THE IMPACT OF ECONOMIC ANALYSIS METHODS ON PROJECT DECISION-MAKING IN AIRPORT PAVEMENT MANAGEMENT

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Graphical abstract

Abstrak

Lapangan terbang adalah sebahagian daripada rangkaian pengangkutan dunia. Sejumlah besar wang dibelanjakan setiap tahun untuk pembinaan, penyelenggaraan dan pemuliharaan turapan lapangan terbang. Idea untuk menggabungkan penilaian kitaran hidup (LCA) dan analisis kos kitaran hayat (LCCA) adalah pendekatan terbaru untuk membangunkan kaedah penilaian turapan lestari. Dalam hal ini, kajian tentang kaedah analisis penilaian ekonomi telah menghasilkan pembangunan dan perambahan baik di dalam sistem pengurusan turapan (PMS). Kertas ini membandingkan dua analisis ekonomi dalam LCCA iaitu nilai masa depan bersih (NFV) dan nilai masa sekarang bersih (NPV). Satu kajian kes telah diperlihatkan untuk menunjukkan kesan penilaian ekonomi ini. Dalam kajian ini,
1.0 INTRODUCTION

Airports are one of the valued component of the world transportation network. They enable efficient movement of people and goods across vast distances, strengthen ties between communities, regions, and countries and promote economic growth. Huge investments are made annually for airport pavement maintenance and rehabilitation and sustaining the method on existing pavement. Airport stakeholders are looking for ways to achieve sustainability to increase operational effectiveness [1].

According to Hudson et al. [2], additional maintenance and rehabilitation of dilapidated pavements is a viable option from an economic point of view. Research on pavement management methods has resulted in pavement management systems (PMS) that provides a consistent, objective and systematic procedure for determining priorities, scheduling, allocating resources, and budgeting for pavement maintenance and rehabilitation [3]. Most PMS seek to maximize pavement maintenance and rehabilitation effectiveness by ensuring maximum benefits from the available fund. PMS provides the basis for an informed understanding of the possible consequences of alternative policies. The detailed analysis and design of pavement rehabilitation strategies in the project-level phase is performed by pavement engineering specialists [4].

Life-cycle assessment (LCA) is a comparatively recent environmental analysis method. Even though developed in the 1970s, LCA became popular at the end of the 1990s [5]. LCA is a method for quantifying the environmental impact associated with a product over its lifetime by considering the acquisition, transportation, construction, usage, maintenance and rehabilitation, and final disposal stages. Environmental problems such as climate change, stratospheric ozone depletion, tropospheric ozone formation, eutrophication, acidification and harmful impacts on human health and the ecosystems [6]. There is currently no standard LCA model specific for airport pavement usage [7]. In the LCA of highways, different methods are employed to evaluate the environmental impact. Each method has significant, unique benefits and drawbacks. According to Treloar et al. [8], the major drawback of most available methods is they encourage environmental responsibility in the construction industry instead of promoting environmental sustainability. More recently, several methods, such as those proposed by Stripple and Erlandsson [9], Santero et al. [10], and Bin Yu et al. [11], were developed to use LCA in environmental assessment.

Life-cycle cost analysis (LCCA) is an analysis technique that builds on the well-founded economic analysis principles to evaluate the overall long-term economic efficiency between competing alternative investment options. It identifies the best value (the lowest long-term cost that satisfies the desired performance objective) for investment expenditures [12]. In pavement design, LCCA is carried out in the project design stage. The LCCA analysis period should be sufficient to reflect long-term cost differences associated with reasonable design strategies. The Federal Highway Administration (FHWA) LCCA Policy Statement recommends an analysis period of at least 35 years for all pavement projects [13].

LCCA is suitable for many investment-related decisions to evaluate the economic worth of various designs, projects, alternatives, or system investment strategies to get the best return on the currency used [14]. The economic analysis helps decision-makers to make better choices regarding the alternative uses of scarce funds. LCCA provides the means to include the total cost to both airport management and user in the investment decision. However, the lowest LCC option may not necessarily be implemented when other factors such as risk, available budgets, and political and environmental concerns are considered. LCCA provides critical information to the overall decision-making process but is not the final answer [15]. Ozbay et al. [16] stated that LCCA would be used more often if the public and policymakers demand better resource management. The most common economic analyses are Benefit/Cost (B/C) Ratio, Internal Rate of Return (IRR), Net Present Value (NPV), Equivalent
Uniform Annual Cost (EUAC), Equivalent Uniform Annual Benefit, and Net Future Value (NFV).

