Technical Paper

ISSN 1997-1400 Int. J. Pavement Res. Technol. 7(3):185-192

Toward a Holistic Performance Measurement of the Pavement Management

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Abstract: With limited budgets and increasing pressure from related stakeholders, together with the threat of extreme weather, we may need brand-new thinking in PMS implementation. The purpose of this article is to explore how governance function may link to sustainability regarding PMS implementation. Our theoretical analysis found that governance notion and a sound governance structure may help top management in dealing with inter-agency affairs and aligning customers' needs with an agency's goal. Also, a holistic sustainable framework for pavement management allows us to take from a broader consideration within the pavement context. In the empirical study, we used a Quality Function Deployment (QFD) matrix that can incorporate 7 customers' needs into 25 technical requirements. After the revision of relative importance including subjective and objective weights, 10 performance indicators through sustainability perspective have been established.

DOI:10.6135/ijprt.org.tw/2014.7(3).185

Key words: *Corporate governance; Pavement management system; Performance indicators; Quality function development; Sustainability.*

Introduction

In the modern era, problems faced by pavement agencies have become more complicated so they may not be solved by the effort of one department alone. Pavement administration agencies are also under limited budget constraints and increasing pressure from related stakeholders. The term governance has become an important concept in a variety of scholarly disciplines and proven to be beneficial to firm's performance in business; however, governance function and its linkage to sustainability applied to public transport and pavement management has not receive equivalent focus. This article explores pavement management from a different angle, focusing on the governance perspective within an organization. While sustainable construction is efficiently achieved through the collaboration of supply chain within the whole life-cycle, the sustainable development in pavement management would not be confined to this stage alone. A holistic framework provides a more integrated perspective, embedded in sustainability notion for the whole pavement context.

Pavement Management Systems (PMS) assist decision makers in finding strategies for prioritizing project activities to maintain a pavement network based on objective information provided by the system, rather than on subjective experience alone. Although the concept of PMS was introduced to Taiwan in 1983, the actual application indicates that limited roadway agencies reach a true practical status to apply PMS for assisting decision-making in pavement strategies [1]. In the qualitative analysis, it is worth exploring that what kind of barriers the pavement agencies encountered and whether the situation was similar to the early stage of development process in the United States. To capture the trend of the development of contemporary PMS, Taiwan Highway Bureau (THB) undertakes an empirical study for quantitative analysis. We use QFD matrix that can translate customers' needs into technical requirements. Finally, it is expected to establish a set of performance indicators, including subjective and objective weights through the sustainability perspective.

Why Governance Matters

The term "governance" originally traces its roots to the Latin word *gubernare* – to steer – as in directing a ship towards its destination, which implies that governance refers to the job of setting the direction rather than controlling. While sovereign weakened over the centuries, democracy governed not by edict, but rather by a system of checks and balances, by negotiating a settlement between competing interests. The role of governance is, therefore, not merely to set direction, but rather to *mediate* between the various parties contesting for control of resources [2]. The characteristic of modern business is the separation of ownership and control, which leads to the conflict of interests between the shareholders and top managers. Accordingly, "corporate governance" is a mechanism to ensure that manager action aligns with the interests of shareholders. Corporate governance can be defined as the systems and processes by which companies are directed and controlled [3]. Recently, the concept of governance has spread to the public and voluntary sectors. The primary function of public sector is to deliver diversified services (health, education, transportation and social service, for example) to taxpayers and the general public.

