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Sustainable Cost Optimisation Measures for The Lifecycle of Tolled Highway Projects in Malaysia

Sukhadeva S.Sukumar[a], Abu Hanifah Yusof[b], Muhamad Iqbal Aslam Abd Hafiz[a], Muhamad Razuhanafi Mat Yazid[a,d], Mohd Azizul Ladin[c] & Mukhlis Nahriri Bastam[e]

[a] *Department of Civil Engineering, Faculty of Engineering & Built Environment, Universiti Kebangsaan Malaysia, Malaysia, 43600 Bangi, Selangor, Malaysia*
[b] *Civil Engineering Department, Politeknik Kota Bharu, KM24, Kok Lanas, 16450 Ketereh, Kelantan*
[c] *Faculty of Engineering, Universiti Malaysia Sabah, Kota Kinabalu, Malaysia*
[d] *Sustainable Urban Transport Research Centre, Universiti Kebangsaan Malaysia, Bangi 43600, Selangor, Malaysia*
[e] *Department of Civil Engineering, Faculty of Engineering, Universitas Bina Darma, Indonesia*

**Corresponding author: razuhanafi@ukm.edu.my*

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ABSTRACT

The implementation and maintenance of highway infrastructure often requires significant capital throughout its life cycle which affects stakeholders including the government, developers, operators, users, etc. Furthermore, the sustainability aspect and existing toll systems in Malaysia are currently in the midst of being re-evaluated in order to attain a long-term gain that benefits both road users and relevant stakeholders. The objective of this study is to propose a Life Cycle Cost Analysis (LCCA) model for sustainable highway projects in Malaysia which considers certain cost optimisation measures throughout the stages of concept, design, construction, and operation & maintenance. The proposed LCCA model intends to act as a cost optimisation tool that provides sustainability recommendations for toll systems, highway alignments, pavement maintenance and rehabilitation, existing policies, contract and project type, material, equipment, time-cost factor, etc. Additionally, a relationship between the financial efficiency of toll systems and the affect it has on the overall cost of highway projects was established. The significance of cost pertaining to highway infrastructure components and the perception of toll systems was evaluated via a survey questionnaire; distributed to a select group of senior and principal engineers. The survey utilised a 5-point Likert scale which assisted in forming a regression analysis along with determining a correlation between toll systems and the overall cost of highway projects. Secondary data obtained from a reputable consultancy aided in understanding highway components that could potentially undergo further cost optimisation. Lastly, the sustainable and cost optimised LCCA model consists of recommendations and measures intended for a new age of sustainable highway projects in Malaysia.

Keywords: Life cycle cost analysis; cost optimisation; sustainability; toll systems

INTRODUCTION

The challenge of sustaining an infrastructure which needs to be planned, constructed, operated and maintained usually comes in the form of adequate funding. This is not just a domestic issue but an ongoing problem faced by numerous countries around the world (Rogers 2008). Highway construction is usually funded with the aid of the public as the government's budget allocations have to cater for numerous other sectors within the economy. As of 2020, the budget allocated for development expenditure in Malaysia is RM56 billion while operating expenditure is RM241 billion with highway infrastructure development, maintenance and proposed acquisition taken into account (Bernama 2019).

In order to reap the benefits of a well-connected highway network, the involvement of either government authorities or privately owned concessionaires have allowed for the stimulation of economic activity that is practically unseen in other parts of the world. However, most private or public/private partnerships have yet to indicate substantial evidence of being financially sustainable on a long term basis (Hassan & Ibrahim 2013). One of the many financial mechanisms that aid in funding most highway projects throughout its lifecycle is the utilisation of toll systems. This led to the interest of further understanding the fundamental issues pertaining to toll systems and the affect it has on the overall lifecycle cost of highway projects. Additionally, the understanding and comparisons of cost contributing factors of certain highway infrastructure components will be further explored and discussed.

Hence, this study intends to reduce the research gap between the current/traditional Life Cycle Cost Analysis (LCCA) models and a sustainability based LCCA model by further exploring and recommending relevant cost optimisation measures where applicable. This study would not only deepen the understanding of relevant cost implications throughout the lifecycle of highway projects but would greatly benefit the government, key industry players and public users within Malaysia. Studies such as these would allow for sustainability related considerations to be in place prior to the implementation of highway and transportation projects. This study also aims to contribute to the limited body of knowledge pertaining to LCCA while bringing awareness to the vital importance of the relationship between costing and sustainability; in turn allowing for the future of better implementation of sustainable highway projects in Malaysia.

The urban and infrastructure renewal efforts that many countries are taking has led to a large influx in the construction of transport systems such as roads and highways. These development efforts are usually carried out in order to revitalise stagnant economies or improve upon the overall efficiency of a country's transport system (Kandil et al. 2010). However, the lack of readily available information and studies pertaining to cost optimisation and sustainability has led to the need for further exploration into the life cycle cost analysis (LCCA) of highway projects (Goh & Yang 2010). Highway infrastructure being a vital component of Malaysia's transportation network has led to the government and other stakeholders to emphasize on cost optimisation measures throughout the life cycle of highway projects. This includes the restructuring of toll systems and ongoing negotiations with highway concessionaires in order to ease the cost related burden experienced by highway users (Aswad 2019).

