A Review on the State of Cost Data Inputs of Life Cycle Cost (LCC) for Rigid Pavement Maintenance and Rehabilitation in Malaysia

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Many scholars asserted that LCC plays an important role in the cost estimation of rigid pavement due to high construction, maintenance and reconstruction costs in Malaysia. Due to high budget allocation and expenditure on the maintenance and rehabilitation works of pavements in Malaysia by the government, it is crucial for the transportation agencies to optimize the budget allocation and select the most cost-effective pavement maintenance and rehabilitation alternatives. LCC is a useful economic assessment technique that compares the cost-effectiveness of different maintenance and rehabilitation approaches within the same road pavement type. However, in order to produce a comprehensive and reliable LCC output, there is need to ensure the cost data inputs is ready and quality enough to be used in the LCC estimation. This paper presents the outcomes of the comprehensive literature review on the state of cost data inputs for LCC analysis of rigid pavement maintenance and rehabilitation in Malaysia. The outcomes of the literature study have established that the majority of the construction industry key players are aware LCC analysis should be practiced in the rigid pavement maintenance and rehabilitation. However, the current state of LCC practice of rigid pavement maintenance and rehabilitation in Malaysia is still at the infancy stage and unready to be implemented due to the difficulties in attaining quality cost data for generating a comprehensive and reliable LCC analysis. The findings provide information on the current state of cost data inputs of LCC analysis of rigid pavement maintenance and rehabilitation in the Malaysian construction industry.

Keywords: *Life cycle cost (LCC), rigid pavement, maintenance and rehabilitation, cost data input*

1. INTRODUCTION

The transportation system in Malaysia is experiencing a rapid development in the recent years, which can sustain Malaysia's economic growth and the national development (Ayob Bidi, Ahmad Jasmi, Wan Omar & Ali, 2017; Ramachandran, 2017; Wan Imran, 2015). In the Eleventh Malaysia Plan (2016 to 2020), about 3,000 kilometres of paved road will be constructed, where the Prime Minister has declared in Malaysia's budget 2018 that RM2 billion has been apportioned for the construction of Pan-Borneo Highway and another RM934 million for constructing and improving the road infrastructure in the rural areas of Malaysia (Economic Planning Unit, 2015). Although such amount of budget has been allocated by the government for the construction of new roads and highways, the quality of the existing roads throughout its lifespan cannot be neglected.

More recent attention has focused on maintaining the infrastructure assets in good condition to ensure that the asset continues to be effective and functions to its required standards throughout its entire design lifespan (Ayob et al., 2017; Economic Planning Unit, 2015; Mohd Yunus, 2017; Nurul Wahida, 2010; Rangaraju et al., 2008). The Malaysia government has allocated a huge budget for improving and maintaining the existing road condition, where approximately RM5 billion has been spent in the maintenance and rehabilitation works of all federal roads in Malaysia from 2001 to 2010 (Ayob et al., 2017; Wan Imran, 2015). Besides that, in 2016, PLUS Malaysia Bhd spent about RM1 billion for preserving about 5,000 kilometres of highways in the country (Malay Mail Online, 2018). Thus, due to the increasing demand for road funds and budget limitations, the most optimum total ownership cost and cost-effective pavement preservation alternatives must be determined by the transportation agencies (i.e. clients, investors, managers, concessioners etc.). This can be done by taking into account the total cost estimation of the road construction and maintenance during the conceptual stage (Ayob et al., 2017; Kurshid et al., 2011; Rangaraju et al., 2008; Sodikov, 2005; Wan Imran, 2015). According to the research report by Ayob, Abdul Rashid, Bidi and Ahmad Jasmi (2017), most of the asset owners only focused on the cheapest initial capital cost but disregarded the future cost as a significant aspect in optimizing total cost of the asset and achieve the best value for money. A study by Awang et al (2017) also highlighted that maintenance can affect the quality of living environment as poor maintenance of the existing infrastructures and facilities creates obstructions and become hindrance to the users.

