic Of Each Factor

Factor	Mean, μ	Standard deviation, σ	Coefficient of variance, *CV*	Number of subjects analyzed
Cost/M	1.8611	0.6825	0.37	36
Maintenance cost	1.6944	0.5767	0.34	36
Budgeted cost	2.1944	0.9508	0.43	36
Durable Period	1.5890	0.7030	0.44	36
Improved performance	1.7500	0.8062	0.46	36
More significant improvement of surface course drainage function	1.5556	0.7725	0.50	36
Response of each unit to effectiveness of this engineering method	1.9722	0.8447	0.43	36
Practicability	1.5000	0.6094	0.41	36
Aging resistance	1.7778	0.7968	0.45	36
Durability	1.6667	0.8258	0.50	36
Safety	1.3611	0.5929	0.44	36
Concept of drainage permeabil-	1.4444	0.5578	0.39	36

ity				
Comparison with traditional engineering method	2.2222	0.9595	0.43	36
Construction difficulty	1.7778	0.7216	0.41	36
Visual aesthetic	2.5556	0.9394	0.37	36

CV is calculated by dividing the standard deviation by the mean, as shown below; the smaller the CV, the more consensus among expert opinions.

When CV≦0.3, the expert opinions have high homogeneity; when CV is between 0.3 and 0.5, the expert opinions fall within the acceptable range, and when CV≧0.5, the reason with low homogeneity should be analyzed.

CV: Coefficient of variance (CV)

$$CV = \sigma/\mu$$

σ: standard deviation; μ: mean

In this study, the CV of each factor ranged from 0.3 to 0.5, indicating that the expert opinions fell within the acceptable range and the test was appropriate.

2. Kaiser-Meyer-Olkin and Bartlett's test (Table 5)

Table 5 Kasier-Meyer-Olkin & Bartlett's Test

Kasier-Meyer-Olkin	0.619
Bartlett's Sphere Test Quasi Chi-Square Distribution	358.643
Degree of freedom	136
Significance	0.000

Source: Compiled by this study

- (1) Judged from the KMO value and Bartlett's test value, this sample data is suitable for factor analysis.
- (2) In this study, the KMO value was 0.619, making it suitable for factor analysis. The significance level of Bartlett's sphere test was 0.000; therefore, the null hypothesis of Bartlett's sphere test was rejected and it was suitable for factor analysis.

3. Communality among factors (Table 6).

Table 6. Communality Scale

Factor	Initial	Extracted
More significant improvement of surface course drainage function	1.00	0.847
Concept of drainage permeability	1.00	0.809
Improved performance	1.00	0.772
Durable Period	1.00	0.556
Safety	1.00	0.705
Maintenance Cost	1.00	0.846
Aging resistance	1.00	0.632
Durability	1.00	0.725
Budgeted Cost	1.00	0.853
Visual aesthetic	1.00	0.826
Response of each unit to effectiveness of this engineering method	1.00	0.735
Construction difficulty	1.00	0.714
Cost /M	1.00	0.653
Practicability	1.00	0.766
Comparison with traditional engineering method	1.00	0.751

➢ 17 Factors; communality: 0.556-0.853>0.5, the test result is acceptable.

4. The screen plot for the factor analysis is shown in Figure 2.

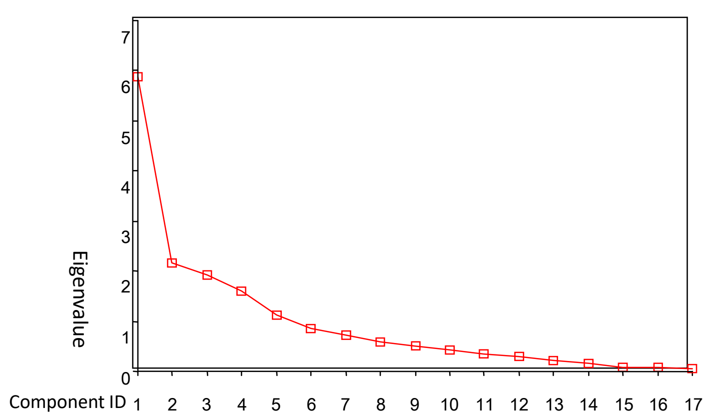

Figure 2. Factor screen plot

- For component ID 1-5: eigenvalue>1, and in steep slope, therefore five component factors were extracted, constituting five new aspects.
- 5. The rotated factor matrix as shown in table 7.

