EVALUATING LIFE CYCLE COST (LCC) AND PERFORMANCE BETWEEN COLD IN PLACE RECYCLING (CIPR) AND RECONSTRUCTION METHOD

BY

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ABSTRACT

Pavement management is a very important subject that demands proper planning and implementation. The maintenance of a road pavement throughout its life cycle had to be carried out timely using the most economical method. However, rapid road deterioration and eventual failure from both climatic and vehicle loads impacts have significantly incurred the total cost of road maintenance works. In the maintenance of road pavement rehabilitation, alternatives method to reconstruction method that called cold-in place recycling (CIPR) which has been employed in many countries worldwide, including Malaysia to overcome the quality of road. In this case study, a comparative performance and life cycle costs analysis of CIPR versus reconstruction method is established. The actual functional and structural performances of both alternatives are measured and compared against the prediction using the performance condition index (PCI). In addition, the life cycle cost (LCC) for the two alternatives are performed and compared, taking into consideration of the net present value (NPV) in the calculation. LCC is the most cost effective approach so that the least long term cost of ownership is achieve. LCC is a process of evaluating the economic performance of the roads over its entire life. Lastly, the performance and cost analysis for each method are integrated to provide a composite view of the correlation between the two major elements. It is found that even though the CIPR is slightly more expansive than the conventional method, but its performance is substantially superior. The study indicates that CIPR can be considered as the more optimum method of pavement rehabilitation between the two alternatives. In conclusion, we can say that although CIPR incurred a higher initial cost but with its better performance, future maintenance cost is become lower than reconstruction method.

خلاصة البحث

إدارة الرصيف هو موضوع مهم جدا تتطلب التخطيط والتنفيذ السليم .كان الحفاظ على الرصيف الطريق طوال دورة حياتها التي يتعين الاضطلاع بها في الوقت المناسب باستخدام الأسلوب الأكثر اقتصادا .ومع ذلك، وتدهور الطريق السريع وفشل في نهاية المطاف من الأحمال على حد سواء المناخية ومركبة الآثار تكبدت كثيرا من التكلفة الإجمالية لأعمال صيانة الطرق .في الحفاظ على تأهيل رصف الطرق، طريقة بدائل لطريقة إعادة الإعمار التي دعت الباردة في إعادة تدوير مكان (CIPR) التي استخدمت في العديد من البلدان في جميع أنحاء العالم، بما في ذلك ماليزيا للتغلب على نوعية الطريق .في دراسة الحالة هذه، يتم تأسيس تحليل الأداء وتكاليف دورة الحياة المقارن من CIPR مقابل طريقة إعادة الإعمار .يتم قياس الأداء الوظيفية والهيكلية الفعلية لكل من البدائل ومقارنتها التنبؤ باستخدام مؤشر حالة الأداء .(PCI) وبالإضافة إلى ذلك، فإن تكلفة دورة الحياة (LCC) لالبديلين يتم تنفيذ ومقارنة، مع الأخذ بعين الاعتبار لصافي القيمة الحالية (NPV) في الحساب LCC .هو النهج الأكثر فعالية من حيث التكلفة بحيث أقل تكلفة على المدى الطويل من ملكية وتحقيق LCC .هو عملية تقييم الأداء الاقتصادي من الطرق على مدى حياته كلها .وأخيرا، يتم دمج الأداء وتحليل التكاليف لكل طريقة لتقديم وجهة نظر مركب للعلاقة بين اثنين من العناصر الرئيسية .وجدت أنه على الرغم من CIPR قليلا أكثر توسعا من الطريقة التقليدية، ولكن أدائها المتفوق بشكل كبير .وتشير الدراسة إلى أن CIPR يمكن اعتبار طريقة أكثر الأمثل لإعادة تأهيل الرصيف بين البديلين .في الختام، يمكننا القول أنه على الرغم من CIPR تكبدت التكلفة الأولية أعلى ولكن مع أداء أفضل لها، وأصبحت تكلفة الصيانة في المستقبل أقل من طريقة إعادة الإعمار.

APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Master of Business Administration (Construction Business).

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DECLARATION

I hereby declare that this dissertation is the result of my own investigation, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degree at IIUM or other institution.

Wan Imran Bin Wan Omar

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CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

Transportation infrastructure is an essential service in any community, its brings many benefits and is very important for a nation's development and growth. Examination of most developed and industrialized nations indicates that they have been noted for high-quality transportation systems and services. Inadequate and inefficient transportation services will hinder or limit the potential for a nation or region to achieve its full economic growth. However, constructing and maintaining infrastructure, especially the roads and highways is expensive (Chong et al 2004). The road engineer major task is to balance society's demand for fast and efficient transportation system with the costs incurred to construct, operate and maintain the road. But transportation system also has negative impact. It consumes energy resources and can have many negative impacts on its surroundings, which includes the environment issue such as water and air pollution. In any country, government decisions must be guided by a responsibility to respect public interests and priorities, and to make sure that public funds are spent wisely and sustainably. In the maintenance of road pavement, the performance and cost must be properly balanced and optimized to obtain the most economical option (Chong et al 2004). In addition, the duration of the maintenance work is usually also an important factor that need to be considered especially when road is located at a heavily used traffic area whereby the closing of the road or part of it becomes a big issue.

There are two major types of road pavement: concrete and flexible pavement, which is made of asphalt. Considering the life cycle cost, concrete pavement has high initial cost but low maintenance. In contrast, flexible pavement has significantly low initial cost but high maintenance and rehabilitation cost. Due to this fact, the introduction of a new method to reduce maintenance expenditure and increase the lifetime of a flexible pavement is considered as highly important.

In order to achieve a more sustainable freight and passenger transportation, both internal and external costs need to be factored into decision-making. Developing the capacity to evaluate the transportation options in these terms is an essential part of encouraging government decision-making that provides the best long-range return on investment.

Decision making of the stakeholder on the pavement rehabilitation method is very critical because it involves a large fund outlay. Life cycle costing (LCC) is important for any pavement projects because the decision of pavement rehabilitation method has a significant impact on future cost and service quality. The LCC have to perform during project planning and project evaluation. LCC have been quite extensively used in United State and Europe, but in Malaysia pavement stakeholder is still lacked of knowledge on LCC. So, the right decision has to be made by the stakeholder before choose the pavement rehabilitation method.

1.2 ROAD MAINTENANCE IN MALAYSIA

In 2010, there are currently more than 138,885.48 km length of roads in Malaysia, it's can be divided into three main categories namely toll expressway (1,666km), federal roads (18,920.07km) and state roads (118,299.41km) (Mohammad Arif Abdullah 2010). The remaining roads are maintained either by local municipal council in urban area or by district office in villages (Haron 2004). Some of these roads especially the expressway are privatized and therefore their maintenance responsibility is under the jurisdiction the respective concessionaires companies. However, the federal roads and state roads are still under the responsibility of the Federal and State government respectively.

Road system consists of two major components: road pavement and drainage system. Since water is one of the external factors that can cause damage to road pavement, the proper and adequate design of drainage system is paramount. This effect is very dominant in Malaysia due to the inclement weather of heavy rain throughout the year especially during the monsoon season on the East coast region. For this study the focus is concentrated on the issue of flexible pavement only, which is well known for low initial capital cost, but high maintenance. Therefore the finding of most economical way to reduce the maintenance cost is highly appreciated by all parties concerned (Zulakmal et al 2009).

Most flexible pavements in Malaysia are designed to have a lifetime of ten to fifteen years (Zakaria and Hassan 2005). Nonetheless a few years after construction, some flexible pavement begins to show signs of defect and requires repair as part of its maintenance works. Road maintenance is essential in order to (1) preserve the road in its originally constructed condition, (2) protect adjacent resources and user safety, and (3) provide efficient and comfortable ride for road users. The maintenance of road pavement involves two processes known as maintenance and rehabilitation (M&R). Comparing the two, the latter is more extensive and involves the structural strength of the pavement, which requires a substantially longer period to carry out and definitely more costly. The repairing work usually involves only the resurface of the wearing course. Therefore the use of best alternative out of the available methods of rehabilitation is paramount, which is the focus of this study.

