Leadership in Sustainable Infrastructure

Leadership en Infrastructures Durables

Vancouver, Canada

May 31 – June 3, 2017/ *Mai 31 – Juin 3, 2017*

EVALUATING STAGE CONSTRUCTION APPROACH AS AN EFFICIENT TOOL FOR REDUCING ENVIRONMENTAL IMPACTS OF HIGHWAY PROJECTS

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ABSTRACT

Roadway construction has an important role in development of each country. Paying attention to “sustainable development”, highway management organizations should consider long-term environmental effects on the in their design strategies and apply the procedures with lowest possible destructive effects on the environment. Stage construction is a reasoning approach can be utilized in highway construction. Economic advantages of this approach is well clarified. Among them are: deferral in investing a portion of initial construction costs results in decreased life cycle rehabilitation costs; and reaching more suitable surface and thereupon lower vehicle operating costs. In addition to such benefits, stage construction is environmentally feasible. In this paper, a quantitative life-cycle assessment method is used to evaluate the environmental effects of stage construction. As a case study, stage construction approach and traditional construction approach are compared in a highway project in Iran. It is expected that, life-cycle environmental effects of pavement construction are considerably decreased due to probable future technology improvements during the pavement life-cycle. Also the excess fuel consumption of vehicles due to surface quality decline is lowered since having a better surface in stage construction.

Keywords: Stage Construction, Life-Cycle Assessment, Pavement, Environmental Impacts, Highway Construction

1. INTRODUCTION

Dynamic investments in infrastructure development can be best described in developing countries as an essence for prevention from financial crises in projects and obtaining to a consistent and sustainable development. Developing countries often suffer from poor infrastructures especially in transportation sector in which substandard road networks provides interrelationships between areas and highways can accelerate the procedure of development with transportation expanding and access easing.

Since the transportation growth rate is related to countries’ development, providing of high capacity facilities and infrastructures is not rational at the first stages of development; in addition, budget scarcity always suffers developing countries and infrastructure development projects. Because of these facts multiple stage development policies have long been advocated for underdeveloped countries (Fernandez and Friesz 1981). Developed countries also use stage construction due to economical and financial benefits of this method.

Optimal allocation of limited resources is another motive for using stage construction, in which capacity and characteristics of pavement is modified with traffic demand and a trade-off between costs and values and pavement performance should be considered for providing minimum performance with optimization of financial resources allocation. Pavement stage construction can be defined as construction activities planning based on traffic demands pavement performance and economical benefits for satisfying relative criteria.

As soon as sustainable development phenomena raised, environmental impact evaluation was used for investigating one aspect of sustainability. Life-cycle assessment (LCA) is a method of quantifying environmental impacts by assessing the whole life cycle stages and finding areas of improvement (Kofoworola and Gheewala 2008; Wu et al. 2011). In infrastructures with long life span, environmental impacts of other phases than initial construction should be considered beside the evaluation of initial phases like initial construction and material extraction.

In pavements with having long life spans, activities are planned for different times and an activity profile is defined. In life-cycle cost analysis (LCCA) for evaluating financial and economical costs and benefits, discount rate is used for considering the time value of money in which a same amount of money loses its value by time pass and different payments in different times, should be discounted to a same time by a specified rate for being comparable. However, in financial analysis, selection of appropriate discount rate is always a conflict between researchers and decision makers since the large effect of discount rate in analysis results.

In LCA, different problems are related to activities timing which can be categorized to industrial and technological improvements and discounting the effects of future emissions (Reap et al. 2008). Different physical models based on life-cycle inventories and impact assessment methods can be used to solve the problem of future emission discount (Hellweg et al. 2003; Hellweg et al. 2004).

In this study in addition to a brief LCCA, LCA of stage construction is performed considering the activities profile and time of occurrence with an adequate discount rate for later activities environmental effects. As a result, stage construction with its financial and environmental benefits can be considered among pavement strategy alternatives and performed especially in developing and not developed countries in the way of sustainable infrastructure development.

2. LITERATURE REVIEW

Life cycle should be defined in the first step of every life-cycle assessment or analysis and pavement life-cycle can be divided to several categories which cover the whole life cycle like construction, operation and maintenance, final disposal and removal of reuse of materials or manufacturing of construction materials, construction, maintenance and repair and demolition and recycling or raw material extraction and initial transformation, manufacturing, placement, use and maintenance and removal, recycling and disposal (Stripple and Hakan 2001, Zapata and Gambatese 2005, Park et al. 2003).