Life cycle cost (LCC) can be defined as an economic assessment technique that uses a mathematical method to estimate total ownership costs of an asset over its anticipated life and to determine the most cost-effective option among different competing alternatives (Ayob, 2014; BS ISO 15686-5, 2008; Langdon, 2010; Ramachandran, 2017). According to recent studies by Wan Imran (2015), Ayob et al. (2017), and Mohd Yunus (2017), life cycle cost (LCC) is crucial for pavement projects including rigid pavement due to its huge fund involvement for the pavement maintenance and rehabilitation method, which give a significant impact to the future cost and the service quality. Besides that, it is also has been emphasized in the Eleventh Malaysia Plan (2016-2020) that the Malaysia government will be focussing on preventive maintenance and adopting a life cycle costing approach in the road maintenance programmes (Economic Planning Unit, 2015). This shows that, LCC has been increasingly recognized as an important tool to develop more economical strategies for transportation agencies in order to optimize the budget allocated for maintenance of roads and highways infrastructure in Malaysia (Ayob & Abdul Rashid, 2013; Ayob et al., 2017; Economic Planning Unit, 2015; Rangaraju et al., 2008; Wan Imran, 2015). However, most studies in the LCC analysis field have only focused on the methodology and models to compute LCC, but very limited study exists, which adequately stressed on the state and quality of cost data inputs (i.e. cost data availability, accessibility, currency and reliability) to be used for producing a reliable LCC outputs for rigid pavement maintenance and rehabilitation. Thus, this study is significant in order to assists the transportation agencies in carrying out LCC of rigid pavement maintenance and rehabilitation by using quality cost data inputs. The outcome of the reliable LCC output can help the agencies in achieving the best value for money on the investment and long-term economic savings.

This paper presents the outcomes of a comprehensive literature review on the state of cost data inputs for LCC analysis of rigid pavement maintenance and rehabilitation in the Malaysian construction industry. The literature findings reported in this paper is part of an ongoing two-year postgraduate study undertaken by the first author on the investigation of cost data used as inputs in producing a comprehensive and reliable LCC estimation of maintenance and rehabilitation approaches of rigid pavement in the Malaysia construction industry.

2. RESEARCH METHODOLOGY

A comprehensive literature review was carried out in the study to provide an overview of wide range of elements and models of LCC analysis in the pavement maintenance and rehabilitation, and to explore the state of cost data inputs that can be used for the LCC analysis of rigid pavement maintenance and rehabilitation in the Malaysian construction industry. According to Korpi and Ala-Risku (2008), the literature in the field of life cycle cost was quite scattered, and they recommended online databases source because it is more preferable than individual journals for providing LCC literature. These findings seem to be consistent with other LCC scholars that have done study on LCC in the past, i.e. Kambanou and Lindahl (2016) and Bengtsson and Kurdve (2016).

The researchers used keywords to search and identify related journal articles, conference papers and reports, which dated from 2000 to 2018 from several online databases that covered the disciplines of general, sciences, engineering and economics. These include IEEE Xplore, Emerald Insight, ScienceDirect, Taylor & Francis Online, and Google Scholar. The following are the keywords that were used in the literature search: i.e. (i) “life cycle cost” AND cost data, (ii) “life cycle cost” AND pavement maintenance, and (iii) “life cycle cost” AND rigid pavement maintenance. The term “life cycle cost” was sought from all text fields since the focus of the paper lies within the life cycle cost context. The other terms, i.e. cost data, pavement, pavement maintenance and rigid pavement maintenance, were used but limited to the abstract, title or keywords section of the articles since the articles were not considered as significant when the terms were not mentioned in these sections. However, in the Google Scholar, the online literature search was done but limited to the article title only because the keywords cannot be used to search required information in the article section.

The results of the literature search is presented in Table 1. Some of these articles were filtered and dismissed from the literature review due to the limited access to the full text and not meet the criteria as well as the scope of the study. Referring to the results reported in Table 1, it can be seen that very limited publication is currently available online focusing on the subject matter, i.e. life cycle cost and rigid pavement maintenance. This means that more study to increase the publication in relation to the life cycle cost and rigid pavement maintenance is necessarily need be carried out to provide enhancement of knowledge on LCC practice.

Table 1. Search keywords and results

Databases	**"life cycle cost" AND cost data**	**"life cycle cost" AND pavement**	**"life cycle cost" AND pavement maintenance**	**"life cycle cost" AND rigid pavement maintenance**
IEEE Xplore	611	7	3	2
Emerald Insight	844	60	7	0
ScienceDirect	6582	628	133	7
Taylor & Francis Online	22	276	33	0
Google Scholar	35	123	19	0