Although key construction industry players are well aware of the importance of LCCA, the current state of the LCCA practise and understanding in Malaysia is still at its infancy and is unready to be implemented due to difficulty in obtaining sufficient data and generating a reliable LCCA model (Jasmi et al. 2017). Numerous studies have greatly focused on certain components of highway project which contribute to cost including pavement rehabilitation, highway bridges, highway management, etc (Goh & Yang 2010) but not many have emphasised on the entirety of the highway infrastructure throughout its lifecycle.

The following research intends to establish; (i) determine and propose an LCCA model that intends to act as a cost optimisation tool providing sustainability recommendations for toll systems, highway alignments, pavement maintenance and rehabilitation, existing policies, contract and project type, material, equipment, time factor, (ii) to develop a relationship between the perception of existing toll systems and the affect it has on the overall cost of highway projects (necessity) and (iii) analyse the impact of toll systems by understanding the financial efficiency of funding a highway throughout its lifecycle.

METHODOLOGY

This study utilises quantitative approaches to understand cost related factors that significantly affect the sustainable LCCA model being proposed. Firstly, the study of secondary data obtained from a reputable engineering consultancy firm consisting of the Bill of Quantities (BQs) of three separate highway projects will be evaluated via the utilization of a financial analysis. This financial analysis will consist of the Net Present Value (NPV), Cost Benefit Analysis (CBA) and Internal Rate of Return (IRR) which helps determine the efficiency of the funding mechanism in place. Once the financial analysis has been carried out, a survey questionnaire will be distributed to selected participants with results that will aid in establishing a relationship between the perception of existing toll systems and the impact it has on the overall cost of highway projects.

Results obtained from this survey questionnaire will then undergo a correlation and regression analysis in order to formulate and model an equation which determines a relationship between existing toll systems and cost contributing factors of highway projects. These results will then be presented and discussed in the form of tables and graphs with comparisons to the existing literature and knowledge. Lastly, the discussion portion of this study will also contain the LCCA model which is to be presented in the form of a table indicating cost contributing components throughout the different stages of the highway's lifecycle and the cost optimization measures in place which best suits each cost contributing item or component.

SECONDARY DATA

Secondary data for this study will be obtained from a reputable engineering consultancy with vast experience in highway and transportation related projects. The secondary data will consist of the Bill of Quantities (BQs) which provides information on rates and detailed breakdown of highway components/items that contribute to the cost factor of highway projects. Three BQs will be selected for this study and will utilise the industry's most preferred financial analysis to evaluate the main funding mechanism in place being the toll systems itself. This portion of the study intends to study the efficiency of toll systems and its long term financing capabilities of the funding highway systems in place by extracting the information such as relevant items, quantities and rates that contribute significantly to the cost of highway projects.

The projected future revenue of a project's present value is determined by using NPV calculations. The NPV alongside an escalation factor is ideally used for the long term operation and maintenance cost and is calculated accordingly to make sure that the project cash flow is accurate, achievable, acceptable and reasonable to achieve a good project return. Projects will only be implemented and approved if the NPV value is positive and rejected if it is negative. This allows to determine the project's success or failure prior to implementation while assessing as to whether the toll rates allows for the return of investment throughout the concession period.

In order to evaluate the costing aspect, studies conducted by (Ghazali et al. 2017) covered the framework and evaluation technique that is including the utilisation of NPV, IRR and CBA via tabulation and graphs produced by Microsoft Excel. This financial analysis would aid in understanding the viability of the financial mechanism in place, highway project's viability and the long term cost impact to the life cycle of the highway project. The formulas utilised for the financial analysis are as follows;

- Net Present Value (NPV) = $\frac{M_n}{(1+i)^n}$

  where M_n = Cash Flow
  i = Discount Rate (%)
  n = Number of Years (n^{th} Period)

- Internal Rate of Return (IRR) = $\sum_{n=1}^{N} \frac{B_n - C_n}{(1+irr)^n} = 0$

  where B_n = Benefit at end of n^{th} period
  C_n = Cost at end n^{th} period
  irr = Internal Rate of Return

- Cost Benefit Ratio = $\frac{\text{Sum of NPV Benefit}}{\text{Sum of NPV Cost}}$

Sample Size Determination

Studies such as the sample size chosen by (Ghazali et al. 2017)it is essential to determine the critical success factor (CSF and (Rahman & Zakaria 2016) proved that a sample size of either 1 to 10 respondents allows for sufficient data to be collected and evaluated. Hence, this study will utilise a sample size of 10 respondents consisting of experienced senior and principal engineers with at least 10 years of experience in highway and transportation related projects as according to (Ericsson et al. 1993), (Atman et al. 2007) and (Cross 2004), an individual with at least 10 years of experience is deemed an expert in their field of work. The chosen sample size abides by studies utilising smaller sample sizes while allowing for this study to be conducted within a timely manner. The results obtained will provide the respondent's chosen answers and years of experience while the identities of the respondents itself will not be disclosed as it will simply be utilised as a means of identification for data collection.

