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Assessment framework for pavement material and technology elements in green highway index

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ABSTRACT

Sustainability concept in highway development needs to be addressed critically in order to alleviate the effect of global warming and depletion of natural resources issues. In Malaysia, there are a lot of alternative pavement materials and technology that have been introduced to the industry so that green highway can be achieved. However, Malaysia does not have any tools to assess the level of greenness for any highway projects and still lacks of awareness in sustainable highway. Thus, the main objective of this study is to develop an assessment framework for pavement material and technology elements in Malaysia green highway index. An extensive literature were reviewed and expert discussion was conducted to identify the 13 vital elements of pavement material and technology which include regional materials; reuse of top soil; reused and/or recycled of non-hazardous materials; earthwork balance; usage of industrial by-products; subgrade improvement/soil stabilization, permeable pavement, pavement design life, quiet pavement, recycled pavement or new sustainable techniques; cool pavement; soil biotechnical engineering treatment; and green techniques. Questionnaires were distributed among the 109 highway practitioners to obtain their agreement level on these elements. Then, all the data were analyzed by using factor analysis approach which generated from Statistical Package for Social Science (SPSS) software. The assessment score of each element was calculated from the findings and assessment framework for pavement material and technology elements was established. Results show that all the elements were grouped into four main factor namely environmental control, economical resources, innovation technology and erosion control with four point was considered as a maximum point score to be achieved in green highway assessment framework. Hence, the research clearly indicates that these elements are essential to be implemented in Malaysia's highway development indirectly as an encouragement to improve the performance of transportation sector.

1. Introduction

Over the last decade, the concern on sustainability in the civil engineering industry is always debated among the parties involved due to its potential in affecting the changes in many aspects (Steele et al., 2002). Bruntland (1987) has defined the sustainable development as a development that meets the present's needs without diminishing the needs of future generations. Thus, there are three major aspects that need to be taken into consideration in order to achieve the sustainability development which include economic, social, and environmental. As a basic need for human beings, the demand for highway development keeps on continuously growing rapidly with the increasing of population growth, urbanization, and industrialization.

Parallel to its importance, transportation is a large contributor to the environmental impact, especially related to the large emissions of harmful CO_2 gas that contribute to the global warming effect. According to AASHTO (2009), transportation sector consumes 22 percent of global energy, burns 25 percent of fossil fuel, and releases about 30 percent of air pollution and greenhouse gasses. Hence, this sector can cause toxic pollution, changing of global climate, ecosystem disruption, and natural resources depletion

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especially aggregates and binders due to the higher demand in pavement construction. According to Balubaid et al. (2015), growing concerns to the shortage supply of non-renewable material for construction and increasing cost of natural resources production have encouraged the researchers to initiate in finding an alternative solution to overcome these problems. In Malaysia, five main sector namely energy generation sector, transportation sector, industry and commerce sector, residential building sector and others sector were selected to evaluate the top producer of CO_2 gas emission. Statistic reported by Shamsuddin et al. (2014) has revealed that the transportation sector represented as the second highest contributor of gas CO_2 emissions apart from the energy generation sector as illustrated in Fig. 1. In addition, the generation of these hazardous gases shows an increment quantity from years 1971–2010 as compared to the other sectors. In an economic aspect, the application of waste materials is seen to provide high potential to replace conventional materials as they are proven in exhibiting good performance as well as natural resources. Although the environmental pollution cannot be avoided during any projects, they can be controlled and alleviated in terms of the pollutant amount in the surrounding if the sustainable pattern practice is implemented.

Green highway is one of the sustainable practices that have been introduced in highway development by using environmental approach throughout every stage of the projects. In Malaysia, there are few studies regarding the sustainable elements but they are not fully implemented in the highway industry due to the lack of awareness on the sustainability concept (Bujang et al., 2014; Aifa et al., 2015). In contrast to the other country such as Norway, the number of vehicle tires collected was about 32,000 tons per year and the placement of whole tires in landfill was prohibited by the Norwegian legislation (Johnsen, 2003). As a result, new technology was introduced and proved by Reddy et al. (2010) in the performance of the cover system with a shredded scrap tire drainage which was found to be similar as the cover system with a sand drainage layer. Apart from that, it shows that the usage of shredded tires as a drainage material is an efficient, economical, and practical solution for mitigating scrap tire disposal problem.