3. LITERATURE REVIEW

3.1 Overview of Rigid Pavement

There are two main categories of paved roads in Malaysia, which are flexible and rigid pavements (Koting et al., 2011; Ayob et al., 2017). Rigid pavement is classified based on its concrete surfaces and bases, which implies high strength and durable characteristic that allow it to span some minor irregularities in the sub-grade or sub-base of the pavement (Koting et al., 2011; Hong Kong Highways Department, 2012; Ayob et al., 2017). The basis for classification of concrete pavement types is the jointing and reinforcing system adopted. According to Public Works Department (2014), the construction of the road layer is similar to flexible pavement except the surface structure is made of concrete slab. Figure 1 shows the differences of construction layers in the flexible and rigid pavement designs. Basically, rigid pavement consists of four (4) layers, i.e. sub-grade, sub-base, base course, concrete slab and the reinforcement steel. There are three types of rigid pavement, i.e. Jointed Plain Concrete Pavement (JPCP), Jointed Reinforced Concrete Pavement (JRCP), and Continuously Reinforced Concrete Pavement (CRCP) (Mallick & El-Korchi, 2013; Public Works Department, 2014). A study by Wan Imran (2015) stated that the rigid pavement has high initial capital cost but low in maintenance cost. On the other hand, the flexible pavement has low initial cost but high in maintenance cost. According to PWD (2014), the rigid pavement has been in used in Malaysia for not less than three decades. Though it is not commonly used as that of flexible pavement due to higher construction cost, as concrete generally has high initial cost than asphalt, but rigid pavement has a lower maintenance cost and lasts longer. However, due to lack of awareness of rigid pavement advantages, the number of new construction of rigid pavement in Malaysia is very limited, which rigid pavement only make up less than 1% of total Malaysian roads (Tan, 2015; Ayob et al., 2017).

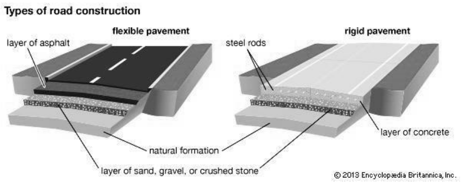

Fig. 1: Difference between flexible and rigid pavement designs
(Source: Encyclopaedia Britannica, 2013)

3.2 Rigid Pavement Maintenance and Rehabilitation

There are several factors that may lead to the deterioration of rigid pavement over time such as increases in traffic volume, movement in underground structure or environmental factor, i.e. moisture and temperature (Public Works Department, 1994; Suanmali & Ammarapala, 2010). The rigid pavement needs to be properly maintained in order to decelerate or reset the deterioration process of the pavement. It has been highlighted in the Strategy A2 in Chapter 7 of the Eleventh Malaysia Plan, where maintaining the roads in good condition is essential for ensuring the effectiveness of the road network, and functions as required standards throughout its lifespan. Basically, road maintenance work can be divided into three main categories, which are preventive maintenance, corrective maintenance and emergency maintenance, which are as follows:

i) **Preventive maintenance**: normally deals with the proactive activities, which are performed periodically to slow down or prevent the probability occurrence of the pavement distress to ensure its serviceability (i.e. diamond grinding, slab stabilization, dowel-bar retrofit, etc.) (Cement Concrete & Aggregates Australia, 2009; Nikolaides, 2015; Reina, Kocsis, Merlo, Németh, & Aggogeri, 2016).
ii) **Corrective maintenance**: refers to the activities carried out after the distress occurs in the pavement to repair and improve the serviceability of the pavement (i.e. full-depth repairs, partial-depth repairs, cracking and sealing, etc.) (Cement Concrete & Aggregates Australia, 2009; Nikolaides, 2015; Reina et al., 2016).
iii) **Emergency maintenance**: applied to the emergency situations that need to be attended immediately. This type of maintenance activities aims to prolong the life of the pavement with an acceptable level of functionality until rehabilitation or reconstruction can be done (Nikolaides, 2015).

On the other hand, rehabilitation involves the activity of restoring the condition of failed pavement to the original standards (Cement Concrete & Aggregates Australia, 2009). Nikolaides (2015) defined the rehabilitation as an appropriate measure to extend the pavement structure’s life when there are no maintenance activities is able to maintain the pavement adequate serviceability. Maintenance activities (i.e. joint and crack resealing, slab stabilization, overlays, etc.) help to slow the rate of the rigid pavement deterioration by assessing the condition of the existing rigid pavement (Mallick & El-Korchi, 2013; Public Works Department, 2014). The road owner needs to predict and evaluate the pavement conditions on the network accurately in order to identify the lowest cost maintenance and rehabilitation of the pavement (Mohd Yunus, 2017). Besides that, in order to achieve satisfactory performance and cost-effectiveness in the pavement rehabilitation, it is important to identify the type of rigid pavement distress in order to effectively repair the distress by using the appropriate maintenance and rehabilitation approach. Thus, Table 2 briefly presents the type of rigid pavement maintenance and rehabilitation approaches that are commonly used in Malaysia. A maintenance and rehabilitation action can help to address more than one possible distress as shown in Table 2.