SURVEY QUESTIONNAIRE

The survey questionnaire will be divided into three sections with Section 1 focusing on the basic details of the respondent, Section 2 containing the perception of toll systems and Section 3 containing the ranking of cost contributing components and items of highway infrastructure projects. Upon conducting the survey and obtaining the answered questionnaires from selected participants, the findings will utilise a similar approach to that of (Rahman & Zakaria 2016) and (Goh & Yang 2010) where the tabulation and analysis was carried out via Microsoft Excel and IBM SPSS Statistics in order to obtain either a Spearman or Pearson's correlation coefficient while identifying the mean, standard deviation and ranking based on the respondent's choices.

REGRESSION & CORRELATION ANALYSIS

The analysis will utilise both a regression and correlation analysis in order to determine a relationship between the results obtained from sections 2 and 3 of the survey questionnaire. Firstly, a correlation analysis will be carried out between the results obtained from the survey in order to form a joint variability of two random variables. This allows for information on the strength and direction (positive or negative) of a relationship between two continuous variables to be determined. The second portion of the analysis will consist of a regression analysis whereby a model of either a linear relationship (Pearson's correlation coefficient) or a non-linear relationship (Spearman correlation constant) is determined (Franzese & Iuliano 2018). The regression analysis that has a linear correlation will be represented using the least squares regression line with y being the dependent variable and x the independent variable. If a linear relationship would require for the x and y to be quantitative measures of two random variables on the same sample of n. The formula for computing the Pearson's correlation coefficient, r will be as follows;

$$r = \frac{\sum_{n=1}^{n}(x-\bar{x})(y-\bar{y})}{\sqrt{\sum_{n=1}^{n}(x-\bar{x})^2}\sqrt{\sum_{n=1}^{n}(y-\bar{y})^2}}$$

where $\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x$

$\bar{y} = \frac{1}{n}\sum_{i=1}^{n} y$

The correlation will utilise the following guidelines to describe the strength of the correlation for the absolute value of r_s:

- 0.00-0.19 = very weak correlation
- 0.20-0.39 = weak correlation
- 0.40-0.59 = moderate correlation
- 0.60-0.79 = strong correlation
- 0.80-1.0 = very strong correlation

TABULATION TECHNIQUE

Tabulation and data will be represented in a clear and concise manner in which a ranking, mean and standard deviation will be given to the results obtained from the survey questionnaire. The table is a recreation of the table presented in the study by (Goh & Yang 2010).

FORMULATION OF AN LCCA MODEL

The equation that determines the relationship between the perception of toll systems and cost contributing components would allow for a relationship to be formulated in order to produce the LCCA model. The LCCA model aims to recommend cost optimization measures for each component or stage of a highway project. Ideally it would be presented in a table format and enclosed within Results and Discussion. Numerous existing studies will be utilised in order to formulate a comparison and recommendation for cost optimization measures.

RESULTS AND DISCUSSION

FINANCIAL ANALYSIS

The financial viability of a highway project requires to be determined prior to the implementation process. This would require certain testing methods established as part of the financial analysis which is utilised by (Babashamsi et al. 2016) along with the framework and evaluation technique by (Mohamed et al. 2017). The financial analysis which utilizes NPV, IRR and Cost-Benefit Analysis is not only considered as standard practice methods but ones that are recommended by (Donald S. Remer & P.Neito 1995) based on 25 projects evaluation techniques.

For Highway 1, the cost-benefit analysis indicated a positive ratio value of 6.53 which would justify the economic and financial viability of the project especially for stakeholders involved in implementing the highway project. The IRR obtained is 47% which indicates that the stakeholder's initial expenditure on the project yields a financial return in about 2.1 years of operation with profits from around year 4 onwards. The NPV values obtained for cost and benefit are RM1,664,243,547.25 and RM 10,861,408,607.27 respectively which indicates significant financial benefits for the highway system in place.

For Highway 2, the cost-benefit analysis indicated a positive ratio value of 4.66 which would justify the economic and financial viability of the project especially for stakeholders involved in implementing the highway project. The IRR obtained is 42% which indicates that the stakeholder's initial expenditure on the project yields a financial return in about 2.4 years of operation with profits from around year 4 onwards. The NPV values obtained for cost and benefit are RM216,344,660.62 and RM1,008,175,303.89 respectively which indicates significant financial benefits for the highway system in place.

For Highway 3, the cost-benefit analysis indicated a positive ratio value of 3.30 which would justify the economic and financial viability of the project especially for stakeholders involved in implementing the highway project. The IRR obtained is 27% which indicates that the stakeholder's initial expenditure on the project yields a financial return in about 3.7 years of operation with profits from around year 5 onwards. The NPV values obtained for cost and benefit are RM3,389,660,215.27 and RM11,201,947,821.03 respectively which indicates significant financial benefits for the highway system in place.