Publication of AASHTO red book can be mentioned as the start point of long term analysis in highway and pavement projects. Later researches also have been done for analysing the life cycle cost of pavements and optimization of resource allocation in pavement projects, considering maintenance and rehabilitation costs and presented benefits as decrease in vehicle operating cost, crash cost and travel time. Some other researches, provided vehicle operating costs and entered them into cost analysis. Costs were separated in two groups first, construction, investment depreciation, maintenance and land ownership and second, costs related to road use which should be considered in economical analysis. During 1960 decade, Flexible Pavement System (FPS) and Rigid Pavement System (RPS) projects in the US conducted to collaborate the concept of life cycle cost analysis. It can be proposed that the object of highway and transportation infrastructures should be minimizing the total transportation costs (Curry and Haney 1966, Winfrey 1969, Hindley 1971, Robinson 1986).

Stage construction phenomena is aroused from old efforts for optimization of resource allocation in construction projects especially pavement and roads with long life spans. From early efforts for solving dynamic investment problems, and later works on using dynamic programming and working with uncertainty till later works using different heuristic and non-heuristic methods, the researchers were trying to optimize resource allocation. Since the time value of money and resource scarcity in developing countries, stage construction is recommended by researchers. This approach is beneficial when funds are insufficient for constructing a pavement with a long design life. Stage construction is also desirable when there is a great amount of uncertainty in estimating traffic (Marglin 1963, De and Mori 1970, Venezia 1977, Sathaye and Madanat 2011, Chu and Chen 2012, Lee and Madanat 2015, Huang 2004).

The LCA is trace and determination of environmental impacts in life-cycle stages of a product for monitoring and control of adverse effects, however resource limitations, obstructs the procedure and due to research constraints, previous investigations in pavement LCA can mainly be evaluated as partial life cycle assessments since not including the whole life cycle. Like other research fields, similarities and differences are determined between previous research like comparison between concrete and asphalt pavements for optimizing the pavement selection under different circumstances as a similarity and concentrating on special kinds of pavements or special geographical regions leading to different results as a difference (Santero 2010, Santero et al. 2011).

The LCA is described with three main characteristics, functional unit, system boundaries and environmental criteria like determined length or special properties of a pavement as a functional unit, content of details and procedures as system boundaries and carbon dioxide (CO_2) for evaluating global warming effects, energy consumption, water pollution, air pollutions or any other environmental criteria. Different functional unit selection in previous research is another difference which impedes the comparison of investigation results. Hence, making functional unites more similar with use of prevalent technical specifications in definitions will improve the comparability of results. In pavement LCA, system boundary is mainly concerned with consideration of life cycle stages. Although some life cycle stages like material extraction and production have been considered in previous investigations, but not considering same stages in literature is another obstacle in the way of results comparison. Use phase with large environmental effects, is an important life cycle stage and not considering it has large effects on results, also a subtle change in the large amount of use phase environmental impacts can make vast benefits or damages for society. In case of selecting between different alternatives differential effects should be assessed since large amount of environmental effects due to vehicle operation in life span impresses the final results and neglecting of other life-cycle stages is probable. Accurate prediction of pavement performance resulting in vehicle fuel consumption changes can be used as a right method for evaluating different alternatives. (Matthews and Allouche 2010, Santero 2010, Chan 2007, Egbu et al. 2009, White et al. 2010, Häkkinen and Mäkelä 1996, Treloar et al. 2004).
In long life span projects, activity timing plays a vital role in evaluations and analysis. Since the time value of money revealed the reason of inclination to delay activities, previous research proofed the importance of timing in emission and environmental effect evaluation. The concept of dynamic LCA can solve the problem of emission timing in LCA in which technology improvement and the global warming effect of emissions in a defined time horizon can be considered which results in decrease of future emission in comparison with present emission (Kendall and Price 2012, Schwietzke et al. 2011, Levasseur et al. 2010)

3. METHODOLOGY

Methodology used in this research can be divided in two main groups. First life cycle cost analysis which is based on net present value method (NPV) with selecting appropriate discount rate. Second life cycle assessment which is based on selecting a determined length or area of road as functional unit, defined life cycle stages as system boundaries and equivalent CO_2 and energy consumption as criteria.

