LCCA of Rigid Pavement over Bituminous Pavements

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***Abstract*—** Road building needs huge investments not only for construction of new infrastructure but also for the repair and maintenance of the old ones. In case of developing countries, like India, there is a shortage of funds required for new infrastructure projects both for construction and more significantly for their maintenance and repairs. Today's focus is on the construction of long-term performing pavement. Most of our roads are bituminous pavements which are showing early sign of distresses like rutting, cracking, ageing, etc due to increasing loads, intensity of traffic, high tyre pressure, etc. Concrete pavements can be adopted as an alternative to traditional bituminous pavements. One of the possible alternative rehabilitation solutions to bituminous overlays is the use of whitetopping overlay on an existing bituminous pavement. In this study an attempt is made to evaluate life cycle cost analysis of concrete and bituminous pavements and suggest a beneficial alternative amongst them

Keywords *– LCCA, Whitetopping, Pavement rehabilitation, VOC, Fuel Saving*

1 INTRODUCTION

1.1INTRODUCTION

This chapter gives information about LCCA Rigid pavement and LCCA is an economic method to compare alternatives that satisfy a need in order to determine the lowest cost alternative. In this study an attempt is made to evaluate life cycle cost analysis of concrete and bituminous pavements and suggest a beneficial alternative amongst them.

1.2 CONTEXT

In many countries with developed road networks, new road construction typically accounts of more or less 50% of the road budget. While the remaining of national road budgets is spent on maintenance and rehabilitation of existing roads. Long-life Pavements (LLP) project is approved if the costs of future maintenance, rehabilitation and the resulting road user delay costs are economically justified. There has been historically difference of opinion as to whether Hot Mix Asphalt (flexible) pavements are more economical or less economical over time than Portland Cement Concrete (rigid) pavements. Even experienced state highway agencies and highway engineers disagree on the subject. Ethiopian has been undertaking massive development programs to eradicate the country's poverty problems and to bring up the country to the level of middle income countries in 2025. Aware of the road infrastructure development as the backbone and the blood artery for all economic, social progress, due emphasis has been given to the implementation of the Road Sector Development Program (RSDP) since 1997. To execute such a very crucial project, large amount of budget will be allocated for the surfacing of pavements. Hence, it is important to go for careful evaluation of the alternatives in order to make the right choice before implementation of such projects.

In Ethiopia, very few and short kilometer lengths of road projects are constructed with rigid pavement viz; in Oromia (Chancho-Derba-Bocho and Beseka road), Addis Ababa (Rehabilitation projects) and Tigray (Michew – Adigudem), of which Beseka and Addis Ababa rehabilitation projects were completed. Even though there are newly emerging cement and reinforcement production factories in Ethiopia that can avoid foreign currency to buy materials for flexible pavement, only few and small scale concrete pavement projects have been undertaken in the country. Among these projects, Beseka Road, a one kilometer long which was considered the first cement concrete pavement in the history of the Ethiopian road construction project. In the last seventeen years (1997- 2014), the total length of rigid pavement constructed was only 2.3 kilometers while about 99.9 IIJSER (International Journal of Scientific & Engineering Research), 12,640 kilometers are flexible pavement. Over the past 17 years, 41.2% of the total Ethiopian Road, Sector Development Program (RSDP) expenditures was allocated for the rehabilitation and upgrading roads, 28.8% for construction of link roads, 5.7% for maintenance of Federal roads, 8% of Regional road and 11.7% of Woreda roads, 2.8% of Institutional support projects, and other activities at the Federal level. During the last four years (2010-2014) RSDP accomplishment expenditure showed that 4.3 billion for rehabilitation, 4.8 billion for periodic and 0.7 billion for routine maintenance were utilized to Federal and Regional flexible pavement roads.

Road building needs huge investments not only for construction of new infrastructure but also for the repair and maintenance of the old ones. In case of developing countries, like India, there is a shortage of funds required for new infrastructure projects both for construction and more significantly for their maintenance and repairs .Road building needs huge investments not only for construction of new infrastructure but also for the repair and maintenance of the old ones. In case of developing countries, like India, there is a shortage of funds required for new infrastructure projects both for construction and more significantly for their maintenance and repairs.

1.3 SCOPE OF PROJECT

- Make better transportation investment decisions.
- Assist in determining the lowest cost way to meet the performance objectives of the project.
- Dwindling resources and reduced purchasing power makes the employment of LCCA even more critical.