The United Kingdom's Good Governance Code for public services and Code of Good Practices for central government department have made corporate governance explicit in the public sector since 2004. The aim of governance in the public sector is to ensure that an organization fulfils its overall purpose for citizens and service users, and operates in an effective, efficient, and ethical manner [4]. It seems to be attempting to replicate private sector

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Note: Submitted May 31, 2012; Revised December 19, 2013; Accepted December 25, 2013.

thinking of governance in the public services, without full recognition of the different contexts. However, ethical concerns, social responsibility, and automatically focusing on broad stakeholder accountability are central to governance in public sector organizations due to their not-for-profit nature [5]. The field work undertaken by OECD (Organization for Economic Co-operation and Development) project reveals that the reform on governance structure and commercialization within the land transport industry in New Zealand contributes to better service performance [6]. "Accountability", "director independence", "director code of conduct", and "conformance with corporate governance good practices"—all related to governance issues—are major performance indicators shown on the sustainability performance metrics in Canada TransLink's sustainability report [7]. In this section, we demonstrate the importance of governance, whether in private sector or public organization. Without exception, the governance notion also has been applied to roadway agencies and proves its merit to better service performance.

Governance Linkage to Sustainability

The concept of sustainability arises naturally from stakeholder theory. The stakeholder model goes beyond the conventional input-output model that the firm can be seen as the "black box" transformation, with resources input and product output. Rather, stakeholder analysts argue that all persons or groups with legitimate interests merit consideration by the top managers for running their business [8]. Evan and Freeman (1993) asserted that management has a duty of *balancing* the conflicting claims of multiple stakeholders to achieve the goal of corporation. Thus, the stakeholder theory suggests that success in satisfying multiple stakeholder interests—rather than in meeting conventional economic and financial criteria—would constitute the ultimate test of corporate performance [9]. Alternatively, the underlying idea of stakeholder theory redefines the purpose of the firm, which is to pursue both financial and non-economic performance. The notion of sustainability or sustainable development was contextually defined by the World Commission on Environment and Development (WCED) as "development which meets the needs of present without compromising the ability of future generations to meet their own needs" [10]. The two words—sustainability and development—need to be held together and without sacrificing the other if we want to pursue sustainable development in any industry. Therefore, it concludes that *balance* is at the heart of sustainable development.

The business perspective generally agrees that corporations are the most important players in pursuit of sustainability. The board of directors is the central body of governance structure within a corporation, which serves as monitor of top management on behalf of shareholders. Recently, the new thinking on the role of board shifts from "monitoring" to "mediating". The board's main task as a mediating hierarchy is to *balance* team members' competing interests in a way that keeps everyone contributing their efforts altogether toward the success of a corporation [11]. These interests need to reconcile with the societal and environmental dimension when pursuing economic growth of business. Governance function constitutes a key factor in the pursuit of sustainability in that material decisions have to be made by board of directors when facing conflicts of interest. To make the disclosure of corporation's performance more accurate to the public, the *triple bottom line* coined by John Elkington, the founder of a think-tank called Sustain Ability, implied the inclusion in financial reports regarding social and environmental impacts [12]. Similarly, the "balanced scorecard", which is developed under the guise of sustainability, gives equal weight to customer and employee relationship factors and financial factors [13]. In addition, the GRI (Global Reporting Initiative) Sustainability Reporting Guidelines emphasize the need for an extension of traditional financial accounting to a more comprehensive balance sheet, which includes measures of social, economic, and environmental performance.

Climate change has emerged as one of the most important and urgent corporate responsibility issues. To cope with the threat of climate change, Federal Highway Administration already conducted an assessment of coastal bridges potentially vulnerable to failure from coastal storm events. Furthermore, they established adaptation activities through inter-agency cooperation and building strong partnerships with support from the local, state, and tribal level to combat the impacts of extreme weather [14]. In Taiwan, THB has applied "carbon footprint management" in the Suhua Highway reconstruction project, which has cost over 1.6 billion U.S. dollars to fix the root cause of the existing vulnerable coastal roadway system since 2010. Through the establishment of carbon accounting framework and carbon appraisal method, together with appropriate carbon-deduction strategy, the whole monitoring results are expected to be verified by international certified agents [15].