4. PAVEMENT LIFE-CYCLE

As stated in Figure 1, five main categories are considered including raw material extraction and production, pavement construction, maintenance and rehabilitation, use and end of life. Raw material extraction and production category includes extraction and production of materials needed for pavement construction and the transportation of materials. In construction category all construction activities and procedures like equipment needed for pavement construction is and the transportation of materials is included. In maintenance and rehabilitation stage, activities like crack sealing as a preventive maintenance and mill and overlay as a rehabilitation, are considered. In the use stage, the interaction of vehicles and pavement is investigated and the pavement performance as a serviceability or roughness index (PSI or IRI) can be predicted. End of life includes the demolition and disposal of old pavement and procedures related to recycling.

Figure 1- Pavement Life-Cycle Stages

5. LIFE CYCLE COST ANALYSIS

FHWA defines LCCA as "a process for evaluating the total economic worth of a usable project segment by analyzing initial costs and discounted future cost, such as maintenance, user, reconstruction, rehabilitation, restoring, and resurfacing costs, over the life of the project segment" (Walls and Smith 1998). FHWA also recommends to evaluate costs and benefits of governmental projects without considering inflation in projects life span. But negative effects of inflation on projects funding and government abilities for developing infrastructure is more tangible in developing countries with high inflation rates and will impede programming and scheduling projects. In addition, even with low inflation rates the time value of monetary resources should be considered since accurate investment of resources will have revenues during the time. As a result, discount rate is defined and used in economic analysis presenting the time value of monetary resources. A proper discount rate can be calculated by subtracting inflation rate from governmental loan rate.

In life-cycle analysis, evaluation horizon should be defined and be same in different alternatives evaluation. FHWA proposed 35 years as the least analysis period for all kind of pavement projects. Among different analyze methods, some research proposed that net present value (NPV) method and equivalent uniform annual cost/benefit (EUAC/EUAB) are the more useful (Zimmerman et al. 2000). Since the cost nature of pavement projects, NPV method can perform better in LCCA and comparison between alternatives.

Pavement life cycle costs can be categorized in two main groups, like illustrated in Figure 2, agency cost and user cost. Agency costs are investments in construction and utilization of pavements for providing desired serviceability including, construction, maintenance and rehabilitation, residual value which can be estimated from previous projects data, current contracts or expert judgment (FHWA 2002). Initial construction cost is often calculated by multiplying the amount of materials and works in their unit rate cost. Maintenance and rehabilitation cost can be calculated same as construction cost but should be discounted to the first year. The residual value can be omitted since the long life span of roads and pavements; In addition, since the income nature of residual value in comparison to cost nature of other parameters it would be more conservative.

User costs include three categories, vehicle operating cost, travel time cost and crash cost. Travel time cost and crash cost is almost same among alternatives but vehicle operating cost differs since different pavement serviceability levels in alternatives along analysis horizon. User costs can be derived by multiplying the amount of each cost category in relevant unit rate cost. In this study, life-cycle cost analysis is based on different cost stated in Figure 2, and NPV is the economical criterion for evaluating alternatives.