There are many types of sustainable elements can be applied in highway development but the level of greenness for each highway cannot be measured without a tool. Thus, rating system can be recognized as a performance measurer or baseline reference that function as a guidance to adopt the sustainable elements in highway construction other than fulfilling all the standard requirements. By applying these rating systems, all the highway projects can be evaluated and assessed based on the implementation of green material and technology especially on the low impact elements toward the environment, economy, and society such as the application of warm mix asphalt (WMA) technique in the highway development (Bujang et al., 2014).

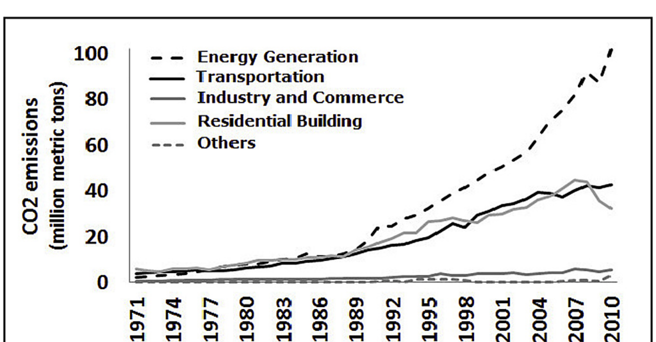

Fig. 1. The trends of CO2 emission by different sectors in Malaysia during 1971–2010 (Source: Shamsuddin et al., 2014).

Malaysia is expected to experience the critical reduction amount of natural aggregates and binders in the future if no actions are taken to overcome these matters. Besides, the depletion of the existing natural pavement materials resources is notable with the increment of waste materials generated in the landfills which do not assure the sustainability for the future generations (Idham and Hainin, 2015; Azahar et al., 2016). Therefore, pavement material and technology elements in green highway rating system should be promoted in Malaysia in order to make this concept more applicable and induce an awareness improvement among the parties involved in highway projects.

This paper presents the development of assessment framework for pavement material and technology elements in the green highway index. This research attempts to enhance the green awareness among the authorities and concessionaires in upgrading the highway development in Malaysia. Besides, it may help the government to make a policy on sustainable highway development and assist the authorities in assessing the highway projects. In addition, the developed framework is suitable for tropical weather, environment, cultural, and social needs that will be well-contributed to the nation.

2. Methodology

In order to fulfill the objectives, this study was carried out in three phases as shown in Fig. 2. Phase 1 involved the extensive literature review and expert discussion for identifying the critical elements of pavement material and technology in highway construction. Data collection and analysis were done in Phase 2 by using questionnaire surveys and factor analysis method respectively. The assessment framework which was used to evaluate the highway projects in terms of pavement material and technology elements was developed in Phase 3.

2.1. Phase 1: literature review and expert discussion

Phase 1 reviewed on the effect of natural resources, energy and gas emission that are released from the pavement construction as shown in Fig. 3 and Fig. 4 in order to identify the main problem area. Next, a literature from the previous research was reviewed comprehensively to both define and refine the current understanding of how the sustainability concept plays its roles in pavement industry. Hence, the identification of pavement material and technology elements for Malaysia green highway index were acknowledged as a general outcome from the literature review. In order to verify the proposed elements, a workshop was conducted with participation of 30 highway experts from local authorities in road construction and management. The views, suggestions, and knowledge of parties involved in highway development have been solicited with regards to improve the proposed elements. The workshop was recognized as a pilot survey for testing whether the questionnaire draft is intelligible, understandable to answer, and unambiguous before the finalized questionnaires were distributed to the respondents.