The asphalt factory and pavement industry generally consumes immense resources and incurs pollution to the environment during the stages of pavement production and construction. To pursue the sustainable development in pavement context, it is suggested that more attention is being paid to *balance* the economic considerations and engineering strategies of infrastructure development with the need for environmental stewardship [16]. Currently, with limited budgets and increasing pressure from related stakeholders, as well as the threat of climate change, we need brand-new thinking for the implementation of PMS. Based on the analysis of these two sections, we may draw the conclusion that the governance notion by addressing *balance* and *mediation* on the conflicts of interest among stakeholders can help top management dealing with inter-agency affairs and aligning the customer's need with the road agency's goal. Also, an effective and sound governance structure accountable for related customers could be beneficial to the pavement administration. Theoretical discourse mentioned above suggests that governance may link to sustainability in that its function plays a key role in pursuit of sustainability. Some studies untaken by road transport agencies further reveal that governance and sustainability could interconnect to performance measurement in the pavement context.

PMS Implementation in Taiwan

According to Smith (1992) [17], in the early years of PMS implementation and development in the San Francisco Bay Area, some of the biggest barriers were "technical". With the rapid development of technology, now the state-of-the-art PMS can provide a more user-friendly environment. Many of the most

Table 1. Comparisons for Barriers in PMS Implementation between Taiwan and USA.

Taiwan	USA.	Comparisons and Analyses
Resistance to Change	Fear of Exposure to PMS	Fear of PMS Technique Leads to Resistance to Change
Bureaucratic Culture	Turf Protection	Turf Issue not Common in Taiwan due to PMS Still not Prevalent
Low Organizational Level	Low Organizational Level	Engineers Involved in PMS Sit on Low Level
Lack of Accurate Understanding	Black-box PMS	Both May Hinder the Development of PMS
Limited Use of PMS Result	Matched to Agency Needs	PMS's Result Still Require Manual Effort to Match to Agency Needs
Competing Funding Needs	Competing Funding Needs	Tight Financial Budget Leads to the Status for Competing Funding Needs
One Person Sow	One Person Show	Few People Realize the Sophisticated Technique of PMS May Contribute to "One Person Show"
Lack of Standardization	Every Agency Wants to Develop its Unique PMS System	System Standardization Helps saving Money and can be Beneficial to PMS Implementation

troublesome barriers to implementation now are "people" related. To realize the PMS implementation in Taiwan, some in-depth interviews with pavement engineers and top management in the Taiwan Freeway Bureau (TFB) and Taiwan Highway Bureau (THB) have been conducted for qualitative analysis. Due to the immature status of most local roadway agencies in Taiwan, comparisons are made with the early stage of implementation process of the US. The comparisons on barriers encountered in PMS implementation between both countries are summarized as Table 1, of which most comparison items are cited from Smith's survey.

It is found that "low organizational level", "competing funding needs", and "one person show" are common to both countries. It merits attention that "resistance to change" or "fear of exposure to PMS" is inevitable in the early stage of implementation on both sides. PMS can provide information on planning or funding need, so that information is power in an organization. The circumscribed area developed by those who can access to such information becomes their turf. While "turf protection" emerges in the U.S., this symptom has not been found yet in Taiwan since it is not prevalent in PMS implementation here. In the early stage, PMS software is considered as a "black box" because the developer purposely refused to describe the programmed analysis procedures. Indeed, it is noted that PMS is a concept rather than a computer system only, and the software is a decision support tool. People involved in PMS lacking accurate understanding of black-box may hinder the development of PMS. While many US' states have reached system maturity due to the pressure of Federal Highway's funding policy, the comparison revealed that limited local pavement agencies in Taiwan have developed their comprehensive system well and used PMS for decision-making.

Our survey indicates that only IRI (international roughness index) and PCI (pavement condition index) are employed by TFB; IRI and rutting index are used by THB. IRI and rutting data are evaluated in the annual maintenance audit and competition program; however, only some district maintenance offices use these data for benchmarking purpose in THB. Fortunately, according to declaration of THB's director, a comprehensive pavement maintenance and management system (PMMS) will be developed by the end of 2013. It is expected that more performance indexes such as "riding comfort index" and "distress manifestation index" can be incorporated into the existing system. In the long term, PMMS can provide the real assistance for decision-making on the maintenance works, which comprise highway networks with total length over 5,000 kilometers. Therefore, there is much room for progress in PMS implementation both by central and local government in Taiwan.