Malaysian government spent RM5 billion between 2001 and 2010 to keep sustaining all the Federal roads (New Strait Times 2010). Due to its high cost, pavement maintenance is unfortunately often neglected, thus resulting in rapid deterioration of the road and eventual failure from both climatic and vehicle loads impacts. To overcome this problem, a new method of flexible pavement maintenance was introduced in Malaysia in the mid 1980 to rehabilitate distressed flexible pavements. This method is called cold in-placed recycling (CIPR). Pavement recycling technology is relatively new in the country, yet in terms of machine availability and successful application of the technique, Malaysia is among the active recyclers in the world (Chong et al., 2004). However the high cost of the machinery has been the drawback in its implementation in Malaysia. Only few high profile players in the local market can afford to buy the machine, and the detail study on the cost implication is a necessity.

1.3 COLD IN-PLACED RECYCLING (CIPR) METHOD

Cold recycling is an economically efficient and environmentally friendly method for producing superior quality base layers pavement. The overall strength of the road is therefore significantly increased compared to conventional method. Another great advantage of this technique is that the recycled layer could be opened to traffic immediately after construction and is later sealed with asphaltic surfacing within seven days (Chong et al., 2004). The cost effectiveness coupled with high performance and low risk rehabilitation procedure with relatively small impact to the traffic is among the identified major benefits of CIPR.

Considering the many advantages and overall benefits of the CIPR, this method is popular in most countries worldwide. According to a report produced by the

Ontario Ministry of Transport (OMT 2010), compared to traditional paving methods, CIPR:

- Emits 50% fewer Green House Gas
- Consumes 62% fewer aggregates
- Costs 40 to 50 % less than conventional treatments (per two-lane kilometres of road)

Chong et al. (2004) has performed a case study to investigate the performance of recycled pavements involved in the upgrading and rehabilitation of a Federal road in Pahang, Malaysia. Efforts have been made to monitor the performance of the recycled layer under local climatic and traffic conditions. The performance of recycled pavements monitored in the study over a period of 2 to 5 year indicated the soundly of the rehabilitated pavement. Nonetheless no comparative study is performed on the cost benefits of the CIPR. Even direct comparison on the conventional and CIPR methods is lacking. Hence the advantages of CIPR over the conventional method in terms of both performance and cost life cycle cannot be evaluated.

However the required information can be gathered by referring to a study report published in New York, USA (Cross et al., 2010). Considering the contrasting environment effects exist between New York and Malaysia, the findings of the study done in New York may not be an accurate representative of similar study performed in Malaysia. The hot climate and high rainfall intensity are two important external environmental factors that could adversely affect the performance of rehabilitated pavement in Malaysia. Nonetheless the report could be useful as a reference and guidance if similar study to be performed in Malaysia.

The CIPR is not without its disadvantages. From the comparative study done in New York State, the CIPR has its identified problems such as the weather related issues, traffic control, road closure times, and consistency problems. However most identified cases usually performed well with life expectancy of 15-20 years. Another important issue that relates to CIPR is the prediction on the suitability of existing materials to be used as recycled asphalt pavement (RAP). The use of RAP as a base layer is gaining popularity, but there are gaps in the literature about its material performance (Attia et al., 2010b). On the laboratory characterization of RAP as a base layer, literature indicates that RAP has a structural value as a pavement layer (Alam 2010). However limited research exists to quantify its structural capacity with fundamental engineering properties, especially for high RAP content.