1.4OBJECTIVES

1. To study the concept of life cycle cost benefit of rigid pavement and bituminous pavement.
2. To perform a case study.
3. To prepare comparative analysis of rigid pavement and bituminous pavement using MSP/PRIMAVERA.

4. Result analysis of comparative analysis of rigid pavement and bituminous pavement.

1.5ORGANISATION OF REPORT

- Topic selection
- Collection of literature
- Study the concept of life cycle cost benefit of rigid pavement and flexible pavement
- Perform a case study
- Site data
- Estimatimate of rigid pavement/km
- Estimatimate of flexible pavement/km
- Schedule of rigid pavement/km
- Schedule of flexible pavement/km
- Results and discussion

This chapter gives information about Mivan technology and line of balance method. Mivan is basically Aluminium formwork system. Mivan system was invention by Construction Company from Europe. In 1990, Mivancompany from Malaysia start manufacturing formwork, then after give name MIVAN. This technology is extensively used in Europe, Gulf country and Asia. Formwork is defined as the temporary structure whose purpose to support the building structure. Line of balance (LOB) is a management control process used in construction where the project contains blocks of repetitive work activities, such as roads, pipelines, tunnels, railways and high-rise buildings, precast construction, row houses etc..

1.2 MIVAN TECHNOLOGY

Mivan is basically Aluminium formwork system. Mivan system was invention by Construction Company from Europe. In 1990, Mivancompany from Malaysia start manufacturing formwork, then after give name MIVAN. This technology is extensively used in Europe, Gulf country and Asia. Formwork is defined as the temporary structure whose purpose to support the building structure. The progress of the formwork equidistant with the progress of concrete construction through the 20thcentury. Modern technology must be required in this time because of increasing the population and land available for constructing houses in limitation. For mass housing project, it is essential to know the new technology for completion of project in fast rate, stand to good quality and able to withstand wear. Mivan technology is capable to constructing a huge no. of houses within short period. Mivan formwork is easily removed. All the activity can arrange in simple manner and get result more accurate, well regulate and high quality production at economically with less period

The system of aluminium formwork (MIVAN) has been used widely in the construction of residential units and mass housing projects. It is fast, simple, adaptable and cost – effective. It produces total quality work which requires minimum maintenance and when durability is the prime consideration. This system is most suitable for Indian condition as a tailor–made aluminium formwork for cast–in–situ fully concrete structure. In this system of formwork construction, cast – in – situ concrete wall and floor slabs cast monolithic provides the structural system in one continuous pour. Large room sized forms for walls and floors slabs are erected at site. These forms are made strong and sturdy, fabricated with accuracy and easy to handle. They can be used repeatedly for approximately 250 times. The concrete is produced in RMC batching plants under strict quality control and convey it to site with transit mixers. The frames for windows and door as well as ducts for services are placed in the form before concreting. Staircase flights, elevation panels, chajjas and jails etc. and other prefabricated items are also integrated into the structure.

Construction is one of the significant sectors of Indian economy and is an integral part of the development. Today India's urban population is the second largest in the world and its future development leads to increased demand for housing to cope with this problem India should desperately need to plan for acquisition of land and rapid creation of dwelling units. Construction is a complex process involving basically the areas of Architectural planning, Engineering & Construction. There is growing realization today that speed of construction needs to be given greater importance especially for large housing projects. This is not only essential for the faster turnover of equipment and investment – leading possible to the reduction in the housing cost but also for achieving the national objective of creating a large stock to overcome shortest possible time. Fortunately, some of the advanced technologies catering to faster speed of construction are already available in the country. For e.g. Prefabrication, autoclaved blocks, tunnel formwork, aluminium formwork (MIVAN Technology) of construction etc.

1.3LINE OF BALANCE (LOB)

Line of balance (LOB) is a management control process used in construction where the project contains blocks of repetitive work activities, such as roads, pipelines, tunnels, railways and high-rise buildings, precast construction, row houses etc. It is a control process for collecting facts relating to time, cost and schedule accomplishment, all the project related task is measured against specific plan. LOB shows the process, status of project, crew size continuity, and background of work, time and phase of project activities providing management with measuring tools. LOB assists project management by comparing a formal objective against actual progress, examining only the deviations from established plans, and gauging their degree of severity with respect to the remainder of the project, dealing with problem and trouble causing areas and problem solving within specific constrains.

1. Forecasting future performance.
2. A programmed rate of completed units is met.
3. A constant rate of repetitive work is maintained.
4. Labour and plant move through the project in continuous manner such that a balanced labour force is maintained and keep fully employed.
5. The cost benefits of repetitive working are achieved.