A Holistic Framework for Sustainability in Pavement Management

System analysis aims to gain insights into the whole by understanding the linkages, interactions, and processes between the elements that comprise the whole system. This thinking was applied to the problem of managing pavements in 1970s. Subsequently, the system analysis of managing pavement is known as Pavement Management Systems [18]. Very much like system analysis, a holistic approach means that based on the principle that a whole thing or being is more than just a collection of parts added together. As sustainable construction is efficiently achieved through the collaboration of supply chain under the thinking of whole life-cycle, the sustainable development in pavement management would not confine to this stage alone. A holistic perspective applied to pavement management allows us to take from a broad and comprehensive consideration within the pavement context. It starts from pavement production, and goes up-stream through pavement management to pavement infrastructure, further reaching the whole road transport system which constitutes a holistic framework for sustainability in pavement context.

In Fig. 1 (source revised from Barrett et al. 1998 [19]), moving from Level A to Level D involves increasing spatial boundary and time frame shown on the vertical axis, as well as increasing complexity, concern for related stakeholders, and need for collaboration and integration, with other sectors shown on horizontal axis. The primary consequence of this nested context is that any management decision will affect several scales (higher and lower levels) Thus, interaction and inter-relationship among different levels need to be taken into account continuously. For instance, new construction and maintenance works are managed by different departments in Taiwan Highway Bureau. Although the main advantage is that pavement works are done by each professional entity, both parties may claim irresponsibility for some

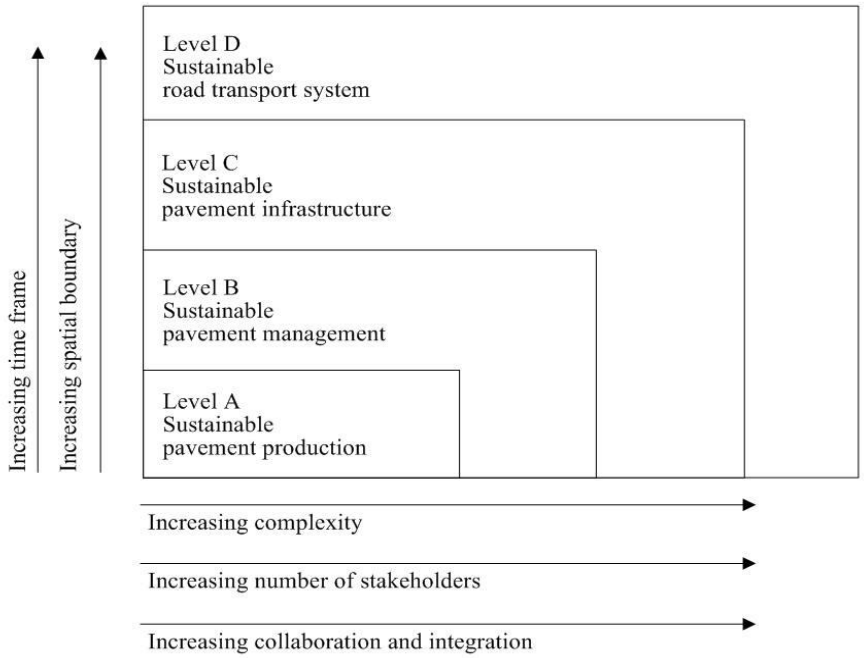

Fig. 1. A Holistic Framework for Sustainability in Pavement Context**.**

Table 2. Key Sustainable Strategies for Each Level of Pavement Management.