The LCCA approach is preferred over the deterministic approach because it allows risk evaluation from the outputs. LCCA calculates the probabilities of each outcome represented by the parameter distributions. FHWA [17] developed the most recent program, RealCost, as a mechanism for probabilistic LCCA. Chen and Flintsch [18] proposed a logic-based model that aim to structure the mechanisms for decoding various intrinsically unclear inputs. The model assists in the further development of the probabilistic LCCA approach.

The integration of the two approaches provides a way to assess pavement sustainability. The integrated LCCA and LCA model is used to assess two bridge deck designs, conventional concrete bridge deck, and ECC link slab design in terms of total life-cycle costs, including direct costs, indirect costs, and environmental damage costs (EDC) by Kendall [19].

Airport pavements are critical for the taking off and landing of an aircraft. An immediate repair of the damaged pavement is necessary to ensure safety. This is a difficult task because of the limited funds and deterioration of pavement structures over time due to environmental factors and increasing traffic loads. This research describes the concept of NFV as an economic analysis in LCCA for the airport management system. This research presents the impact of different economic analysis method in project decision-making, especially concerning airport pavement management.

### 2.0 METHODOLOGY

This study aims to emphasis the effect of economic evaluation method in LCCA for assessing and improving the sustainability of airport pavements. The different economic analysis can be selected by pavement managers/engineers to evaluate the best pavement option. Nowadays, the use of LCCA is more established in highway pavement management rather than airports. The previous and only standard airport pavement management employed a simple Excel program, AirCost [20], which required much improvement. Babashamsi et al. [21] adopted the same approach to develop specific elements such as direct costs, indirect costs and salvage value and moreover considered uncertainty by using a risk assessment approach. His latest integrated method for airport pavement management (APMS) based on integrated LCCA and LCA appears in Figure 1. The proposed method makes a comprehensive and detailed environmental evaluation of airport pavements. The goal is to allow pavement practitioners with little specialized LCCA and LCA knowledge or resources to conduct a pavement sustainable development and obtain acceptable results using the inputs available to them within a reasonable timeframe.

**Figure 1** Flowchart for integrated LCA-LCCA model

LCCA comprises three main components, direct costs, indirect costs, and salvage value. An accurate LCCA approach relies on choosing an appropriate contracting model (alternate vs traditional contract) designed and prepared for agreement, the reliability of data to bolster the assessment, and the level of detail that can be managed for the analysis. The LCCA for airport pavement management incorporates the following steps that it is shown in Figure 2.

**Figure 2** Process for conducting airport pavement LCCA
After defining the project scope, the basic pavement LCCA process requires that the analyst defines the schedule of first and future activities involved in implementing a particular alternative (whether new construction or rehabilitation), after that the costs of each of these activities are estimated. The predicted schedule of activities and their associated costs comprise the projected life-cycle cost stream. Using an economic analysis technique known as “discounting,” all projected costs are either converted into present dollars and summed to produce a net present value (NPV), or calculated into future cost price and summed to produce a net future value (NFV). Discounting approach is standard practice among government agencies and is suggested by the FHWA [22]. LCCA should establish based on project budget, allocation and resources. FAA direction on utilizing NPV is sufficient. The NPV should be connected utilizing constant/real dollars and a discount [20]. As an alternative to NPV, NFV can be used. The advantage of NFV is that the analysis can show the real amount of costs that should be spent during the analysis period, while the NPV just indicates the project value. However, both of the economic analysis techniques are sufficient when comparing alternatives.

The main section in LCCA is estimating unit costs of constructing, maintaining and rehabilitating for each alternative strategy. The best way to evaluate physical costs is to recognize adequate and trustworthy unit cost data for pay items that contribute to the initial construction and all M&R treatments. The source of these data could be the historical bid records of construction projects in current years (ideally, the previous 7 years) [23]. Although experience-based estimates can quantify many LCCA inputs, it is suggested to be done using all available, applicable, and reliable data.

In 2007, Schumer reported that airport delays cost the economy approximately 40.7 billion dollars [24]. In this section, two specific user costs are considered.

- Airport Revenue Reduction Cost (ARRC)
- Airline Delay Cost (ADC)

Each alternative uses different constructional activities (initial construction/rehabilitation and future M&R) in the life-cycle period and affects the airport daily revenue reduction during execution. Key perspectives incorporated are characterizing by duration of each pavement event construction, reduction in airplane operations, and loss of daily operating revenue.