Line-of-balance (LOB) is a variation of linear scheduling methods that allows the balancing of operations such that each activity is continuously performed. The major benefit of the LOB methodology is that it provides production rate and duration information in the form of an easily interpreted graphics format. The LOB plot can show at a glance what is wrong with the progress of an activity, and can detect potential future bottlenecks. Obviously, LOB allows a better grasp of a project composed of repetitive activities than any other scheduling technique, because it allows the possibility to adjust activities' rates of production. It allows a smooth and efficient

Flow of resources, and requires less time and effort to produce than network schedules

An early attempt to develop a computer application was made to schedule repetitive-unit construction It was limited to solving the basic LOB problem and was not designed to deal with the many implementation-related problems that were later identified. Clearly, there was a need to develop a computerized system that would make use of the principles but that would also eliminate all of the associated shortcomings. A computer program that can easily and effectively be used by contractors could improve construction productivity significantly.

The Goodyear Company founded the LOB technique in the 1940's and it was then developed by the USNavy in the 1950's. Since then LOB techniques have taken a back Seat and have never been commercialized due to the explosion of systems based on Network Analysis and Critical Path Method (CPM). It should be said that these

network and CPM systems have never actually replaced the LOB method; their popularity has simply been due to the unavailability of commercially accessible LOB software. A modified form of the LOB method has been the dominant scheduling technique in Finland since the 1980's.

1.4 SCOPE OF PROJECT

- Forecasting future performance.
- A programmed rate of completed units is met.
- A constant rate of repetitive work is maintained.
- Labour and plant move through the project in continuous manner such that a balanced labour force is maintained and keep fully employed.
- The cost benefits of repetitive working are achieved.

1.5 OBJECTIVES

1. To study the concept of LOB and MIVAN Technology.
2. To understand the relation between LOB and MIVAN Technology.
3. Evaluation of LOB in MIVAN Technology using software.
4. Give discussion and suggestion for effective utilisation of line of balance method in mivan technology for high rise building

1.6 ORGANISATION OF REPORT

- Topic selection
- Collection of literature
- Study of mivan technology
- Study of line of balance method
- Case study
- Evaluation and application of LOB in mivantechonology
- Comparative study of mivan and conventional formwork
- Discussion and suggestions for implementing LOB effective in mivan technology

2 METHODOLOGY

CONCEPT OF LIFE CYCLE COST

2.1INTRODUCTION

This chapter gives information about LCCA Rigid pavement and LCCA is an economic method to compare alternatives that satisfy a need in order to determine the lowest cost alternative. In this study an attempt is made to evaluate life cycle cost analysis of concrete and bituminous pavements and suggest a beneficial alternative amongst them.

2.2LIFE CYCLE COST ANALYSIS (LCCA)

The SHRP2 R-23 Guidelines provide a number of possible alternative designs using either rigid of flexible pavements. There is usually not a single design that meets the design criteria but a number of alternative designs that can be considered as viable solutions. The method of selecting the best possible approach may consist of an economic evaluation, a decision matrix, or a combination of those approaches. There are several types of economic or criteria based evaluations that can be carried out as part of conducting a life cycle cost analysis (LCCA): cost-benefit analysis, cost effectiveness analysis, multi-criteria analysis, risk-benefit analysis, etc. At one extreme lies the purely multi-criteria analysis, which employs weights from a variety of sources that contain a large degree of subjective assessment. At the other extreme lies the purely cost-benefit analysis that exclusively employs monetary valuation and has generally more explicitly defined criteria. Most Highway Agencies have established some form of selection process and it is expected that those Agencies will apply those to select between different options. For those Agencies who do not have a formal selection procedure in place, the following guidance for conducting life cycle cost analysis is provided and recommended to aid the selection process.

Typically, LCCA involves the following basic steps:

- Make initial strategy and analysis decisions. Certain baseline decisions, estimates and assumptions are needed in order to establish the parameters under which a LCCA can be carried out.
- Estimate costs. Costs associated with the owning agency and users are calculated for each alternative.
- Compare alternatives. Comparison usually involves expressing each alternative using a common metric such as net present value (NPV) or benefit-cost ratio (B/C).
- Analyze the results and reevaluate alternatives. Results should be scrutinized for the most influential costs, factors and assumptions. A sensitivity analysis is often used to do this. Original design strategy alternatives should be reevaluated base on these results analysis in order to improve the cost-effectiveness of each alternative