Stage	Sustainable Strategies
Pavement Construction	Apply Life-cycle Concept into Whole Process; Utilize Recycling Asphalt Pavement; Improve Asphalt Plant Efficiency; Reduce Pollution and Emission; Invent other Recycled Materials
Pavement Management	Adopt a Sound Governance Structure; Enhance on-job Training; Build an Accurate Knowledge on PMS; Create an Efficient and Compatible PMS System
Pavement Infrastructure	Adopt Environmental Oriented Design (Green-roads, for Example); Innovation of Construction Technique; Develop a Fair and Efficient Outsourcing Rule; Enhance Quality Management and Audit Control
Road Transport System	Enhance Inter-agencies Partnership; Encourage Stakeholder Dialogue and Engagement; Coordinate with Utility Firms; Mitigation and Adaptation for Climate Change; Quick Responsiveness to Societal Needs (Mobility, Accessibility, Safety and Equity)

defective works in the pavement infrastructure. Thus, under governance and holistic thinking, it is worth refining the governance structure and incorporating the maintenance concept into the planning and design phase so that it can be beneficial to increase facility life and shrink maintenance costs in the future.

The different perspective to sustainability falls along a spectrum, with "narrow" view at one hand and "broad" view placed at the other. Similarly, research on pavement sustainability ranges from the broad concept that incorporates all aspects of sustainability to the narrow view focusing on specific sustainable features, such as recycling material or energy efficiency [20]. To help attain the sustainable development in pavement context, it needs to establish key sustainable strategies for each stage from Level A to level D. In Level A, focus is on reuse of asphalt recycling material, reduction on pollution, and improvement on production efficiency. Next, emphasis is laid on governance structure and pavement management issues for PMS in Level B. Further in Level C, strategies ranging from design phase to construction phase are found, along with feasible measures adopted by pavement agency regarding procurement methods and internal control. Finally, the broad view related to the whole transport system in Level D strategies include inter-agency partnership; stakeholder dialogue and engagement; collaboration with other agencies beyond pavement administration; and quick responsiveness to societal needs. The detailed sustainable strategies for the whole stages are summarized as Table 2.

Empirical Study

"Key performance indicators will be dramatically different if sustainability is the key driver for decision making," said a Transit New Zealand official. The scan team of FHWA met with officials from transportation departments of countries such as Canada, Japan, and New Zealand. It was found that some performance-based planning and decision-making framework toward sustainability has been developed [1]. In this empirical study, we borrow material from FHWA, of which seven items of the strategic goal are identified as "customer needs", together with twenty five performance indicators related to economic, social, and environmental components as measuring "technical requirements" of the road transport system in Taiwan. We sent 30 questionnaires and received 24 effective respondents who were pavement engineers in the roadway maintenance office and top management officials in

Table 3. Relative Importance for Customers' Needs

Customers' Needs	Importance	Customers' Needs	Importance
Ensure High Standards for Safe and Secure Transport System	0.323	Transportation Industry becomes More Competitive	0.047
Contribute to Economic Growth and Social Development	0.065	Enhance Financial Performance	0.151
Protect the Physical Environment	0.046	Achieve Excellent Customer Service	0.046
Provide a Safe and Reliable Highway System	0.323		

the Taiwan Highway Bureau. The study process is summarized as follow:

1. Build the relative importance for customers' needs by AHP

Analytical Hierarchy Process (AHP) is a methodology to develop a hierarchy of factors influencing the final decision. At the top level of the hierarchy is the decision or objective itself, and the bottom level consists of the alternatives under evaluation. There are four major steps in applying AHP in our case. First, this approach requires analysts to systematically elicit inputs by asking respondents from THB to evaluate the relative importance of one factor when compared to another factor—pairwise comparisons—with respect to a third controlling factor. Secondly, the recommended value assigned to the comparisons of the factors is made in the range 1/9 to 9, where a value of 9 means a factor is extremely dominant or more important than another, 1 means indifference between the factors, and 1/9 means one factor is dominated by the other [22]. Third, calculate the relative ranking of factors with respect to the corresponding controlling factor for each pairwise comparison matrix obtained from the first step. An eigenvalue problem needs to be solved to estimate these relative importance weights in this step. Lastly, through the development of comparison matrix, the relative importance of these customers' needs can be obtained, as listed in Table 3.