2.2. Phase 2: data collection and analysis

There were 13 elements selected in the questionnaire survey which had been extracted from intensive literature review and approved during the expert discussion in order to determine the agreement level of each element that is suitable for

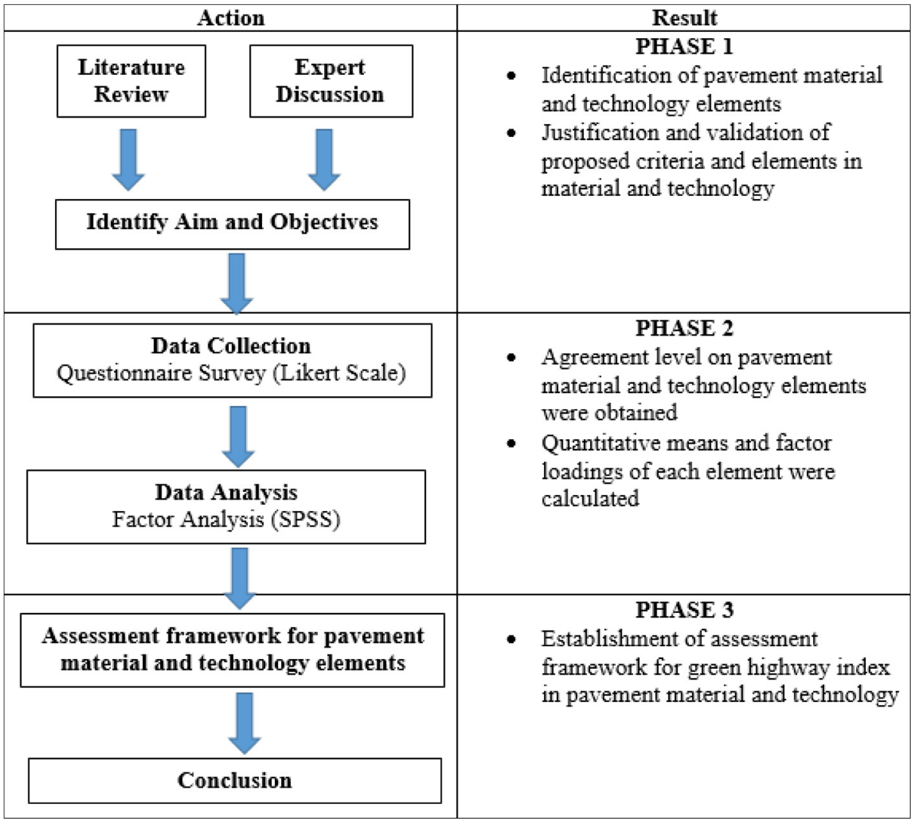

Fig. 2. Research operational framework.

implementation in Malaysia's highway construction. The questionnaire survey was comprised of 13 Likert-type-five-scale question, where scale 1 refers to strongly disagree and scale 5 refers to strongly agree (Marzouk et al., 2014; Husin et al., 2016). All the questionnaires were distributed over to 22 highway concessionaires and consultant firms with a total of 109 respondents that have valuable experiences in highway development. In addition, all the questionnaires were distributed by manually and an informal interview was conducted during the survey. The purpose of the interview was to provide green concept understandings and avoid any discrepancies among the respondents regarding on the questionnaires.

Then, all the data and information obtained from the questionnaires were analyzed by using SPSS software version 18.0 to achieve the objectives of this study. SPSS is a useful tool among researchers for analyzing the statistical problems in social sciences. All the data were tabulated to calculate the mean value of each pavement material and technology elements by using the similar classification of the rating scale which was proposed by Abd. Majid and McCaffer (1997). The significant and acceptable mean value in this research is equal or more than 3.5. Equation (1) shows the formula of the average index based on study done by Al-Hammad and Assaf (1996).