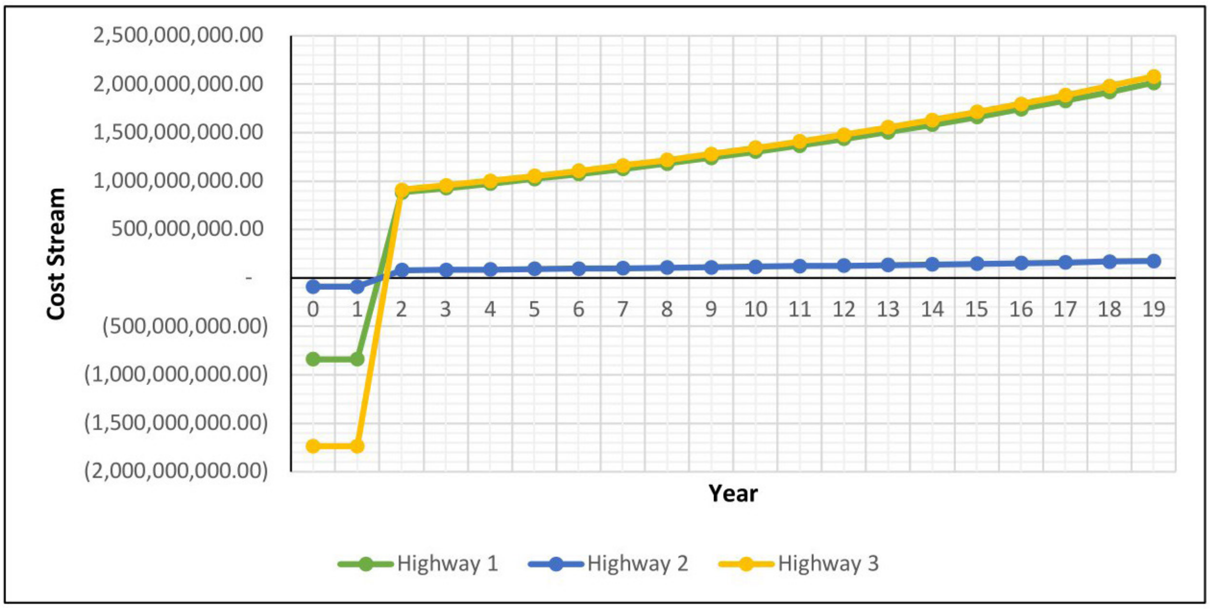

FIGURE 1. Overall cost stream for all three highway projects

Although the financial analysis indicated that the three highway projects evaluated would be profitable, numerous highway and transportation projects tend to undergo certain financial issues and constraints in the long run. In some cases, initiatives that aid in reducing future costs (e.g. durability, energy saving measures) would often result in a greater initial investment costs (e.g. addition of thermal insulation, durable pavement materials, etc.) which is the main reason that toll systems are utilised as a funding mechanism.

However, based on the responses from the survey conducted by (Sidhu 2019), there was indication of dissatisfaction with the charges incurred by the end user when utilizing toll systems. This prompted the idea of conducting a survey questionnaire with participation by selected individual working within the industry while abiding by the approach utilised by (Goh & Yang 2010) and (Rahman & Zakaria 2016). This section of the analysis focuses on the perception of toll system (Section 2) in which the questions curated deals with the relevance of toll systems with regards to external factors such as efficiency, toll fares justification, abolishment of tolls & long term financing, level of service (LOS), upgrading requirements, funding, partnerships, modal shift influence and congestion charging effect.

As shown in Figure 1, Highway 1 and 3 seem to increase in unison on the graph plot, the benefit-cost ratio along with the IRR values are significantly different. This would likely be due to Highway 3 having the highest project cost in comparison to Highway 1 but cost stream values that taper off with a similar trend. Highway 2 required the least initial capital and project cost but indicated to provide a near IRR value to Highway 1. Overall, all three highways indicated some form of profitable projection and abide by the financial analysis related studies carried out (Hassan & Ibrahim 2013); (Alfan 2010).

The highest ranked external factor that significantly affects toll systems would be the abolishment of toll systems itself as this could have an adverse effect on long term financing. The lowest ranked external factor would be the modal shift influence and as to whether current toll fares are successful in influencing a shift from private vehicular usage to public transportation. The second lowest ranked item indicates that congestion charging within urban areas has minimum effects on influencing toll fares. Based on the median values in the table, respondents seem to have either rate their responses at a Likert scale of 4 (agree/relevant) or 5 (strongly agree/highly relevant) while the only two outliers in the median column seemed to be rank 8 and rank 10 pertaining to public-private partnerships (PPPs) and modal shift influence respectively.

The data was represented as a histogram indicating that the top four ranked items (abolishment & long term financing, upgrading requirements, efficient funding mechanism and efficiency & LOS) were items that respondents thought were highly relevant in terms of the perception of toll systems. The external factors evaluated along with the responses are shown in Table 1.