Figure 2 illustrates the summarized six steps of the general process of selecting the most appropriate and cost-effective maintenance and rehabilitation strategy for existing rigid pavement as mentioned in the study by Hall et al. (2001). In relation to that, the authors also have highlighted in their study that the maintenance and rehabilitation strategy selection process might be different in the details depending on the highway agencies; however, the typical process consists of the following main activities:

i) Data collection of the necessary information, to evaluate the current condition of rigid pavement and type of maintenance and rehabilitation method needed. Besides that, the information is needed to predict the performance of each strategy and estimate the cost of each strategy. For example, roadway section definition, traffic analysis, distress survey etc.
ii) Pavement evaluation is carried out to assess the present condition of the rigid pavement i.e. type of deterioration,

deficiencies to be addressed by rehabilitation, uniform sections for rehabilitation design and construction over project length.

iii) Selection of rigid pavement maintenance and rehabilitation techniques that are best suited to the correction of existing distress and achieved the required improvements of the rigid pavement structure.

iv) Formation of maintenance and rehabilitation strategies, developed in sufficient detail that the performance and the cost of each strategy can be estimated.

Table 2**.** Types of rigid pavement maintenance and rehabilitation approaches and the rigid pavement distress that can be repaired

Types of maintenance	**Description**	**Types of rigid pavement distress that can be repaired**
Joint and crack resealing	Prevents damage caused by water and non-compressible materials to enter the joint and crack.	Structural Distress i) *Punch Outs* Functional Distress: i) *Joint Seal Damage* ii) *Shrinkage Cracks*
Slab stabilization	Fills voids formed underneath the slab caused by a combination of pumping, erosion, or consolidation of the base.	Structural Distress: i) *Faulting of Joints and Cracks* ii) *Pumping* iii) *Settlement* Functional Distress: i) *Lane to shoulder Drop off*
Grinding and grooving	Restores the friction or the smoothness of the pavement surface by grinding off the thin surface layer using a gang- mounted diamond saw blade.	Functional Distress: i) *Bleeding* ii) *Scaling* iii) *Polished Aggregate* iv) *Rain Damage Surface*
Structural overlays	Helps to extend pavement service life, increase structural capacity, and reduce maintenance work requirements and lower life cycle costs. (i.e. concrete or asphalt overlays/inlays)	Structural Distress: i) *Settlement* Functional Distress: i) *Map/Spider/Crazing Cracks* ii) *Scaling* iii) *Shrinkage Cracks* iv) *Patch Deterioration*
Partial-depth repair	Restores the confined areas of slab damage that is the upper one-third of slab depth. It is normally used for moderate spalling and localized areas of severe scaling that do not exceed 3 inches deep and that cover an area less than 12 sq. ft.	Structural Distress: i) *Transverse cracks* ii) *Longitudinal cracks*

		iii) *Corner Breaks* iv) *Spalling at Joints* <u>Functional Distress</u>: i) *Bleeding* ii) *Map/Spider/Crazing Cracks* iii) *Shrinkage Cracks*. iv) *Pop-outs* v) *Lane to shoulder Drop off* vi) *Patch Deterioration* <u>Durability Distress</u>: i) *Durability Cracks (D-cracks)*
Full-depth repair	Restores confined areas of slab damage that is beyond the upper one-third of slab depth or initiated from the slab bottom. Generally, it is used to repair severe spalling, punch outs, corner breaks, severe cracking and areas of severe scaling.	<u>Structural Distress</u>: i) *Transverse cracks* ii) *Longitudinal cracks* iii) *Corner Breaks* iv) *Spalling at Joints* v) *Punch Outs* vi) *Blowups* vii) *Faulting of Joints and Cracks* viii) *Pumping* ix) *Settlement* <u>Functional Distress</u>: i) *Bleeding* ii) *Map/Spider/Crazing Cracks* iii) *Shrinkage Cracks* iv) *Lane to shoulder Drop off* v) *Patch Deterioration* <u>Durability Distress</u>: i) *Durability cracks (D-cracks)*
Load transfer restoration	Helps to maintain alignment of adjoining slabs and to hinder further deterioration of the rigid pavement by reducing the potential of the load distress.	<u>Structural Distress</u> i) *Faulting of Joints and Cracks* ii) *Pumping* iii) *Spalling at Joints*
Dowel bar retrofit	Repairs or delivers better load transfer across transverse joints or cracks by using dowel bars. Typically, it is required when the aggregate	<u>Structural Distress</u>: i) *Transverse cracks*

	interlock loosen over time.	ii) *Faulting of Joints and Cracks* iii) *Pumping*

(Source: Hall et al., 2001; Hong Kong Highways Department, 2012; Mallick & El-Korchi, 2013; Public Works Department, 2014)