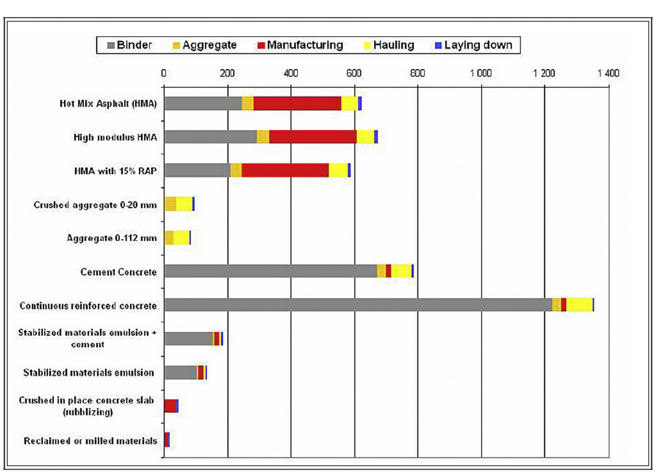

Fig. 3. Energy consumption for the manufacture and laying of pavement materials.

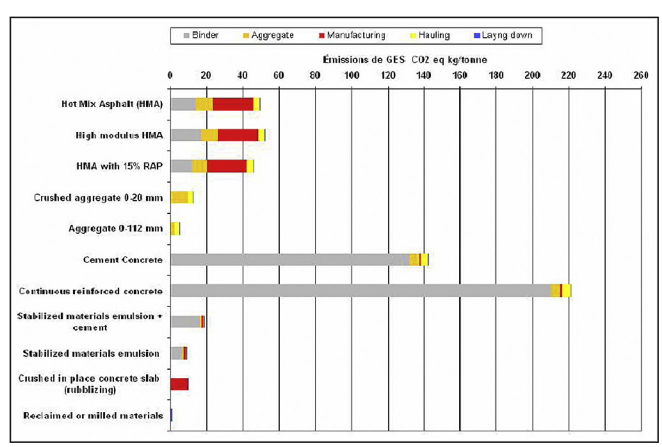

Fig. 4. Gas emissions during manufacture and construction of pavement materials(Source: Dorchies, 2008).

Table 1
Pavement material and technology elements.

Criteria	Sub-Criteria
Recycled and Reused Materials	Reuse of top soil Reused and recycled non-hazardous materials Reused and recycled industrial by-products Recycled materials for sub-grade improvement/soil stabilization
Regional Materials	Usage of local materials Earthwork balance
Pavement Design Life	Long lasting pavement design life
Cool Pavement	Reflectance of sunlight energy (Albedo and Solar Reflectance Index)
Reuse Pavement	Usage of Reclaimed Asphalt Pavement (RAP) and Recycled Concrete Material (RCM)
Permeable Pavement	Storm-water runoff quality and flow water control improvement
Quiet Pavement	Reduction of noise level
Erosion Control	Soil biotechnical engineering treatments Green techniques

$$\text{Average index} = \frac{\sum alxl}{\sum xl} \quad (1)$$

where:

al = Likert scale (1 = strongly disagree; 2 = disagree; 3 = moderate; 4 = agree; 5 = strongly agree).

xl = Number of respondent.

Next, data was analyzed by using factor analysis method that involves a technique of grouping and reducing an original number of variables into a smaller set of factors with a minimum loss of data (Hair et al., 2010). Moreover, Kaiser-Meyer-Olkin (KMO) test and Bartlett's test need to be conducted to ensure the set of data can be analyzed by using factor analysis. According to Kaiser (1974), the acceptable value of KMO test is more than 0.5, however Hutcheson and Sofroniou (1999) stated that the ideal KMO value is between 0.7 and 0.8. For Bartlett's test, if $r = 1$, it indicates that each element correlates perfectly with itself while if $r = 0$, it means that there is no correlation between the elements. Hence, the statistical significance value should be less than the significance level value, $\alpha = 0.001$ (0.1%). The factor that has eigenvalue more than one will be retained for analysis and be the most utilised in practice (Kaiser, 1960; Fabrigar et al., 1999).

Factor score is a method that is used for calculating the point score for each element in a set of factors. Based on study done by Dien and Frishkoff (2005) and DiStefano et al. (2009), factor score is acquired by multiplying the mean values with factor loadings as shown in equation (2). In this study, each pavement material and technology elements will have different mean values and factor loadings due to the different agreement levels of every respondent involved. Therefore, point score of each element will be different according to their mean values and factor loadings obtained. These

Table 2
Assessment framework for pavement material and technology elements.