2. Develop QFD Matrix for road transport system

Quality Function Deployment (QFD) is a tool that helps the firms to identify the customers' needs in the early stage of product development. The customers' needs are then translated into technical requirements further into the design and manufacturing process. With the advantage of QFD, the firms could provide products that satisfy customers' needs [23]. The QFD matrix in Table 4 indicates the relationship between customers' needs and technical requirements for the road transport system with value in the range 0 to 9, where 0 means unimportant, and 9 means extremely important. The row "importance of technical requirements" can be obtained with customers' needs multiplied by technical requirements. It implies that the relative importance of each performance indicator incorporate customers' needs into technical requirements. Besides, the row "modified importance" is obtained with each technical requirement importance divided by the sum of importance of 25 items.

3. Build the weights of performance indicators based on AHP

Because numerous indicators (or factors) may lead to unconformity on weight's transitivity, the test of consistency using consistency ratio (CR) is required, which generally suggests an acceptable rating when CR < 0.1. In our study, there 9 respondents pass this test on the performance indicator "ensure high standards for safe and secure transport system". If the 25 items are all used for performance indicators, too many items may confuse respondents who are asked if they understand the actual meaning for each item. It is suggested that the value of modified importance smaller than 0.05 be eliminated on the survey sheet. Finally, 10 indicators for technical requirements are left, which can explain 77.16% of total importance may present the overall transport performance. The value 77.16% is the sum of the revised importance of those largest 10 indicators. Thus, the revised weights of those 10 performance indicators based on AHP are shown as Table 5.

4. Combine AHP and DEA into a revised weight

Data Envelop Analysis (DEA) is a multi-criteria approach widely used in the evaluation of performance of decision-making units (DMUs) such as business units or government agencies. The main feature is that DEA is a methodology directed to frontiers rather than central tendencies. While statistical procedures are based on central tendencies, DEA is a process of extremities. Also, it has the advantage of avoiding the need for assigning *a priori* measures of relative importance to any input or output [24]. In this study, we choose all the 32 district maintenance offices of Taiwan Highway Bureau as DMUs. We build an input-output matrix based on the 10 performance indicators through normalization on the scores of 32 maintenance offices. It is found that the top three prioritized performance indicators are "maintenance cost vs. budget", "costs of safe device", and "roughness index of jurisdiction" in order. However, the top three prioritized performance indicators based on AHP with subjective judgment are "roughness index", "numbers of accident compared to last year", and "cost of safe device". Finally, to compromise the subjective weight of AHP and objective weight of DEA, the weights have been revised using Eq. (1). Computation results for revised weights are produced as Table 6. It is found that "roughness index", "annual budget per square meter", and "cost of safe device per square meter" rank as top three prioritized indicators in order. Alternatively, it indicates that safety and smooth pavement surface are top issues for performance measurement, which is consistent with our metempirical knowledge.

$$w_i^T = \frac{w_i v_i}{\sum_{j=1}^{n} w_j v_j} \tag{1}$$

w_i^T : revised weight for i_{th} indicator

w_i : revised weight for i_{th} indicator from AHP

v_i : revised weight for i_{th} indicator from DEA

Verification

In contrast to the previous DEA method adopted by local researchers on pavement performance, we use the revised weights of performance indicators as a maintenance evaluation model to test 32 district maintenance offices. We consult with senior pavement engineers of THB and ask them to score their maintenance offices

Table 4. Quality Function Deployment Matrix for Road Transport System.