TABLE 1. Data for perception analysis in terms of descending rank

Rank	Mean	Median	Standard Deviation	External Factor	Question No.
1	4.7	5	0.48	Abolishment & Long Term Financing	3
2	4.6	5	0.52	Upgrading Requirements	5
3	4.3	4	0.48	Efficient Funding Mechanism	1
4	4.1	4	0.99	Efficiency & LOS	4
5	3.8	4	0.79	Toll Fares Justification	2
6	3.8	4	1.03	Public Sector Funding	6
7	3.5	4	0.97	Long Term Financial Subsidisation	7
8	3.5	3.5	0.85	Public-Private Partnerships (PPPs)	8
9	3.5	4	0.97	Congestion Charging Effects	10
10	2.2	2	1.03	Modal Shift Influence	9

Upon understanding the perception of toll systems, there is also a need to understand the necessity of tolled highway systems by evaluating the cost contributing components of these tolled highway systems itself. Prior to comparing and understanding the relationship between perception and necessity of toll systems, this section intends to justify the necessity/relevance of cost contributing components based on a sustainability criteria of agency cost, social cost and environmental cost. This necessity analysis formulates Section 3 of the survey questionnaire that utilizes a degree of relevance scale for each of the 42 cost contributing components in order to understand the impact these items have on the overall cost of highway infrastructure projects. The idea of utilizing these 42 cost contributing components was mainly inspired by numerous studies especially one carried out by (Goh & Yang 2010) which ranked cost contributing components and issues in terms of a sustainability criteria via a survey questionnaire.

As indicated in the Table 2, the highest ranked sub factor that respondents agreed significantly affects the necessity of toll systems would be the major maintenance cost which is considered as an agency cost. The lowest sub factor which is an environmental related cost would be tyre noise while the second lowest is engine noise; both of which are related to noise pollution. Based on the median values in the table, nearly all respondents seem to have either rate their responses at a Likert scale of 3 (neutral) to 5 (highly relevant) with the only outlier being the tyre noise sub factor which indicated a median of 2.90.

A trend can be seen in the first 10 ranks whereby ranks 1 to 6, 8 and 9 are occupied by agency related cost while ranks 7 and 10 have been occupied by social and environmental related cost respectively. This indicates that most respondents believed that agency related cost played a significant role as these sub factors had the highest significance/relevance to the necessity of toll systems. The results obtained in this study varies to that conducted by (Goh & Yang 2010) whereby these participants had ranked the most significant costs elements in highway investments as material costs, plant and equipment costs, and rehabilitation cost. The respondents in (Goh & Yang 2010) study also indicated that accident costs consisted of internal costs, economic value of damage while the external costs was the most significant costs in social aspects. The environmental costs elements and issues that rated the most important in this same study included hydrological impacts, loss of wetland and cost of barriers. The difference in results would likely be attributed to the fact that (Goh & Yang 2010) had utilsed sustainability as a comparison to cost implication while this study is utilizing toll systems as a comparison to cost optimization. Further analysis was carried in terms of sustainability aspects pertaining to agency, environmental and social related costing.

TABLE 2. Data for necessity analysis in terms of descending rank

Rank	Mean	Median	Standard Deviation	Sustainability Cost Components & Issues (Sub Factors)	Sustainability Criteria
1	4.80	5.0	0.42	Major Maintenance Cost	Agency Cost
2	4.60	5.0	0.52	Material Cost	Agency Cost
3	4.60	5.0	0.52	Routine Maintenance Cost	Agency Cost
4	4.40	4.5	0.70	Rehabilitation Cost	Agency Cost
5	4.30	4.0	0.48	Plants & Equipment Cost	Agency Cost
6	4.20	4.5	1.03	Pavement Extension Cost	Agency Cost
7	4.00	4.0	1.05	Reduction of Cultural Heritages & Landscapes	Social Cost
8	3.90	4.0	0.74	Demolition Cost	Agency Cost
9	3.90	4.0	0.74	Disposal Cost	Agency Cost
10	3.90	4.0	0.99	Habitat Disruption & Loss	Environmental Cost
11	3.80	4.0	1.03	Cost of Resettling People	Social Cost
12	3.80	4.0	1.03	Ecology Damage	Environmental Cost
13	3.80	4.0	1.03	Environmental Degradation	Environmental Cost
14	3.70	4.0	0.95	Labour Cost	Agency Cost
15	3.70	4.0	0.82	Recycle & Reuse Cost	Agency Cost
16	3.70	4.0	0.95	Community Cohesion	Social Cost
17	3.70	4.0	0.95	External Cost (affecting parties apart form end user)	Social Cost
18	3.70	3.5	1.06	Driver’s Attitude	Environmental Cost
19	3.70	4.0	0.95	Effects to Human Health	Environmental Cost
20	3.60	4.0	0.84	Traffic Congestion Cost	Social Cost