Factor	Elements	Elements Description	Point Score	Point score for each factor	Total Point Score
Environmental Control	Permeable pavement	Allow the application of porous pavement in any highway project.	**4**	16	**47**
	Pavement design life	Allow long lasting pavement design life to avoid frequent rehabilitation, thus depending on the Average Daily Traffic, ADT and types of pavement that will be going to construct.	**3**		
	Regional materials	Allow the usage of local materials in highway project depending on the location of the project site, whenever practical.	**3**		
	Quiet pavement	The speed that more than 80 km/h could contribute noise disruption and the range of noise level is depending on the types of surface pavement	**3**		
	Recycle pavement or new sustainable techniques	Allow the usage of recycle pavement such as Reclaimed Asphalt Pavement (RAP) or Recycled Concrete Material (RCM) to produce new pavement or implement any new sustainable techniques in highway construction.	**3**		
Economical Resources	Reuse of topsoil	Allow the reuse of top soil that has been removed from grading as long as it is non-contaminated soils.	**4**	11	
	Reused and/or Recycled of non-hazardous materials	Allow the reused and recycled non-hazardous materials in design or during highway construction for other base layers, shoulder, drainage, and highway furniture (signage, guardrail, etc.)	**4**		
	Earthwork balance	Balancing cut and fill quantities can reduce the need for transport of earthen materials	**3**		
Innovation Technology	Usage of industrial by-products	Allow the locally industrial by-products to be reused and recycled in highway construction either in flexible or rigid pavement such as by using steel slag, fly ash, crumb rubber, etc.	**4**	12	
	Cool pavement	Any surface of pavement with lighter colour has higher albedo effect which indicates high reflectance of sunlight from surface pavement whereas darker colour has lower albedo effect which shows the low reflectance of sunlight from surface pavement.	**4**		
	Subgrade improvement/ Soil stabilization	Allow the usage of recycled materials for sub-grade improvement/soil stabilization, if it can be proved that the process will reduce the consumption of virgin materials, cost of project, and will not bring any harm/effect to the road users and environment.	**4**		
Erosion Control	Soil biotechnical engineering treatment	Any highway project that utilizes soil biotechnical engineering treatments which is the combination of plant materials and structural elements that can protect slope and control the erosion. for examples, vegetated gabion, vegetated crib wall, etc.	**4**	8	
	Green techniques	Any highway project that implement green techniques in order to control the soil erosion, protect the slope and embankment such as turfing, planting native vegetation, hydro seeding, soil-tire vegetation, etc.	**4**		

Table 3
Pilot test for highway A.

Factor	Elements	Elements Description	Point Score	Point score for each factor	Total Point Score
Environmental Control	Permeable pavement	Allow the application of porous pavement in any highway project.	**0**	1	**2**
	Pavement design life	Allow long lasting pavement design life to avoid frequent rehabilitation, thus depending on the Average Daily Traffic, ADT and types of pavement that will be going to construct.	**0**		
	Regional materials	Allow the usage of local materials in highway project depending on the location of the project site, whenever practical.	**0**		
	Quiet pavement	The speed that more than 80 km/h could contribute noise disruption and the range of noise level is depending on the types of surface pavement	**1**		
	Recycle pavement or new sustainable techniques	Allow the usage of recycle pavement such as Reclaimed Asphalt Pavement (RAP) or Recycled Concrete Material (RCM) to produce new pavement or implement any new sustainable techniques in highway construction.	**0**		
Economical Resources	Reuse of topsoil	Allow the reuse of top soil that has been removed from grading as long as it is non-contaminated soils.	**0**	0	
	Reused and/or Recycled of non-hazardous materials	Allow the reused and recycled non-hazardous materials in design or during highway construction for other base layers, shoulder, drainage, and highway furniture (signage, guardrail, etc.)	**0**		
	Earthwork balance	Balancing cut and fill quantities can reduce the need for transport of earthen materials	**0**		
Innovation Technology	Usage of industrial by-products	Allow the locally industrial by-products to be reused and recycled in highway construction either in flexible or rigid pavement such as by using steel slag, fly ash, crumb rubber, etc.	**0**	1	
	Cool pavement	Any surface of pavement with lighter colour has higher albedo effect which indicates high reflectance of sunlight from surface pavement whereas darker colour has lower albedo effect which shows the low reflectance of sunlight from surface pavement.	**1**		
	Subgrade improvement/ Soil stabilization	Allow the usage of recycled materials for sub-grade improvement/soil stabilization, if it can be proved that the process will reduce the consumption of virgin materials, cost of project, and will not bring any harm/effect to the road users and environment.	**0**		
Erosion Control	Soil biotechnical engineering treatment	Any highway project that utilizes soil biotechnical engineering treatments which is the combination of plant materials and structural elements that can protect slope and control the erosion. for examples, vegetated gabion, vegetated crib wall, etc.	**0**	0	
	Green techniques	Any highway project that implement green techniques in order to control the soil erosion, protect the slope and embankment such as turfing, planting native vegetation, hydro seeding, soil-tire vegetation, etc.	**0**		