The EU report specifies that delays can be classified into two categories [25]:
- Gate-to-gate delays (single flight)
- Network-level delays.

This study considers only direct costs to the individual flight of such delays. Future work can investigate on the network-level delays and, in addition, subsequent economics costs to different industries and usinesses.

Current FAA guidance suggested calculating salvage value is based only on serviceable life [20]. The implementation and maintenance of APMS require a large investment and time and resources commitment. Larger airports may opt for training in the APMS process and implement and maintain APMS using internal staff. It is critical to identify all potential users of the system and determine their individual needs in the initial design stage of APMS to ensure everyone is satisfied with the end product. The potential users of an APMS differ depending on the implementing agency, whether it is an airport, state, regional planning agency, or branch of the military. APMS is implemented at the state or regional level, regional planning commission, individual airport, and FAA. The APMS implemented by military agencies is used by the military bases and at the federal level.

3.0 RESULTS AND DISCUSSION

NFV and NPV are analysis methods which help a company to prepare for the coming budgets over the life span of the highway. The NFV benefits the companies with the limited budgets. The NFV is the value for the current asset on a specific date in the future based on an assumed growth rate. NFV calculates the LCCA of the project from the start of the project (reconstruction, maintenance, rehabilitation, and salvage value) until the end of life. The NPV is the total amount required to implement the project, including reconstruction, maintenance, rehabilitation, and salvage value. Because the value of money changes over time, the private and public sectors with limited budget will have difficulties carrying out maintenance and rehabilitation after half of the project life span.

3.1 Case Study

The Rocky Mountain Metropolitan Airport was constructed in 1967 in Jefferson County, Denver, Colorado, USA. The airport has received large budgets for improvement and M&R for the past decades. Table 1 shows the specifications of the existing runway at the airport. The airport PCC pavement is at the end of its service life and has to be reconstructed to restore its serviceability. The existing base course is assumed to perform well and can function without intensive maintenance activities. Three replacement options are considered.
i. Remove and replace existing pavement with PCC (henceforth the PCC option). Remove existing PCC, keep the existing base and subgrade in place, and repave with a 300 mm (12 in.) PCC layer.

ii. Remove and replace existing pavement with HMA (henceforth the HMA option). Remove existing PCC, retain existing base and subgrade and repave with up to 250 mm (10 in.) HMA. Use a mill-and-fill (removal of the HMA surface and replace with new HMA) as a periodic rehabilitation strategy.

iii. Crack, seat, and overlay (henceforth the CSOL option). Crack and seat existing PCC pavement and overlay it with 150 mm (6 in.) HMA. Use mill-and-fill as a periodic rehabilitation strategy.

Table 1 Specification of the existing runway

| Runway Information | Description |
|--------------------|-------------|
| Runway length      | 1000 m      |
| Runway width       | 61 m        |
| Existing pavement  | Concrete    |
| Existing surface   | 25 cm       |
| Existing base      | 25 cm       |
| Distance from depot to plant | 50 km |
| Distance from plant to site | 50 km |

3.2 LCCA Input Data

The three pavement overlay design followed the AASHTO pavement design guide. The standard designs are structural design, and the estimation for other necessary parameters such as equipment and transportation were based on general practice and reasonable assumptions. For example, the HMA mix was 5% asphalt, 85% crushed aggregate, and 10% natural aggregate by weight and the PCC mix design was 10% cement, 75% crushed aggregate, 10% natural aggregate, and 5% water. The transport distance for all materials from the depot to plant to site and vice versa was 50 km. Table 2 lists the structural design of the three overlay system options.

Table 2 Structural design for the three alternatives

| PCC         | HMA         | CSOL         |
|-------------|-------------|--------------|
| 300 mm      | 250 mm      | 150 mm HMA   |
| Existing crushed aggregate | Existing crushed aggregate | Existing crushed aggregate |

According to the Airport Cooperative Research Program (ACRP) [26], concrete slab rehabilitation is usually carried out every 18-20 years, and according to California Department of Transportation (Caltrans), the average life of a diamond-grind surface is 16-20 years [27]. Therefore, PCC rehabilitation for the PCC option is carried out every 20 years. For the other two options, the HMA mill-and-fill plan of every 15 years used in previous research [28–29] is employed in this study. Figure 3 shows the maintenance and rehabilitation schedule for regular preventive maintenance activities adopted by the airport in Jefferson country (Colorado), and Table 3 shows the types of maintenance and rehabilitation.