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21	3.60	3.5	0.97	Negative Visual Impact	Social Cost
22	3.60	4.0	0.87	Land Use Cost	Environmental Cost
23	3.60	4.0	1.07	Carbon Dioxide Emission	Environmental Cost
24	3.60	4.0	0.97	Hydrological Impacts	Environmental Cost
25	3.50	4.0	0.97	Economy Value of Damages	Social Cost
26	3.50	3.50	0.85	Internal Cost (affecting the end user)	Social Cost
27	3.50	3.50	1.08	Energy Consumption Cost	Environmental Cost
28	3.40	3.0	0.84	Vehicle Elements Cost	Social Cost
29	3.40	3.5	0.97	Fuel Consumption Cost	Environmental Cost
30	3.40	4.0	1.17	Cost of Barriers	Environmental Cost
31	3.30	3.0	0.95	Cost of Dredge/Excavate Material	Environmental Cost
32	3.20	3.0	1.23	Property Devaluation	Social Cost
33	3.20	3.0	0.79	Materials Disposal Cost	Environmental Cost
34	3.20	3.5	0.92	Distraction to Soil	Environmental Cost
35	3.20	3.0	1.03	Extent of Tree Falling	Environmental Cost
36	3.20	3.0	1.03	Dust Emission	Environmental Cost
37	3.20	3.0	1.03	Loss of Wetland	Environmental Cost
38	3.10	3.0	0.74	Road Tax & Insurance Cost	Social Cost
39	3.10	3.0	0.57	Speed Changing Cost	Social Cost
40	3.10	3.0	0.74	Waste Management Cost	Environmental Cost
41	3.00	3.0	1.05	Engine Nosie	Environmental Cost
42	2.90	3.0	0.88	Tyre Noise	Environmental Cost

CORRELATION & REGRESSION ANALYSIS

The main aim of this analysis is to answer this study's research question and objective in determining a relationship between the perception of existing toll systems and the affect it has on the overall cost of highway projects (necessity). The analysis will utilise both a regression and correlation analysis in order to determine a relationship between the results obtained from sections 2 and 3 of the survey questionnaires.

This was carried out for agency, environmental and social related cost respectively against the mean perception obtained. As shown in Figure 2, Figure 3 and Figure 4, the regression line indicating a correlation between the mean perception against the mean necessity values has been determined. Table 3 represents the results summary for agency, environmental and social related cost obtained for the correlation and regression analysis which indicates a strong correlation for all sustainability related criteria.