scores will be used as a maximum point for reference in order to decide the point range of credit requirement for each element in the green highway index.

$$\text{Factor score} = z \times F_L \quad (2)$$

where:

z = Mean scores
F_L = Factor loading of each element

2.3. Phase 3: development of assessment framework

Phase 3 highlights the end product of this research after all the findings were evaluated, validated, and summarized so that the development of an assessment framework for pavement material and technology elements can be attained. The assessment framework of these elements was developed based on the factor scores obtained from the Phase 2 analysis.

3. Result and discussion

3.1. Pavement material and technology elements

Table 1 shows the criteria and sub-criteria of pavement material and technology elements that have been verified by 30 highway experts during the pilot workshop before distributing the questionnaire survey to the respondents. All these criteria and sub-criteria were selected based on the critical issues obtained from intensive literature review and during expert discussion. These elements are applicable to be taken into consideration for the material and technology category in Malaysia green highway index based on the experts' feedback and suggestions.

3.2. Factor analysis

The respondents' agreement levels obtained from the questionnaires survey were examined with KMO and Bartlett's Test in SPSS software to measure the adequacy of sampling and analyze the pattern of correlations in the data sample. The results show that the KMO value was 0.72, which is more than 0.70, while the Bartlett's test was significant since χ^2 (78) = 430.71, p < 0.000 (no correlation). Therefore, these result indicated that the method of factor analysis is suitable for this research.

As discussed in the methodology, the factor score can be determined by multiplying the mean values and factor loadings of each element involved in order to obtain the maximum score in every green element practice. Henceforth, all the findings were presented during an expert discussion for acquiring their opinion and feedback pertaining to the elements and their point scores. Since the highway experts had more than 10 years working experience in transportation sector, they were all concerned about the green development in highway industry. Therefore, the proposed name of elements, elements description, and maximum point scores of each pavement material and technology element was shown in Table 2. All the information in the framework have been verified and agreed by the highway parties involved in the expert

Table 4
Pilot test for highway B.