Cold in-place recycling (sometimes referred to as CIR) is a method of rejuvenating flexible roadways by using special equipment to mill up the existing road pavement, process it over onboard screens, mix it with emulsions or additives, and then once cured is overlaid with a wearing course surface for permanent placement with a paver and rollers. Before placing the next pavement course the CIPR mixture should be allowed to cure for a minimum of at least 2 days and in addition, there must be less than 1.5 percent moisture remaining in the CIPR mixture. With conventional emulsions, curing of a new CIPR mix, at least in the initial time-period after placement, depends on the evaporation of water from the surface of the layer (Cross et al., 2010). Therefore, it is important to consider the effect of significant amounts of shaded areas can have on curing as the minimum 1.5% moisture content may not be achievable. Similar slow curing problems may also occur when work takes place in damp or cold weather conditions. A second curing criterion, less than 0.5% moisture remaining in the CIPR mixture above the residual moisture content of the pavement prior to recycling, is recommended to address these situations.

A mix design is a formulation that defines the percent and grade of recycling agent, recommended water content, and additives, for the planned CIPR mixture. The data is used to develop mix properties that will ensure that the mix will exhibit adequate initial strength, resistance to moisture-induced damage, resistance to thermal cracking and resistance to raveling. A formal mix design and a mix design report documenting the design formulation introduces additional quality control that helps to ensure that the pavement will meet desired specifications and performance expectations. It is recommended for all CIPR applications.

Establishing a mix design for a CIPR project requires a collection of field samples of the targeted pavement to be recycled and subsequent laboratory (mix) testing to establish a target formulation of the materials (asphalt emulsion, water, RAP, add-stone and additives) that will be used during construction. Coring the pavement to be recycled is the preferred method for collection of representative samples of the target pavement. This is undertaken to establish whether the properties of the pavement are consistent along its length, width, and depth and to obtain materials for the mix design.

Cold In-Place Recycling (CIPR) is a popular method for rehabilitating asphalt roads, but further research is needed to make performance more predictable. From the studies done, transportation officials have observed roads recycled under similar weather and construction conditions perform very differently for no clear reason (Jahren 2007). Therefore further studies are deemed necessary to achieve the following objectives:

- Investigate the relationships between road performance: age of the recycled pavement, cumulative traffic volume, and subgrade conditions.
- Understand these relationships in terms of the aged engineering properties of the cold in-place recycled (CIPR) materials.

- Consider changes that can be made to design, material selection, and construction to improve the performance of future recycled roads.

1.4 LIFE CYCLE COST ANALYSIS (LCCA)

Road pavement management is a very important subject, which requires proper planning and implementation. The road pavement quality has to be properly maintained in a sustainable condition over a certain period life cycle at the least cost. Life cycle cost analysis (LCCA), which is an important tool for planning of any infrastructure projects, including the road pavement can be employed to achieve this. An important component of the LCCA process is the performance prediction models, which are derived from pavement condition assessment data.

The LCCA is an analysis technique that introduces probabilistic approach based on the well-founded principles of economic analysis to evaluate the overall long-term economic efficiency between the available competing alternatives. By incorporating the necessary net present value (NPV) analysis, it attempts to identify the best value for investment expenditure, i.e. least cost at high performance that can last long. Therefore the study of the alternatives that provide the best overall balance of the cost incurred and the performance gained is paramount and will be performed in this research.

There are many factors to be considered in the comparative analysis of the alternatives, which include the agency costs, user costs, discount rate, selection of rehabilitation activities, use of comparable sections, and duration of the analysis period (Wimsatt et al., 2009). Nonetheless a point of diminishing returns is reached as more and more cost factors are incorporated in an LCCA, such that further inclusion of additional factors does not contribute to better accuracy of the results, but unnecessarily complicates the analysis (Walls et al., 1998).

There are a few of computer software readily available that can be used as a tool in LCCA. One of them is *RealCost*, a program originally developed in Microsoft Excel by the Federal Highway Administration in US and is subsequently adopted and customized by California Transportation (Caltrans 2007) to evaluate and select an optimal maintenance and rehabilitation (M&R) strategy by comparative analysis of two alternatives at a time. Due to its suitability and availability, the *RealCost* is chosen as a tool in this study.