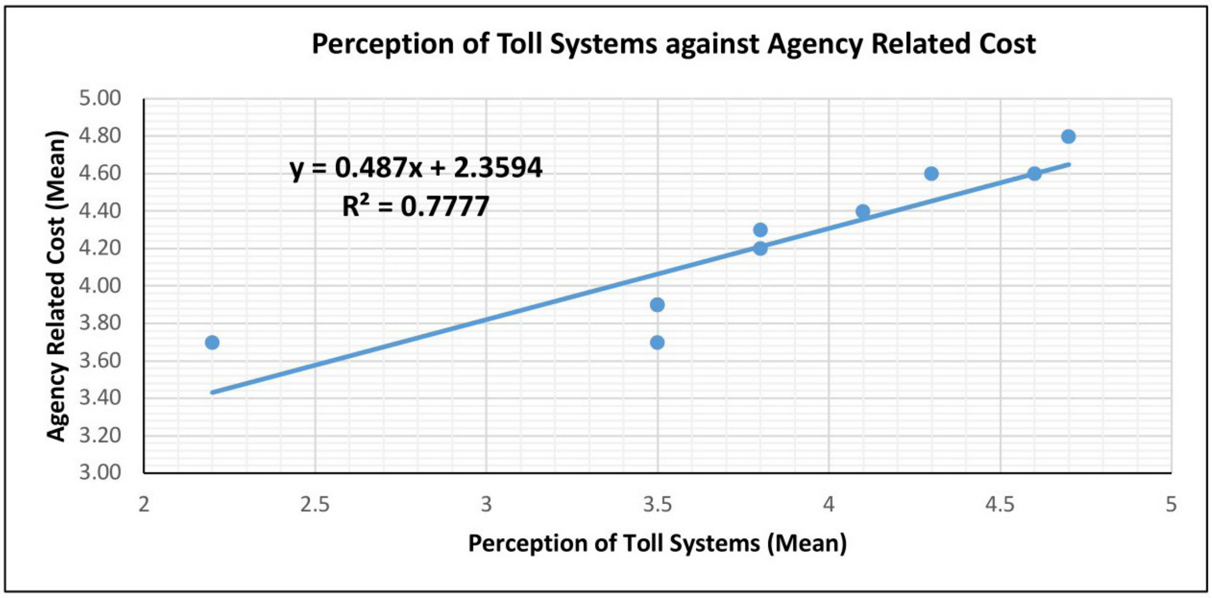

FIGURE 2. Perception against necessity in terms of agency related cost

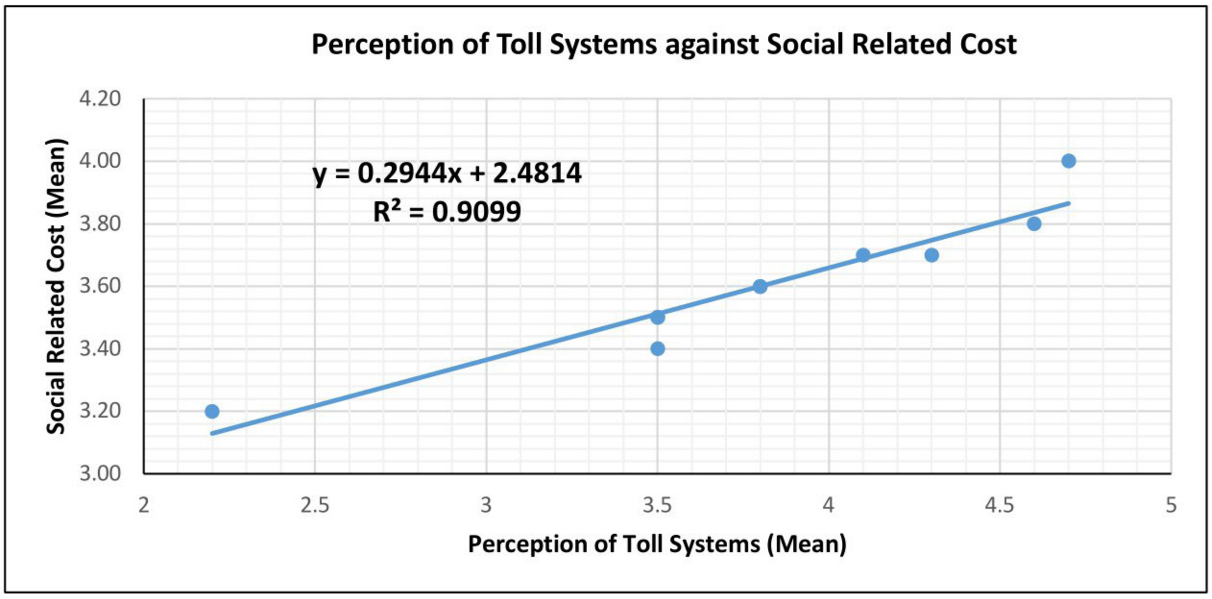

FIGURE 3. Perception against necessity in terms of social related cost

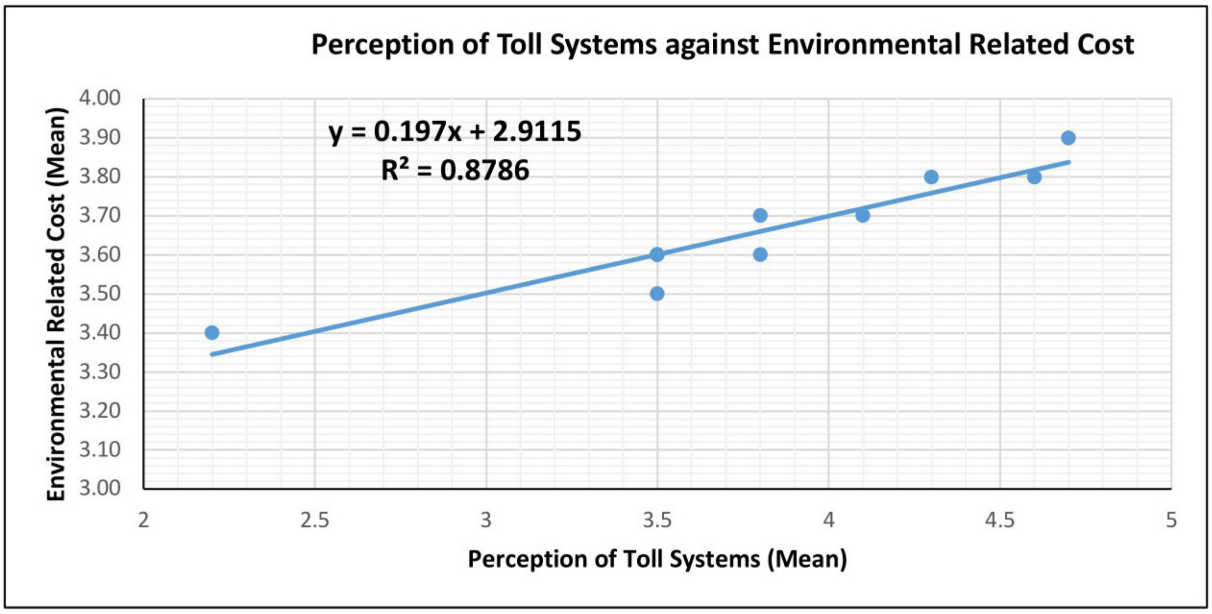

FIGURE 4. Perception against necessity in terms of environmental related cost

TABLE 3. Correlation and regression analysis results summary

Regression & Correlation Variables	Results (Agency)	Results (Social)	Results (Environmental)
R^2 value	0.777699944	0.909878	0.87863933
r value (Pearson's Correlation Coefficient)	0.881872975	0.953875254	0.937357634
Significance F value	0.000736962	0.000018727	0.0000624345
P-value for Intercept	0.000162632	0.000000047282	0.000000002082
P-value for Mean Perception Gradient	0.000736962	0.000018727	0.000062434
Coefficients (y-intercept)	2.359350649	2.48138528	2.91151515
Coefficient (gradient)	0.487012987	0.29437229	0.1969697