Factor	Elements	Elements Description	Point Score	Point score for each factor	Total Point Score
Environmental Control	Permeable pavement	Allow the application of porous pavement in any highway project.	**0**	7	**8**
	Pavement design life	Allow long lasting pavement design life to avoid frequent rehabilitation, thus depending on the Average Daily Traffic, ADT and types of pavement that will be going to construct.	**3**		
	Regional materials	Allow the usage of local materials in highway project depending on the location of the project site, whenever practical.	**3**		
	Quiet pavement	The speed that more than 80 km/h could contribute noise disruption and the range of noise level is depending on the types of surface pavement	**1**		
	Recycle pavement or new sustainable techniques	Allow the usage of recycle pavement such as Reclaimed Asphalt Pavement (RAP) or Recycled Concrete Material (RCM) to produce new pavement or implement any new sustainable techniques in highway construction.	**0**		
Economical Resources	Reuse of topsoil	Allow the reuse of top soil that has been removed from grading as long as it is non-contaminated soils.	**0**	0	
	Reused and/or Recycled of non-hazardous materials	Allow the reused and recycled non-hazardous materials in design or during highway construction for other base layers, shoulder, drainage, and highway furniture (signage, guardrail, etc.)	**0**		
	Earthwork balance	Balancing cut and fill quantities can reduce the need for transport of earthen materials	**0**		
Innovation Technology	Usage of industrial by-products	Allow the locally industrial by-products to be reused and recycled in highway construction either in flexible or rigid pavement such as by using steel slag, fly ash, crumb rubber, etc.	**0**	1	
	Cool pavement	Any surface of pavement with lighter colour has higher albedo effect which indicates high reflectance of sunlight from surface pavement whereas darker colour has lower albedo effect which shows the low reflectance of sunlight from surface pavement.	**1**		
	Subgrade improvement/ Soil stabilization	Allow the usage of recycled materials for sub-grade improvement/soil stabilization, if it can be proved that the process will reduce the consumption of virgin materials, cost of project, and will not bring any harm/effect to the road users and environment.	**0**		
Erosion Control	Soil biotechnical engineering treatment	Any highway project that utilizes soil biotechnical engineering treatments which is the combination of plant materials and structural elements that can protect slope and control the erosion. for examples, vegetated gabion, vegetated crib wall, etc.	**0**	0	
	Green techniques	Any highway project that implement green techniques in order to control the soil erosion, protect the slope and embankment such as turfing, planting native vegetation, hydro seeding, soil-tire vegetation, etc.	**0**		

discussion. This framework was developed in order to ensure the efficiency of practicing green material and technology elements during the project's evaluation session among the highway concessionaires. Based on the results, it is clearly proven that all the four factors were essential to be considered and represented as an essential factor in achieving the sustainable highway development for material and technology category.

3.3. Pilot test

There were two highway projects selected as pilot test to evaluate the performance of assessment framework by measuring the green elements that had been implemented. Tables 3 and 4 show the results obtained from the pilot tests of Highway A and B respectively. The pilot test findings indicated that Highway A achieved the total point score of two out of 47 from the overall maximum point score. Meanwhile, the higher total point score of eight was recorded by the project of Highway B as compared to the Highway A. However, the total point score obtained by the different highway project was considered comparatively very low and indicated that the current highway construction practices need to be improved with the substitution of sustainable element during highway development. Based on these results, it was clearly discovered that green practices in term of pavement material and technology were not fully applied by both highway projects in Malaysia. Therefore, the assessment framework of pavement material and technology elements should be served as a fundamental approach of the current system by encouraging the highway parties to be aware in implementation of the sustainable elements so that the sustainable highway can be achieved.

4. Conclusion

Sustainability and green highway development are prominent concepts of research which have been actively discussed recently. One of the crucial categories that need to be addressed critically in achieving green highway development is material and technology. There are a lot of sustainable efforts and practices that have been implemented in other countries in order to develop green highway but the highway parties involved in Malaysia highway projects are still lacking of knowledge and exposure regarding these matters. Therefore, this research has encouraged them to design and construct an environmental highway, which indirectly establishes an assessment framework for pavement material and technology elements that might become a reference to evaluate the greenness level of any highway project.

The developed framework consisted of 13 elements that were segregated into four main factors which includes environmental control, economical resources, innovation technology, and erosion control. Each of these elements had their own point score which was obtained from the findings of the factor analysis. Then, they will be used during the highway performance assessment which can be presumed that the higher score of each element achieved, therefore representing the more sustainable highway it is. Apart from that, there were two different highway projects that had been selected to be assessed as a pilot test in order to verify the feasibility of the developed framework in this study.

In Malaysia, there are no serious actions taken in complying the sustainability concept in highway development, even though the policy on this issue has been established due to the certain reasons, especially insufficient exposure on green awareness and responsibility, and also monetary allocation. Thus, it is a vital sign for all level of stakeholders to co-operate in order to solve these matters. This assessment framework for pavement material and technology elements has enhanced the current highway development to be more ecological friendly and increase the level of awareness among the highway parties involved.

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