Table 3 LCA Deterministic results of alternatives ($1,000a), NFV

| PCC Reconstruction | HMA Reconstruction | CSOL Reconstruction |
|---------------------|--------------------|---------------------|
| Main#1: Crack & Joint sealing | Main#1: Crack sealing | Main#1: Crack sealing |
| Main#2: Crack sealing | Main#2: Crack sealing | Main#2: Crack sealing |
| Main#3: Seal coating | Main#3: Seal coating | Main#3: Seal coating |
| Main#4: Crack sealing | Main#4: Crack sealing | Main#4: Crack sealing |

Rehab#1: Crack & Joint sealing + Spall Repair + 50% % slab replacement

Rehab#1: 150mm mill and new AC

Rehab#1: Full-depth mill and new AC

Rehab#1: Crack & Joint sealing + Spall Repair + 50% % slab replacement

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Rehab#1: Full-depth mill and new AC

The LCCA model is employed to assess the optimal option for pavement overlay systems. This method comprises three components, direct costs, indirect costs, and salvage value.

a. Indirect/User Costs Input Data

These assumptions are adopted to analyse the user cost of each alternative.

Figure 3 Reconstruction and M&R schedules for the three options
An accurate annual revenue value is confidential information and is dependent on airport size and number of flights and passengers. The value ranges between 10-15 million USD for medium international airports. This study assumed total annual revenue of 12 million USD (48 million MYR).

The revenue growth is 5% in compound mode. A project is worth implementing if the revenue growth is higher than (or equal to) the discount rate.

The number of flights at medium international airports is 300 flights per day, and each flight has 155 seats.

The aeroplane crew cost differs with the level of responsibility. The assumed mean of crew cost is 0.3 dollars (30 cents) per minute, and each flight has ten crew members.

The aeroplane maintenance cost is automatically filled after the type of airplane (mean number of seat) was selected. The analysis can change the value.

Table 4 shows the user costs for revenue reduction, duration, and airplane delay time for each event of the three alternatives.

Table 4 User costs input data for the three alternatives

| Alternatives | Event      | Revenue Reduction | Duration of Construction Day | Airplane Delay Time (min) |
|--------------|------------|-------------------|------------------------------|---------------------------|
| PCC          | Reconstruction | 25                | 7                            | 13                        |
|              | Maintenance#1 | 0                 | 1                            | 0                         |
|              | Maintenance#2 | 0                 | 1                            | 0                         |
|              | Rehabilitation#1 | 10               | 3                            | 10                        |
| HMA          | Reconstruction | 15                | 4                            | 10                        |
|              | Maintenance#1 | 0                 | 1                            | 0                         |
|              | Maintenance#2 | 0                 | 1                            | 0                         |
|              | Maintenance#3 | 0                 | 1                            | 0                         |
|              | Maintenance#4 | 0                 | 1                            | 0                         |
|              | Rehabilitation#1 | 10               | 3                            | 10                        |
|              | Rehabilitation#2 | 10               | 3                            | 10                        |
| CSOL         | Reconstruction | 10                | 3                            | 10                        |
|              | Maintenance#1 | 0                 | 1                            | 0                         |
|              | Maintenance#2 | 0                 | 1                            | 0                         |
|              | Maintenance#3 | 0                 | 1                            | 0                         |
|              | Maintenance#4 | 0                 | 1                            | 0                         |
|              | Rehabilitation#1 | 10               | 3                            | 10                        |
|              | Rehabilitation#2 | 10               | 3                            | 10                        |

b. Direct Cost Input Data

The analysis period of this study is 40 years, and a discount rate of 4% is the customary value for recent years in deterministic LCCA projects. The mean discount rate and standard deviation for probabilistic LCCA are 4% and 1%, respectively. Table 5 shows the mean for pay item costs and maintenance and rehabilitation timetable for all options. For the probabilistic method, the cost variation for each item has a standard deviation of 10%.

Unit Cost values are based on the mean cost of pay items in the Jefferson country airport system bid tabs from 2006 to 2016. The PCC does not have a salvage value because the analysis period and design life are 40 years.