		Technical Requirements for Road Transport System																								
Customers' Needs	Importance of Customers' Needs	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Ensure High Standards for Safe and Secure Transport System	0.323	9	3	3	9	9	3	3	0	3	0	3	0	0	0	0	9	3	0	0	9	9	3	0	0	3
Contribute to Economic Growth and Social Development	0.065	3	3	3	0	0	0	9	9	3	9	3	0	0	0	0	3	0	0	3	3	3	0	0	0	0
Protect the Physical Environment	0.046	0	0	0	0	0	0	0	0	0	0	3	3	3	3	0	0	0	0	3	0	0	0	0	0	0
Provide a Safe and Reliable Highway System	0.323	9	3	3	3	3	0	0	0	3	0	0	0	0	0	9	3	9	0	0	0	3	3	0	0	0
Transportation Industry becomes More Competitive	0.047	0	3	3	0	9	0	0	0	3	0	0	0	0	0	0	0	0	3	3	0	0	0	0	3	3
Enhance Financial Performance	0.151	3	0	0	0	0	3	0	0	3	0	0	0	0	0	9	9	3	0	0	3	9	9	0	0	0
Achieve Excellent Customer Service	0.046	9	3	3	0	3	0	3	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	3	3	0
Importance of Technical Requirement		6.88	2.41	2.41	3.88	4.44	1.42	1.69	0.59	2.73	0.59	1.44	0.14	0.14	0.14	4.27	5.43	4.33	0.14	0.47	3.56	5.43	3.30	0.14	0.28	1.11
Modified Importance		0.12	0.04	0.04	0.07	0.08	0.02	0.03	0.01	0.05	0.01	0.03	0.00	0.00	0.00	0.07	0.09	0.08	0.00	0.01	0.06	0.09	0.06	0.00	0.00	0.02

Note： 1. Reduced accident rate; 2. High public confidence in travel; 3. Stakeholder understanding of safety benefits and issues; 4. reduced security risks ; 5. A regulated community that is engaged and well informed; 6. Increased compliance rate; 7. Service and price levels; 8. Current and prospective viability of system components; 9. Worsening congestion trend in urban area is mitigated; 10. Mobility is improved for highways servicing major economic gateway; 11. Increase public awareness of the environmental impact of transportation activities; 12. Increase in the use of more energy-efficient vehicles; 13. Reduction in annual vehicle kilometers; 14. Reduced greenhouse gas emissions and other air pollutants from transportation sources; 15. Contractors maintain the highway system to a high standard; 16. Existing main highway system is systematically preserved and replaced at least life cycle cost; 17. Highway safety and reliability are improved; 18. Regulatory burden on the public, industry and stakeholders is reduced; 19. Procedures for commercial passenger carriers are simplified, with safety as primary criterion; 20. Actual investment vs. budget; 21.Cost to taxpayer; 22. Trend in operational costs; 23. Ratio of tax revenue from transportation and others; 24. Excellent service to customers and employee satisfaction with organizational improvement; 25. Employees are provided with support, training and working environment.

Table 5. Weights of Performance Indicators Based on AHP.

Performance indicator	Weight
Ensure High Standards for Safe and Secure Transport System	0.397
Reduced Accident Rate	0.191
Reduced Security Risks	0.161
A Regulated Community that is Engaged and well Informed	0.045
Contribute to Economic Growth and Social Development	0.090
Worsening Congestion Trend in Urban Area is Mitigated	0.090
Provide a Safe and Reliable Highway System	0.397
Contractors Maintain the Highway System to a High Standard	0.111
Existing Highway System is Systematically Preserved and Replaced at Least Life Cycle Cost	0.232
Highway Safety and Reliability are Improved	0.054
Enhance Financial Performance	0.116
Actual Investment vs. Budget	0.074
Cost to Taxpayer	0.012
Trend in Operational Cost	0.030

Table 6. Revised Weights for Performance Indicators.

Performance Indicators	AHP Weight	DEA Weight	Revised Weight	Performance Indicators	AHP Weight	DEA Weight	Revised Weight
No. of Accident Compared to Last Year	0.191	0.142	0.301	% of Jurisdiction where Roughness < 3m/km	0.232	0.144	0.312
Costs of Safe Device / Square Meter	0.161	0.172	0.307	Difference on Maintenance Cost Before and After	0.054	0.005	0.003
No. of Warning Sign / Square Meter	0.045	0.071	0.036	Budget Implementation Rate	0.074	0.002	0.001
% of Jurisdiction where Service Level Higher than C	0.090	0.119	0.119	Maintenance Cost / Budget	0.012	0.336	0.038
Maintenance Cost / Kilometer	0.111	0.004	0.178	Annual Budget / Square Meter	0.030	0.004	0.312