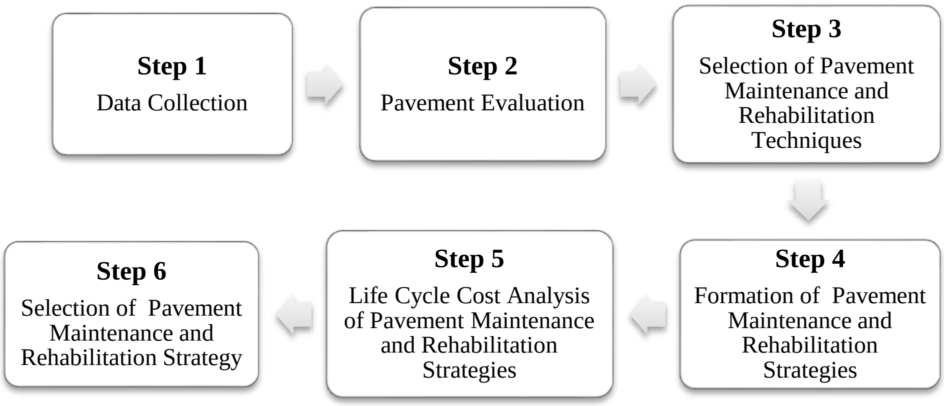

Figure 2**.** Pavement rehabilitation process
(Source: Updated and summarized from Hall et al., 2001, p. 6)

v) Carry out life cycle cost analysis by comparing the monetary costs and benefits of the different rigid pavement maintenance and rehabilitation approach alternatives over an analysis period.
vi) Selection of rigid pavement maintenance and rehabilitation approach considering the monetary factors and non-monetary factors together among the alternatives considered.

Based on the Malaysian guideline of LCC published by PWD, the procedures in the guideline do not provide broad information with specific reference to rigid pavement and pavement maintenance and rehabilitation. According to PWD (1994), there are three main stages of the general process of selecting appropriate maintenance and rehabilitation approach. These three stages are basically on the same agreement with the steps mentioned in Hall et al. (2001) but not specified for the rigid pavement maintenance and rehabilitation, which are listed as follows:

i) Identification of problem; by conducting pavement evaluation and identifying constraints.
ii) Identification of probable alternatives; by selecting possible maintenance and rehabilitation treatments and design checking with construction constraints.
iii) Selection of preferred solution; including the cost analysis, other constraints and detailed design.

Besides that, the rigid pavement needs to be assessed based on the following criteria in selecting the most cost-effective maintenance and rehabilitation approach amongst the competing alternatives:

i) Select alternative approach that can provide the most optimum life cycle cost of renewal, maintenance and rehabilitation during the in-use phases of rigid pavement.
ii) Select the alternative approach that can produce quality rigid pavement performance throughout its service life.
iii) Select alternative approach that can maximize the service life span of rigid pavement.

3.3 Life Cycle Cost (LCC) of Maintenance during the In-use Phases of Rigid Pavement

Life Cycle Cost (LCC) is fast becoming a key instrument in improving cost effectiveness of pavement evaluation, where LCC became popular since the 1960s when the US Government Agencies used LCC to increase the cost-effectiveness of equipment procurement (Tinni, 2013). LCC can be defined as "an economic assessment technique that uses mathematical method to estimate the total ownership costs of an asset or system over an anticipated lifespan" (BSI, 2008; BS ISO 15686-5, 2008; Langdon, 2010; BS 8544, 2013; Ayob & Abdul Rashid, 2013, 2015, 2016; Ayob, 2014). LCC is recommended to be used as a medium when selecting the most cost-effective road designs or evaluating bids. Previous research has indicated that LCC offers a complete and comprehensive costing model to the infrastructure asset owner as it commonly integrated with the total cost of ownership (Ramachandran, 2017).

Currently, in the Malaysian construction industry especially in road construction and maintenance, the practice of LCC is still at its early stages even though it has been extensively applied in the United States and European countries (Ayob, 2014; Wan Imran, 2015; Ayob et al., 2017). Table 3 below shows the list of other countries and their state of LCC practice in comparison with Malaysia. It was reported that the public sector clients in several countries like the UK, the Netherlands, Finland, Sweden etc., have been used LCC to estimate the long-term cost of the public project (Langdon, 2010). However, based on the study by Ayob (2014), the construction industry in Malaysia is the only industry that practices the LCC analysis as an economic assessment technique.