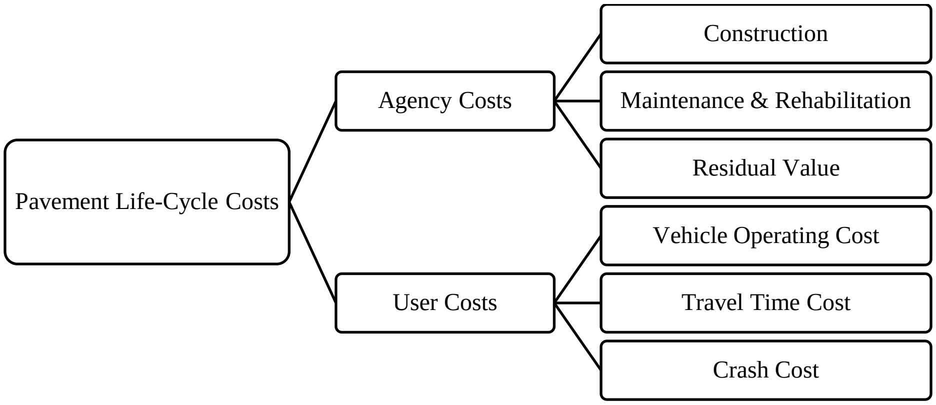

Figure 2- Pavement life-cycle costs

6. STAGE CONSTRUCTION

As can be derived from literature review, with satisfying minimum pavement serviceability and performance, stage construction can optimize resource allocation. Considering different life cycle-costs, the net present value of stage construction with appropriate discount rate will be less than other alternatives specially the ones with massive initial construction. Moreover, construction stages successive to the first stage can perform as a rehabilitation activity which enhances pavement performance and leads to a higher life-cycle performance for the project. In previous researches, less efforts are concentrated in evaluation of environmental effects in stage construction. Hence, evaluation of environmental effects in stage construction with using LCA is investigated showing that with consuming activity's time of occurrence in environmental effects, in addition to economic and financial benefits of stage construction, the environmental performance will be improved.

7. PAVEMENT LIFE-CYCLE ASSESSMENT

Restrictions of information access and evaluation of results from different aspects, lead to use of different environmental criteria in prior research. Nevertheless, equivalent carbon dioxide (CO_2e) is a common criterion in environmental evaluations, showing the global warming effects with a widespread threat for society, and has higher priority than other criteria.

By using life-cycle inventories concluded from previous research, a comprehensive LCA is available with considering adequate stages of life cycle in environmental assessment and utilizing information databases or appropriate software will lead to proper life cycle assessment.

As stated in Figure 2, five main stages are considered for evaluation of environmental impacts including manufacturing, construction, maintenance, use and end of life. In manufacturing stage, the environmental effects of extraction and production of materials needed for pavement construction, is reported as material subdivision and the transportation of materials is also reported in transportation subdivision. In construction stage, the emissions and impacts of equipment needed for pavement construction are included in the equipment subgroup and the transportation of materials is separated as transportation subgroup. In maintenance stage, the impacts of material extraction and production, and equipment needed for maintenance and rehabilitation of pavement like crack sealing as a preventive maintenance and mill and overlay as a rehabilitation, are considered as material and equipment subgroup and transportation is reported in another subgroup. In use stage, the excess fuel consumption of vehicles using the road due to pavement performance and surface quality is considered and assessed. In this stage, based on Pavement-Vehicle Interaction (PVI) Mechanistic model GenII, developed at MIT University, the excess fuel consumption is calculated and reported in two categories as deflection and IRI. Demolition and disposal are considered in this model as end of life group in which environmental impacts of recycled material as a positive effect and emissions from equipment needed for recycling is considered in a subgroup and the transportation of materials is evaluated separately. Also some stages are excluded because of being similar in different pavement alternatives like site preparation, water management utility and infrastructures.