COST OPTIMISATION MEASURES (SUSTAINABLE LCCA MODEL)

The three linear equations in the correlation and regression analysis for each respective sustainability criteria has managed to determine a strong correlation and relationship between the perception of toll systems and cost contributing components (necessity). This would now allow for the formulation of the sustainable LCCA model which aims to recommend cost optimization measures for each component or stage of a highway project. It will be presented in a similar tabular format as established in the methodology and will consist of numerous existing studies in order to formulate a comparison and recommendation pertaining to cost optimization measures that can be applied to sustainable highway projects in Malaysia. The proposed sustainable model also intends to fulfill one of the research objectives that is to determine and propose an LCCA model that intends to act as a cost optimization tool providing sustainability recommendations for toll systems, highway alignments, pavement maintenance and rehabilitation, existing policies, contract and project type, material, equipment, time factor, etc.

The measures represented in tabulation format can be expanded upon or amended according to the highway infrastructure project in place. Since LCCA studies are still considered a fairly recent concept, it has yet to be utilized in its entirety for Malaysian highway projects. Additionally, the idea of incorporating numerous LCCA related studies as a tool for cost optimization would be an advantageous step forward in the lifecycle cost analysis of sustainable highway projects in Malaysia. The analysis and results obtained in this chapter allowed for an in-depth understanding of the topic while ensuring that the relevant objectives and research questions have been met and attended to.

CONCLUSION

The main aim to propose a sustainable Life Cycle Cost Analysis (LCCA) model for sustainable highway projects in Malaysia which considers certain cost optimization measures throughout the stages of concept, design, construction, and operation & maintenance was achieved by the end of the previous chapter. This was initiated by first carrying out an evaluation of tolled highway systems as a funding mechanism in order to understand its effects on the overall cost of highway projects via the utilization of a financial analysis commonly used to evaluate highway infrastructure projects, whilst still being a relevant measure in numerous LCCA related studies. The financial analysis which consisted of utilizing BQs for three highway projects obtained from a reputable engineering consultancy firm produced satisfactory results with the cost stream, NPV, IRR and CBA likely being deemed favourable by relevant stakeholders. This would lead to all three highways achieving the required financial project viability while ensuring that the financial mechanism in place functions as intended. However, the financial analysis utilized certain assumptions including the fixed reduction in travel time, vehicle operating costs, project duration and escalation factors which would likely vary in real world usage.

The perception analysis which consisted of results of the survey questionnaire allowed for the evaluation of external factors in which the highest ranked factors with the most relevance in regards to the perception of toll system included the abolishment & long term financing, upgrading requirements and efficient funding mechanism. Reasonings for each external factor was provided in detail before proceeding with the necessity analysis of tolled highway systems whereby a sustainability criteria of agency, social and environmental related cost was utilized. The agency related cost indicated to have the most relevance in terms of necessity as it occupied the top six ranks with the lowest ranked agency cost at the 15th rank out of the 42 necessity related indicators, while environmental and social related cost was well distributed throughout the given rankings.

The correlation and regression analysis allowed to establish a relationship between the perception and necessity of toll systems which indicated a very strong correlation between them. In fact, strong correlations were shown in all sustainability criteria with social related cost resulting in the highest correlation followed by environmental and agency related cost. Lastly, the cost optimization measures were established via tabulation covering components such as toll systems, highway alignments, pavement maintenance & rehabilitation, policy & contractual matters, infrastructure materials, plant & equipment, time-cost factor, cultural heritages & healthy landscapes, resettling people and ecology damage/habitat disruption. The method utilised to formulate the LCCA model in this study can be expanded upon or amended based on the project specifications. This study has managed to effectively achieve the relevant research objectives while providing the relevant solutions to each of the research questions established.

Although this study managed to achieve its main objective, there are still certain areas of improvement and ambiguity which require to be addressed when conducting LCCA related studies. LCCA studies although highly important and potentially useful in cost optimization has numerous caveats in terms of its estimation methods and data attainability. This would mean that numerous items and components that would need to be evaluated in order to undergo some form of cost optimization may find it difficult to do so due to the lack of data available while in some cases, the process of optimizing the conventional utilised cost may be too complicated or abstract for usage in the construction industry.

Furthermore, some costs are unable to be quantified as exemplified in this study whereby social and environmental related cost items were taken into account but not quantified in terms of cost. This is true for numerous LCCA studies that have either neglected social and environmental related cost or resorted to assumptions. Ideally, it would be best to also close the research gap between the traditional LCCA model and a suitability based LCCA model as inconsistent estimation methods and unclear boundaries tend to exist when taking into consideration sustainability related aspects. In order for LCCA to effectively be utilised and further developed, all parties inclusive of governments, authorities/agencies, contractors and consultants need to work together as to ensure progress is made in terms of cost optimization methods via the exchange and sharing of relevant information. Although LCCA is still at its infancy in Malaysia, there needs to be more emphasis on LCCA related studies as this would be advantageous for not just highway related projects but for numerous other infrastructure related projects in the near future.

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DECLARATION OF COMPETING INTEREST

None

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