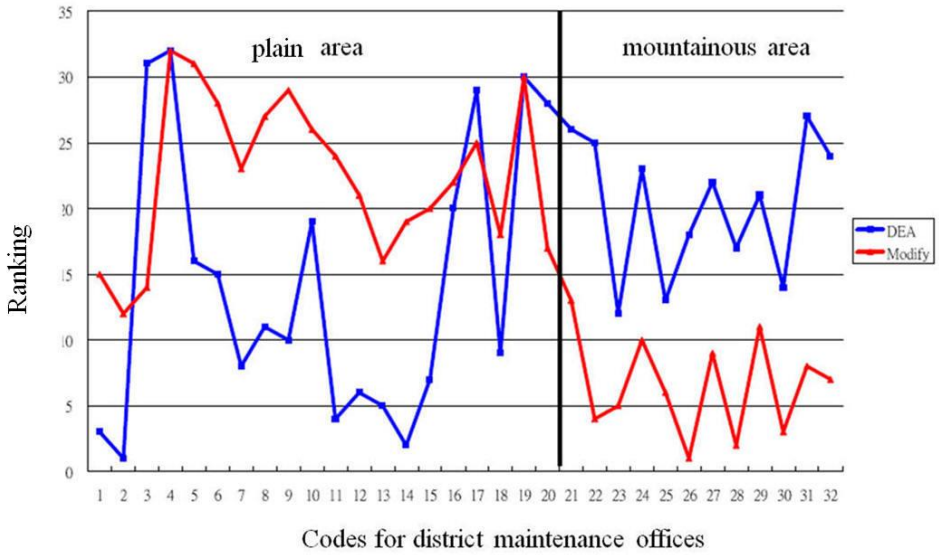

Fig. 2. Ranking on Performance Measurement for 32 District Maintenance Offices Using DEA and Modified Models.

using 10 performance indicators. Then, ranking for each maintenance office can be attained based on its score given by pavement engineers. Rankings on performance measurement for 32 district maintenance offices using the DEA method and modified model (revised weights) are plotted as Fig. 2. It is found that the rankings on performance measurement between plain and mountainous offices using DEA method did not show a significant difference. However, mountainous offices generally receive a better ranking than plain offices do if using revised weights as modified model. Therefore, it is proven that such a modified model can distinguish the emphasis given to performance indicators that are significantly different between offices located in mountainous and plain areas.

Conclusion

The construction and production activities of the pavement industry generally consume many resources, create environmental pollution, and impact society. Therefore, consideration within the pavement context should be paid on stakeholders' interests rather than the pursuit of cost minimization or profit maximization alone. We explore sustainability through stakeholder theory and induce that governance function plays an important role in pursuit of sustainability. The governance notion and a sound governance structure can help top management dealing with inter-agency affairs and aligning customers' need with an agency's goal. To establish a holistic framework applied to pavement management, some key sustainable strategies for each level of pavement context have been built.

In the empirical study, we use QFD matrix that can incorporate 7 customer needs into 25 technical requirements. After the revision of relative importance, 10 performance indicators remain, which can explain the 77.16% of total importance that will be recommended to pavement engineers to use in the future. It is found that top three prioritized performance indicators are "maintenance cost vs. budget", "costs of safe device", and "roughness index of jurisdiction" in order by the DEA method. However, the top three prioritized performance indicators based on AHP are "roughness index", "numbers of accident compared to last year", and "cost of safe device". Finally, the revised weights on AHP and DEA reveal that "roughness index", "annual budget per square meter", and "cost of safe device per square meter" rank as top three prioritized indicators. Those indicators all related to safe and smooth pavement conditions, which are selected as top issues for performance measurement, consistent with our metempirical knowledge. Also, it is proven that the modified model using revised weights can distinguish the performance measurement significantly different between offices located in mountainous and plain areas.

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