Table 3. The comparison of the state of LCC practice in Malaysia and other countries

Country	LCC is a mandatory requirement	LCC is applied but not as a mandatory requirement	LCC is used on a trial basis	LCC is yet to be applied	Reference(s)
MALAYSIA	•				3PU (2009a: 6, 2009b: 5), EPU (2010a, 2010b, 2011)
The United Kingdom	•				Langdon (2010, 2007a); Perera et al. (2009); Flanagan and Jewell (2005)
The United States	•				Perera et al. (2009); Flanagan and Jewell (2005)
Canada	•				Perera et al. (2009)
Japan		•			Perera et al. (2009)
New Zealand		•			Perera et al. (2009)
Australia		•			Perera et al. (2009)
Singapore			•		Perera et al. (2009)
Indonesia				•	Perera et al. (2009)
China			•		Perera et al. (2009)
India			•		Perera et al. (2009)
Austria		•			Perera et al. (2009)
Vietnam				•	Perera et al. (2009)
Mauritius				•	Perera et al. (2009)
Finland	•				Perera et al. (2009); Langdon (2010)
Chile			•		Perera et al. (2009)
Sweden	•				Langdon (2010, 2007a); Perera et al. (2009); Flanagan and Jewell (2005)
Denmark	•				Perera et al. (2009)
Ghana				•	Perera et al. (2009)

The Netherlands		•		Perera et al. (2009); Langdon (2010)
Korea		•		Perera et al. (2009)
Slovenia		•		Langdon (2010)
Switzerland	•			Perera et al. (2009)
Argentina			•	Perera et al. (2009)
Germany		•		Perera et al. (2009)
France		•		Perera et al. (2009)

(Source: Ayob, 2014, pp. 91)

Furthermore, the outcome of the initial study by Ayob (2014) shows that most of the government agencies are aware that LCC should be practiced and applied in the Malaysian construction industry including in the rigid pavement maintenance and rehabilitation. In the United States and the European countries, i.e. Sweden and the United Kingdom, they have fully implemented and practiced the LCC analysis. The UK construction industry has published national standard guidelines to be used for LCC analysis practice, i.e. BS ISO 15686-5 (2008), "International Standard: Buildings and Constructed Assets-Service Life Planning. Part 5: Life Cycle Costing". On the other hand, in Malaysia, the Public Works Department (PWD) has published a standard guideline of LCC called "*Garis Panduan Pengiraan Kitaran Hayat (KKH)*" (Standard Guideline of Estimating Life Cycle Cost (LCC)).

The Malaysia standard guideline of LCC aims to deliver the appropriate methodology of practicing LCC analysis for the upcoming public projects in the Malaysian construction industry (Ayob, 2013). It consists of cost breakdown structure (CBS) standards, LCC models, methodologies and other fundamental components of LCC to be used for public building and civil infrastructure projects in Malaysia (PWD, 2012; Ayob, 2013). However, the PWD guideline is lacking methodology and information to attain a complete, up-to-date and reliable cost data inputs to produce a comprehensive and reliable LCC output for rigid pavement maintenance and rehabilitation in the Malaysian construction industry.

According to BS 8544 (2013), LCC can be applied in the maintenance of the asset or system during the in-use phases, which evaluates the life cycle cost over a period of analysis after the construction phase completed until the end of life phase of the asset. Based on the condition of the asset over the period of analysis, the owner of the asset can identify whether to maintain or renew the asset. In 2002, a study by Reigle and Zaniewski (as cited in Rangaraju et al., 2008) reported that LCC is not only being used by the transportation agencies as a decision support tool for selecting pavement type, but it was also used to evaluate the cost comparison between different rehabilitation strategies within the similar road pavement type. This is also supported by Tinni (2013) who asserted the LCC was applied as an economic assessment technique for the valuation of estimated deterioration models and the cost of routine and periodic maintenance, repair and rehabilitation of road pavement. According to the Pavement related research unit at MIT (2014), LCC plays an important role in the pavement maintenance as the future cost of pavement can be a significant contribution to the total cost of the asset. For an instance, in Florida, a state highway initial construction costs comprised of 47% of the total life cycle cost of the highway, nonetheless, the future maintenance and rehabilitation costs encompassed 53%. This example shows that the future maintenance cost is higher than the initial construction cost of a highway, which the study offers some important insight on the implementation of LCC analysis for road pavement maintenance. The output of a reliable LCC analysis is not solely on the selection of an alternative over the other, but it is about the most cost-effective design strategy selected for certain conditions and factors that influence cost-effectiveness.