Table 7. Rotated Factor Matrix (Before Modification)

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Improved performance		0.773			
More significant improvement of surface course drainage function					0.754
Concept of drainage permeability			0.682		
Durable Period		0.551			
Mainstream trend			0.492		
Aging resistance		0.837			
Safety	0.73				
Durability		0.698			
Maintenance Cost		0.606			
Comfort	0.449				
Budgeted Cost		0.851			
Visual aesthetic		0.726			
Response of each unit to effectiveness					0.56
Cost/M		0.868			
Construction difficulty			0.813		
Practicability			0.716		
Comparison with traditional engineering method				0.733	
Eigenvalue	6.629	2.21	1.951	1.641	1.403
Explainable variance (%)	34.892	11.633	10.262	8.639	7.385
Cumulative explainable variance (%)	34.892	46.525	59.792	65.431	2.816

Source: Compiled by this study.

According to the above rotated factor matrix analysis shown in Table 7, mainstream trend (0.492) and comfort (0.449) were both below 0.5, indicating the factors failed the test; therefore, they were deleted.

6. Rotated factor matrix

Rotated factor matrix after deleting items 12 and 16 in Table 8.

As shown above, rotated factor (factor loading) were 0.544-0.869, therefore there were 17 new factor criteria. Five factors with eigenvalues >1 became five new aspects. The total cumulative explainable variance was 74.315%, indicating that the test result suitable for factor analysis.

Table 8. Rotated Factor Matrix (After Modification)

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Improved performance		0.773			
More significant improvement of surface course drainage function					0.823
Concept of drainage permeability			0.752		
Durable Period		0.621			
Aging resistance			0.757		
Safety		0.750			
Durability		0.598			
Maintenance Cost		0.606			
Budgeted Cost			0.869		
Visual aesthetic			0.734		
Response of each unit to effectivenessof this engineering method					0.544
Cost/M			0.867		
Construction difficulty					0.832
Practicability			0.831		
Comparison with traditional engineering method				0.738	
Eigenvalue	6.025	2.125	2.018	1.361	1.104
Explainable variance (%)	22.167	16.129	15.827	11.79	8.401
Cumulative explainable variance (%)	22.167	38.296	54.124	65.913	74.315

Source: Compiled by this study

Discussion Of The Selected Criteria Factors After Factor Analysis

After an initial classification of the four criteria and 17 evaluation criteria, the results from the first stage of the questionnaire survey were analyzed using factor analysis. Five aspects were redefined, and factors for each aspect were identified. Moreover, 15 factors could be grouped into five main aspects: pavement usability, which included more significant improvement of surface course drainage functions, drainage permeability, and improved performance; material superiority, which consisted of safety, maintenance cost, aging resistance, and durability; construction effectiveness, which covered budget, visual aesthetic, and response of each unit to the effectiveness of this engineering method; technical cost, which encompassed construction difficulty and Cost/M; and adoption principle, which involved practicability and comparison with traditional engineering methods. The analysis of the performance evaluation criteria allowed for the identification of important aspects and criteria factors of asphalt concrete pavement material, serving as the foundation for the asphalt concrete evaluation.

Conclusions and Suggestions

This study carried out an empirical investigation using factor analysis and a questionnaire survey, resulting in findings and recommendations for the ongoing improvement of asphalt concrete pavement materials. A structure consisting of five main dimensions was developed in this research. The empirical investigation identified 15 elements within these five main dimensions pertaining to pavement asphalt concrete, which may be used as a guide for future construction. The analysis of performance evaluation criteria determined key aspects and criteria factors for asphalt concrete pavement material as the foundation for asphalt concrete assessment. The expert questionnaire survey analysis revealed that the asphalt concrete pavement performance evaluation comprised 15 criteria factors and five aspects, including pavement usability, material excellence, construction efficiency, construction cost, and adoption principle. During the early stages of implementing engineering techniques and materials in national highway pavement construction, decision evaluations should give precedence to "safety" and "durability" to bolster decision-making throughout the planning, design, supervision, and evaluation phases. Adherence to budget review systems and regulations, as well as considering drainage and the perspectives of various disciplines during feasibility assessments in the planning and design phase, is equally important. Examining long-term data and contrasting pavement changes pre- and post-construction, as well as throughout maintenance and management, can help tackle pavement challenges and develop solutions for upcoming national highway endeavors. As revealed in the interviews, each pavement material engineering approach possesses its own set of strengths and weaknesses.

Therefore, factors like road category, area, weather, and natural surroundings should be taken into account in national highway pavement construction to maximize the suitability, cost-effectiveness, or longevity of any technique. Transport authorities should conduct initial studies and gather feedback from other stakeholders to promote sustainable, reasonable, and enduring road operations.

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