Table 5 Initial and Maintenance and Rehabilitation unit costs for the three alternatives

| PCC | HMA | CSOL |
|-----|-----|------|
| **Initial Construction Costs** | | |
| PCC Removal, $11.00/m² | PCC Removal, $11.00/m² | Crack and seat, $2.00/m² |
| PCC Paving, $190.00/m² | HMA Paving, $140.00/m² | Prepare surface, $1.00/m² |
| Electrical, $320000.00/km | 41640 litre Tack | HMA Paving, $140.00/m² |
| Geotextile, $1.80/m² | 41640 litre Tack | Crack sealing, $2.00/m² |
| Electrical, $320000.00/km | $12000.00/km | Coating, $1.00/m² |

| **Maintenance Activity Costs** | | |
| Crack and Joint sealing, $3.00/m² | Crack sealing, $2.00/m² | Crack sealing, $2.00/m² |
| Seal Coating, $1.00/m² | Seal Coating, $1.00/m² |

| **Rehabilitation Activity Costs** | | |
| Spall repair, $5.00/m² | HMA Removal, $5.00/m² | HMA Removal, $5.00/m² |
| Slab replacement, $200/m² | HMA Paving, $140.00/m² | Crack sealing, $2.00/m² |
| $4,972,093 | $4,972,093 | Crack sealing, $2.00/m² |
| $3,562,708 | $3,562,708 | Crack sealing, $2.00/m² |

3.3 LCCA Deterministic Output

In the conventional deterministic approach, the best option is based on a single value, the mean of results. Table 6 shows that the direct cost of PCC is $5,553,558 (22 million MYR), while the costs for HMA and CSOL are $5,055,028 (20 million MYR) and $3,645,643 (14.25 million MYR), respectively. The direct costs for HMA and CSOL after deducting salvage values are $4,972,093 and $3,562,708, respectively. In terms of NPV, the cost for CSOL is lower than those of PCC and HMA by 35.8% and 28.3%, respectively. Also Table 6 shows the ARRC and ADC of the CSOL option are lower than for other alternatives. In all three options, ADC assigned a higher indirect cost than to ARRC. The ADC is higher in rehabilitation with HMA and CSOL, while in PCC, the initial construction is higher than that of ADC. Table 7 shows the detailed direct costs and salvage values of the activities.

Table 6 LCCA Deterministic results of the alternatives ($1,000a), NFV

| Option | Activity | Direct Cost | Indirect Costs | Salvage Value |
|--------|----------|-------------|----------------|---------------|
| PCC    | Initial  | 4838.4      | 63.3 1090.2    | 0.0           |
|        | Maintenance | 933.3      | 0.0 0.0        | 0.0           |
|        | Rehabilitation | 2324.0 | 28.8 68.2 | 0.0           |
|        | Total       | 8500.5      | 92.1 1158.4    | 0.0           |
| HMA    | Initial  | 3519.5      | 21.8 414.3     | 2012.5        |
|        | Maintenance | 3178.5      | 0.0 0.0        | 2012.5        |
|        | Rehabilitation | 8752.0 | 59.0 129.1 | 2012.5        |
|        | Total       | 16222       | 80.8 543.6     | 2012.5        |
Table 7 LCCA Deterministic results for the alternatives ($1,000a), NFV

Table 8 LCCA Deterministic results of alternatives ($1,000a), NFV

Table 9 Total costs of the alternatives using NPV and NFV ($1,000)

Table 10 Detailed direct costs of the alternatives using NPV and NFV ($1,000)
The future value of an annuity is the amount of money that will be accrued by making consistent investments over a specific period, assuming compound interest. Instead of planning for a guaranteed amount of future income by calculating the amount that has to be invested now, this formula estimates the growth of savings for a fixed investment rate for a specific period.

4.0 CONCLUSION

LCCA should establish based on project budget, allocation and resources. Various economic evaluation analyses same as are Benefit/Cost (B/C) Ratio, Internal Rate of Return (IRR), Net Present Value (NPV), Equivalent Uniform Annual Cost (EUAC), Equivalent Uniform Annual Benefit, and Net Future Value (NFV) are used in different LCCA. NFV calculates the LCCA of the project from the start of the project (reconstruction, maintenance, rehabilitation, and salvage value) until the end of life. The NPV is the total amount required to implement the project, including reconstruction, maintenance, rehabilitation, and salvage value.

CSOL is 35.8% and 28.3% more cost-effective than PCC and HMA, respectively. Relative to PCC, the cost of the HMA option is lower with the highest uncertainty. PCC has higher indirect costs in terms of ARRC and ADC. The maintenance costs in HMA and CSOL are 10.2% HMA and 14.2% of the total cost, respectively. The rehabilitation costs for PCC, HMA, and CSOL are 16.3%, 25.4%, and 35.2% of total costs. As it shows in results the decision-making of selecting a right economic analysis base on budget, allocation and contracts could increase up the cost to more than hundred present during the life-cycle.

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