Previous research by Ayob (2014), has reported that there are three main phases of LCC estimation process, which are data inputs, conversion and outputs. The output of the LCC estimation is highly depending on the accuracy of the input variables (Mahamid, 2013; Ayob & Abdul Rashid, 2013, 2015, 2016; Ayob, 2014; Ayob et al., 2017). World Road Association (PIARC) (2013) also points out that data is one of the most vital assets in a pavement management organization. However, many commentators asserted that the significant setback of LCC practice in the early phase of the project is the difficulty to identify and acquire quality, reliable and complete data due to lack of primary information, road work cost database and current cost estimation methods for the rigid pavement maintenance and rehabilitation. The LCC analysis requires a comprehensive and specific data information that meet the data input quality requirements of LCC analysis, i.e. material unit cost, traffic volumes, materials volumes, etc. (Kim et al., 2015; Ayob et al., 2017). Due to the complexity of LCC analysis, the estimators and practitioners tend to miscalculate, make assumptions, estimates and projections from inadequate input data that have a tendency to produce non-reliable and inaccurate LCC outputs (Herbold, 2000; Singh & Tiong, 2005; Kim et al., 2015).

In conducting the LCC of rigid pavement with specific reference to its maintenance and rehabilitation approaches, it is important to recognize the certainty of input data since the data will determine the reliability of the LCC outputs. Unfortunately, the past studies have shown that the difficulties in the implementation of LCC analysis of rigid pavement maintenance are the lack of current and reliable maintenance cost data of rigid pavement in Malaysia (Ayob, 2014; Herbold, 2000; Mahamid, 2011). In addition, most of the scholars and estimators are mainly focused on LCC conversion; however, very limited research has been carried out in the past to identify the quality of cost data (i.e. availability, accessibility, currency and reliability of data inputs) as inputs for producing a comprehensive and reliable LCC analysis of rigid pavement maintenance and rehabilitation in the Malaysian construction industry.

3.4 Cost Components of LCC for Rigid Pavement Maintenance and Rehabilitation

The maintenance and rehabilitation costs of rigid pavement consist of cost acquired by the transportation agencies during the performance of a maintenance activity at a certain work site, on a specific day and time. The maintenance (repair) and replacement (renewal) costs of rigid pavement take into account the changes to particular elements, materials and structures. These costs include staff salaries, supervision and installation charges, maintenance contractor's preliminaries, administrative cost, consultant fees and specialist works costs (Table 4).

Table 4. Type of cost data of LCC for rigid pavement maintenance and rehabilitation

Cost data type	Description
Supervision and installation charges	All cost related to the process of supervising and monitoring during execution of the works
Maintenance contractor's preliminaries	The scope of the element of preliminaries such as temporary works, protection, watching, hoarding, testing, site supervision and overheads
Administrative costs	Administration cost includes contract management, legal expenses, professional expenses and executive salaries
Specialist works costs	Fees allocated to the contractor that have been appointed to carry out specialist works where it involves specialist construction knowledge and skills.

(Source: Langdon, 2010; Krstic & Marenjak, 2012; BS 8544, 2013)

3.5 Quality Data Input Requirements of LCC for Rigid Pavement Maintenance and Rehabilitation

A recent study by Langdon (2010) identifies that cost data inputs are the most crucial components in carrying out LCC analysis. The cost data inputs should be recognized and quantified by the estimators in the very early stage of the project (as cited by Ayob & Abdul Rashid, 2013, 2015, 2016; Ayob, 2014; Ayob et al., 2017). In another major study, Tinni (2013) found that the maintenance costs of rigid pavement are by far the most challenging to be estimated as there is a need of establishment of planned and required maintenance works and timings to be done. Besides that, the solid guideline that can assist the transportation agencies in managing the data for maintenance and rehabilitation works have not yet existed as the nature of rigid pavement is complex and complicated (Suanmali & Ammarapala, 2010). Based on the review of the literature, it was observed that there is no maintenance cost data of rigid pavement available and published in the Malaysian construction industry in order to help the cost estimators to estimate the total maintenance cost of rigid pavement.

In a study which set out to determine the quality of cost data inputs to produce a reliable LCC output, Ayob (2014) found that the key quality of cost data input requirements are data availability, accessibility, currency and reliability. The degrees and descriptions of data availability, accessibility, currency and reliability in the quality of cost data input requirements required for LCC analysis are shown in Table 5 below. Data availability refers to the certainty of the cost data to be used in LCC analysis and data accessibility refers to the ease of access in obtaining the cost data to be used in the LCC analysis. Besides that, the currency of cost data presents the recent and updated cost data inputs; and the reliability of cost data refers to the accuracy and consistency of the cost data to be used as inputs for LCC analysis. These key quality requirements are also appropriate to be applied in identifying and checking current and reliable cost data for producing a complete and reliable LCC analysis of rigid pavements maintenance and rehabilitation. The literature study has identified that there is no quality data requirement, which has been established in the Malaysian construction industry that can help the LCC estimators to identify the quality degree of cost data as inputs for producing a comprehensive and reliable LCC analysis of rigid pavement maintenance and rehabilitation (Ayob & Abdul Rashid, 2013, 2015, 2016; Ayob, 2014).