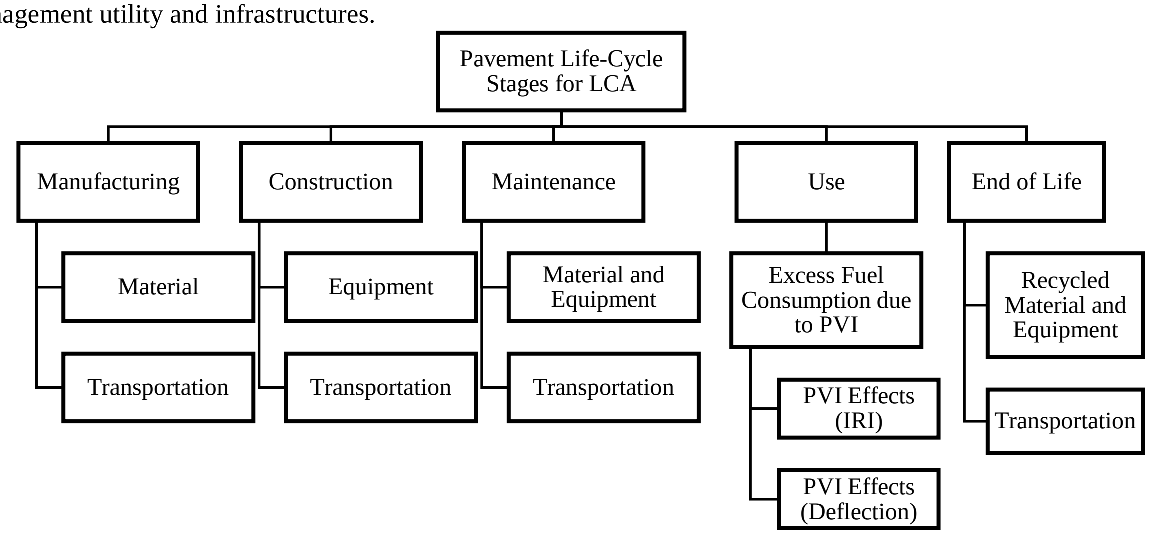

Figure 3- Pavement Life-Cycle Stages for LCA

Two criteria are used in this study: (1) global warming potential (GWP) stated as equivalent carbon dioxide (CO_2e) with GWP factors are 1 for CO_2, 25 for CH4 and 298 for N_2O (Pachauri and Reisinger 2007) and (2) energy consumption reported as mega joule (MJ).

8. EMISSION TIMING IN LCA

Proposed methods for considering emissions timing are based on the IPCC's indicator of global warming, cumulative radiative forcing (CRF), which is the basis for GWP calculations. GWPs are calculated as the ratio between the CRF of a non-CO2 greenhouse gas (GHG) over a defined analytical time horizon and the CRF of CO2 over that same time horizon. Summation of GHGs over a life span and using GWPs will consume that all emissions are occurred at the same time. This action results in over estimation of effects in case of damaging effects and underestimation in case of positive impacts.

In addition to global warming effect and difference of activity timing on it, the technology improvement and governmental legislations will also force industries through the way of environmental damage decrease. In a proper dynamic LCA, the effects of technology improvement should be considered for more accurate estimation of impacts. In some areas like California in the US, department of transportation considers the effects of technology improvement in their assessment and reduction factors are used to estimate future emissions.

In this study, the method proposed by Kendall (2012) is used for calculation of decreasing factor due to later occurrence in a defined horizon. In this method the radiative force of a particular gas during the time it is produced till the end of analysis horizon, is calculated and compared with radiative force of CO_2 during the time horizon; the decreasing factor for time of occurrence is then calculated. In addition, the effect of technology improvement on global warming effect of vehicles reported in equivalent CO_2 is also considered based on the method proposed by California department of transportation and a decreasing factor is used for the improvement of emission control based on years.

9. CASE STUDY

The presented method for LCCA and LCA is used to evaluate stage construction in a case study with following specifications:

- AADT [base (design) year]: 50,000 vehicle/day, (90% light duty traffic, 10% heavy and middle duty traffic)
- Average speed: 110 km/h
- Analysis period: 35 years.
- Traffic Growth Rate: 2 percent
- Discount Rate: 4 percent

Two flexible pavements have been designed, first a base case which has been designed based on Iran Highway Asphalt Paving Code (MPORG 2011) for a 25-year design period and second a stage construction alternative which has been constructed in to stages, a 10-year design period for the first stage and a second stage with 15 years. Both alternatives include preventive maintenance and a rehabilitation activity which are listed in Table 1 presenting activity profile of each strategy.

Life-cycle cost analysis is based on NPV method without considering the effects of inflation with a 4 percent discount rate. The material or work item unit cost is listed in Table 2.

For calculating global warming effect of construction activities and pavement vehicle interaction for 15 kilometers of the road, Athena Pavement LCA software version 2.2.0101 (Public Release) was used and the properties like construction equipment data, material transportation data, pavement design, rehabilitation schedule and pavement vehicle interaction have been adjusted to be consistent with project circumstances.

Table 1- Pavement Strategy Alternatives

Alternative	Service Life (year)	Activity Type	Activity Name	Timing
No. 1	40	IC	Asphalt concrete (5.98)[a]	Base year
		RH	Thick HMA overlay (5.46)[a]	25th year
		PM	HMA crack sealing	4th, 7th, 10th, 13th, 16th, 19th, 22th, 28th, 31th, 34th, 37th year
No. 2	40	IC	Asphalt concrete (4.97)[a]	Base year
		RH	Thick HMA overlay (5.56)[a]	10th year
		RH	Thick HMA overlay (5.46)[a]	25th year
		PM	HMA crack sealing	4th, 7th, 10th, 13th, 16th, 19th, 22th, 28th, 31th, 34th, 37th year

Note: IC = initial construction; RH = rehabilitation; PM = preventive maintenance.
[a] Structural number in flexible pavement design.