1.5 RESEARCH AIM AND OBJECTIVES

The aim of this research is to compare and establish the best performance and economical of pavement rehabilitation with two alternatives method which is CIPR and reconstruction method. Since cost is not the only factor that has to be considered, the performance of the pavement also has to be evaluated in order to correlate the cost incurred against the performance gained. Theoretically a high strength pavement should be able to sustain longer. For this case study, the performance versus cost analysis of the pavement repaired using CIPR method is compared against the reconstruction method. Therefore, the objective of the case study in Malaysia can be summarized as follows:

1) To identify the pavement rehabilitation method used in Malaysia and method to access their performance.
2) To compare the performance of rehabilitated pavements using CIPR versus reconstruction method.
3) To compare life cycle cost analysis (LCCA) of rehabilitated pavements

using CIPR and reconstruction method.

4) To determine the most cost effective method of pavement rehabilitation to produces the highest performance using the LCCA.

Considering the importance of an economical analysis in the maintenance of flexible pavement in Malaysia, a comparative case study of the performance and life cycle cost analysis of CIPR method versus reconstruction method is performed.

1.6 SCOPE AND LIMITATIONS

The case study has its scope and limitations, which include the following:

1. The two samples of CIPR method and conventional one should have the same criteria in terms of project size, location, surrounding environment, traffic loads and source of materials such as the wearing course asphalt. This similarity is important in the analysis to reflect an accurate result on the difference in performance and cost relationship between the two methods. To get the said criteria is not easy, but the samples that constitute the best representative have been chosen to provide the necessary similarities.

2. The analysis period has to be long enough to reflect on the long-term cost effect. A minimum period of five years after the reconstruction is considered adequate, even though an optimum period of between 10 to 15 years is highly recommended, considering most road pavements in Malaysia is designed to have life cycle in that range.

3. The pavement performance is represented by the performance index based on the visual inspection and other surface defects detectors. The detail of the base layer performance or the structural strength of the pavement is provided by the relevant laboratory and field tests. The relevant data gathered for both methods could lead to a

precise assessment of the comparative strength, thus pavement performance before and after the rehabilitation.

4. The life cycle cost analysis is based on the Californian *RealCost* software program, in which the comparative study can be performed based on Microsoft Excel spreadsheet. To perform a proper life cycle analysis (LCA), a tremendous amount of data is needed, ranging from the specifications of the material, sources of materials, the specifications on the equipment used in construction and repair, and much more. However the environmental effects and its implication on the projects are excluded from the scope of study, therefore some of the data mentioned might not be required. An experienced researcher should be able to identify which data are necessary, and which are not.

CHAPTER TWO

LITERATURE REVIEW

2.1 FLEXIBLE PAVEMENT DESIGN

Accurate information is needed in order to adequately design a pavement. This information often includes: traffic loads, serviceability index, reliability, material characterization, drainage characteristics, and the condition of existing pavement conditions.

Flexible pavements are frequently analyzed as a multilayer system under loads. Typically, a flexible pavement consists of a surface layer with an underlying base and sub-base. Each of the layers contributes to the structural support and drainage of the pavement, but when hot mix asphalt is used as the surface course, it usually contributes the most to pavement strength, since it is the stiffest (high resilient modulus) layer. There is a special type of flexible pavement called "Perpetual Pavement" that uses premium Hot Macadam Asphalt (HMA) mixtures to obtain a long-life structure that can support heavier traffic loads. This type of pavement can last up to 30 years or more if it is maintained properly. The typical section for a perpetual pavement has a thickness of about 500mm (20 inches) total (Wimsatt et al., 2009).

2.1.1 Traffic Loading Classification

Pavement structural capacity is classified by the vehicles' loads or equivalent standard axles (ESAL) that the road is designed to carry during its service life. This introduces a time frame that demands a definition of the term "design life". Road authorities normally expect a return on their investment in a pavement and, typically, periods