Table 5. The quality degrees of cost data inputs of LCC analysis

The key quality of data input requirement	The degree of data inputs	Description
Availability	Highly available	Data are freely published online and unrestricted for public use
	Available	Data are available for LCC analysis but need to subscribe from the subscriber-base information services provided
	Limited	Internal data that confined by firms or organizations in the library
Accessibility	Highly accessible	Data are freely published online and unrestricted for public use
	Accessible	Data that need to subscribe from the subscriber-base information services provided
	Limited	Data that have limited public access
Currency	Very current	Data are very often updated either on the weekly, monthly, quarterly or yearly basis
	Current	Data are updated once in a couple years or more but less than 5 years period
	Less current	Data are updated once in a period of more than 5 years
Reliability	Very reliable	The most structured data that are formed in detail, completeness and adequate, and compatible to be used as inputs into the process of generating reliable LCC analysis
	Reliable	Data are consistent and comparable to the actual value which arrived from similar and repetitive methods under the same research condition
	Less reliable	Data are incomplete, inadequate and incompatible which produce outputs not consistent over time

(Source: Ayob, 2014)

4. DISCUSSION

A considerable amount of literature has been reviewed to study the present state of cost data inputs in terms of its availability, accessibility, currency and reliability in Malaysia for LCC analysis of rigid pavement maintenance and rehabilitation. The outcomes of the review, presented in Table 6 have established that the data in Malaysia are not ready and comprehensive enough to be used as inputs for LCC analysis of rigid pavement maintenance and rehabilitation because they are lack of quality required to meet all the key quality cost data input requirements of LCC analysis (i.e. availability, accessibility, currency and reliability). For example, it can be seen from Table 6 that, even though the supervision and installation charges data are available, the data are limited to internal use within the organization and the data are not frequently updated. Thus, the data are considered not reliable to be used as inputs in order to produce a reliable LCC analysis of rigid pavement maintenance and rehabilitation. This results in the inadequacies of cost data inputs for rigid pavement maintenance and rehabilitation that has been pointed out to be one of the main obstacles to implement LCC analysis in the Malaysian construction industry (Ayob & Abdul Rashid, 2013, 2015, 2016; Ayob, 2014; Suanmali & Ammarapala, 2010).

Table 6**:** The state of data availability, accessibility, currency and reliability for LCC analysis of rigid pavement maintenance and rehabilitation

Cost data types	**State of published cost data**			
	Availability	**Accessibility**	**Currency**	**Reliability**
Supervision and installation charges	The data are available and can be obtained from the respective local state agencies i.e. Kuala Lumpur City Hall (DBKL), PWD, highway operator and concessionaires, contractors, professional bodies etc.	All these data have limited accessibility for public use.	Public Works Department has published cost data for rehabilitation, but the cost data is not frequently updated.	All these data are less reliable.
Administrative cost				
Specialist works cost				
Traffic management and control cost	The data cost for traffic management and control also is freely published online by the PWD on the corporate website and the data is highly available for public use.	The data cost for traffic management and control also is freely published online by the PWD in the corporate website and highly accessible for public use.		The cost data for traffic management and control is very reliable.

(Source: updated from Ayob, 2014; Ayob et al., 2017; PWD, 2017)

5. CONCLUSION

This paper reviewed the state of LCC analysis of maintenance during the in-use phases of rigid pavement in Malaysia. The literature review has established that the implementation of LCC analysis of rigid pavement maintenance and rehabilitation in the Malaysian construction industry is still at early stage. This is due to the difficulties in attaining a complete, reliable and current cost data as inputs into the process of generating a comprehensive and reliable LCC analysis of maintenance during the in-use phases of rigid pavement. The inadequacies of quality cost data inputs for rigid pavement maintenance and rehabilitation shows that LCC practice is not ready to be implemented in the Malaysian construction industry. Furthermore, the lack of maintenance and rehabilitation related cost data is attributable to the fact that the majority of the pavement authorities do not have proper methods for systematic data collection or follow-up procedures regarding planning, design, construction, and maintenance of the rigid pavement. The research is on-going and further research is encouraged as a second part of the study to identify appropriate strategies to mitigate the aforesaid limitations of LCC analysis of rigid pavement maintenance and to enhance the quality of LCC data inputs for a comprehensive and reliable LCC estimation of maintenance approaches of rigid pavement in Malaysia construction industry.

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