Table 2- Material/Work Item Unit Cost

Material/Work Item	Unit	Cost
HMA Wearing 19MM	IRR/m³	1,171,100

HMA Binder 25MM	IRR/m³	1,069,400
Granular Base	IRR/m³	214,700
Granular Subbase	IRR/m³	100,075
Tack Coat	IRR/m²	5,500
Prime Coat	IRR/m²	11,100
Crack Sealing	IRR/m	81,000
Mill Asphalt Surface	IRR/m²-cm	15,800

10. RESULTS AND DISSCUSION

After performing LCCA and LCA in the case study the results shown in Table 3 and Figure 4 and Figure 5 support the idea that stage construction has environmental effects superiority in addition to economic and financial benefits for the society and agencies.

Table 3- Life-Cycle Costs, Global Warming Potential and Energy Consumption of Alternatives

	Life-Cycle Costs (billion IRR)	Global Warming Potential (1000 tons of CO_2e)	Energy Consumption (100 million MJ)
Alt. No. 1	304.64	419.20	150.44
Alt. No. 2	299.28	418.96	147.72

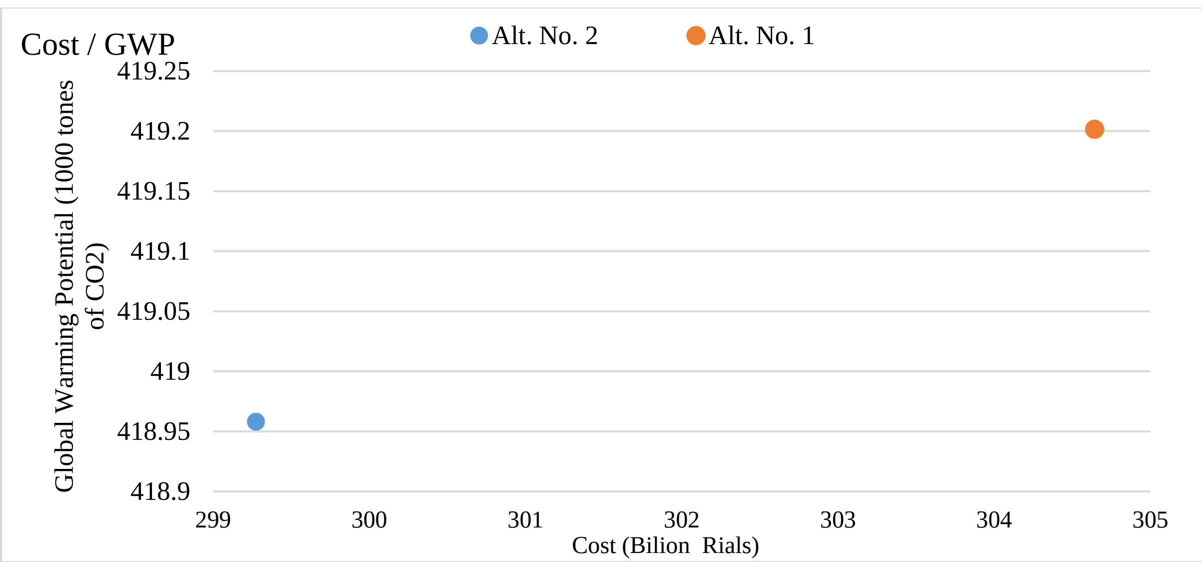

Figure 4- Life-Cycle Costs and Global Warming Potential of the Two Alternatives

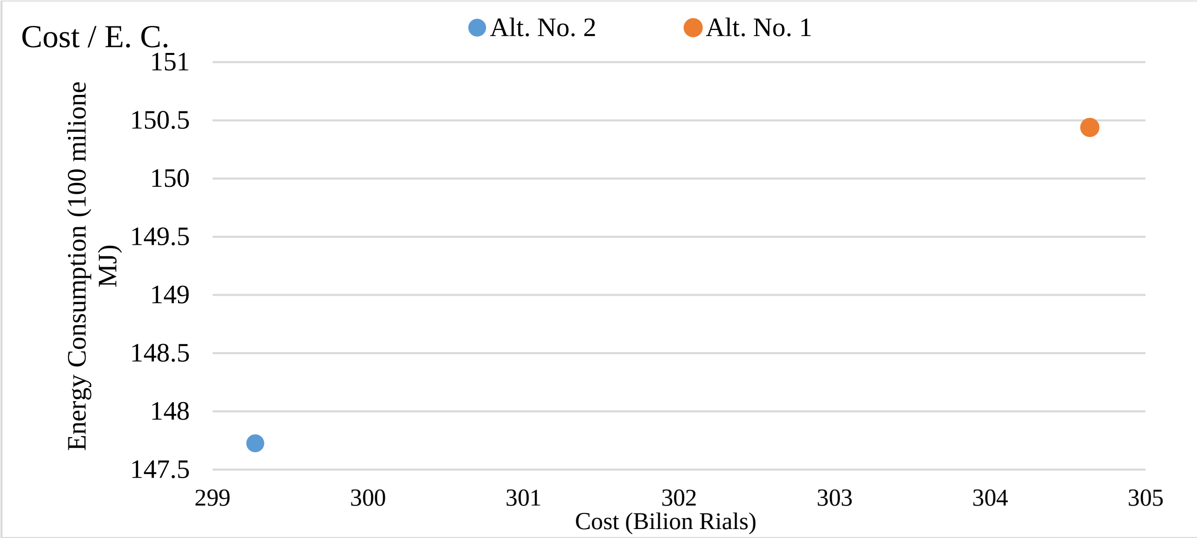

Figure 5- Life-Cycle Costs and Energy Consumption of the Two Alternatives

The thickness of the first stage of alternative 2 (first 10 years) is 14 cm asphalt concrete and the overlay for the second stage (next 15 years) is 8 cm, whereas in the common design procedure (alternative 1) is 20 cm. By applying stage construction, the thickness of the first stage is decreased by 6 cm, but the overall thickness is increased by 2 cm. Although the work zone costs imposed to user costs are higher in the alternative 2 (stage construction), the whole costs of the project life-cycle would be lower for this alternative. Two reasons justify this case: (1) discounted agency costs is lower in stage construction, (2) normal condition user costs are lower in stage construction because of more desirable life-cycle pavement performance and thereupon lower vehicle operating costs and travel time costs.

On the other hand, the delay in constructing a part of initial construction decreased environmental impacts of project implementation. First, technology improvement leads to a lower environmental impact for future works. Second, activity occurring at a future time has minor environmental impacts in the analysis period. Better pavement conditions associated with stage construction prevents the added environmental impacts pavement-vehicle interaction (PVI) effects.

11. CONCLUSION

Lack of resources and budget in construction projects and the tendency for resource allocation optimization especially in long life span projects, leads to stage construction concept arise. Stage construction can be defined as a flexible method of construction in which the capacity and quality of the pavement is adjusted with the demand in a way that minimum serviceability and performance is always satisfied.

The monetary and financial origin of stage construction leads to adequate efforts in the way of proving the financial benefits of this method and also the definition of cost and benefit and the methods of analysis had changed during the time, but the superiority of this method was constant. In addition, methods like life cycle cost analysis (LCCA) shed more light on the benefits of stage construction. But with the extension of sustainable development to all majors related to society, financial and economic superiorities will not ensure the excellence of an alternative. So evaluation of alternative’s performance in sustainability is also needed and environmental assessment as a major criterion in sustainability should be investigated about different alternatives. Life cycle assessment (LCA) as a reliable method of evaluating environmental effects is becoming more useful in industry including construction industry.

In this study, stage construction is evaluated from both aspects of cost and environment with the use of LCCA and LCA with considering time value of time with appropriate discount rate and the decreasing factors for environmental effects with late occurrence since lower radiative force leading to global warming and lower emission due to technology improvement. With such consuming, a case study is investigated and the results proved that stage construction can be proposed as a strong method for better resource allocation and lower environmental effects.

The consideration of difference between future and present emission can be considered in every environmental assessment which will lead to not polluting environment more than our present need. As well as the preference of later expenditure in long life span projects, later pollution and emission is also preferable since the technology improvement and lowering the radiative effects on environment. In addition, much effort is needed in the way of optimizing emissions in industries and minimizing them as much as possible since the cost of excess environmental burden is paid by the global society.

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