Concrete is known to be a relatively stiffer material and is relatively less sensitive to high temperature. Accordingly, concrete pavements can be adopted as anAlternative to traditional bituminous pavements. One of the possible alternative rehabilitation solutions to bituminous overlays is the use of white topping which is a Portland Cement Concrete (PCC) overlay on an existing bituminous pavement. The principal purpose of this technique is either to restore the functional capacity or to increase the load carrying capacity of the road or both, of the existing pavement. In the process of achieving this objective, white topping overlays also restore the ride-ability of the existing asphalt pavements suffering from ruts and deformations, in addition to rectifying other defects such as loss of texture. White topping being stronger than asphalt overlay is more resistant to rutting and surface initiated cracking and thus this technique consists potential, technical and economic benefits.The appropriate solution for economically beneficial pavement type, bituminous or concrete pavement, is calculated by carrying out Life Cycle Cost Analysis (LCCA) which takes into account the initial investment cost and also the maintenance or rehabilitation cost required for the design life of the pavement. Life cycle cost analysis can be defined as a procedure by which a pavement design alternative will be selected, which will give a satisfactory level of service at lowest cost over design life. The economic analysis methods used most commonly for this study are net present worth and rate of return. The analysis depends on the factors such as inflation rate, discount rate and analysis period. In the present study, an attempt is made to study the long term economic benefits of pavements using the net present value (NPV) method of analysis.

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pavements and suggest a beneficial alternative amongst them.

Road construction projects have been implemented all over Ethiopia as part of the national development plan. Roads are one of the country's basic infrastructural facilities where high amounts of budget allocated every fiscal year planning period. Since the cost comprises of a large portion of government investment, a careful evaluation of the alternatives is utmost importance to make the right choice for a particular project. In the history of Ethiopia road development program, almost all of the road pavements are flexible, and it demands high foreign currency for asphalt material importing from abroad. In addition, flexible pavement needs to be maintained and rehabilitated within a few years after its initial construction. In view of the emerging cement factories and the availability of cement in Ethiopia, it is practical to consider rigid pavement as one of the alternatives. Relative to this, the research project was conducted with the main objective of identifying the cost and benefit of rigid and flexible pavements at Chancho-Derba-Becho road project, North Showa Zone in Oromia. The research work had been focused on the specific objectives to determine and compare the life cycle costs of rigid and flexible pavements and to investigate all other qualitative merits of rigid and flexible pavement. To achieve these objectives, a review of related literatures, design and specifications, observations and investigations of the actual pavement construction projects, evaluation of life cycle costs, future value of money and present worth calculation were undertaken with an analysis period of 40 years. While the data considered was gathered through investigation at the actual rigid and flexible pavement projects, examination of specifications, drawings and pavement design, Ethiopian Road Authority manuals, rehabilitation and maintenance strategy. In this regard, the cost parameters investigated are initial construction cost, maintenance cost, rehabilitation cost, user's cost and salvage value, in addition to other qualitative and quantitative data. Based on the results of the research project, it revealed that the initial cost of rigid pavement was almost twice of the flexible pavement, but in the long run, the cost of flexible pavement per kilometer was found out to have 7.9 Million ETB more than the rigid pavement because of the incurring costs of maintenance through its design life. Therefore, it is suggested that Portland Cement Concrete Pavement (PCCP) shall be used in pavement construction to cater local material requirements

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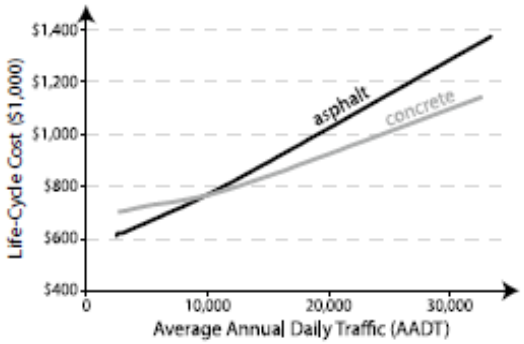

Fig2.1 LCCA Over Rigid pavement over bituminous pavement

CHAPTER 3
FUTURE WORK

3.1LIFE CYCLE COST ANALYSIS PROCEDURE

The steps involved in the LCCA methodology are as follows:

1. Estimate the initial construction cost.
2. Estimate maintenance cost.
3. Estimate road user costs
4. Determine life-cycle cost

3.2 LCCA PROCEDURE

The LCCA structured approach can be outlined in the following steps:

1) Define project's alternatives.
2) Decide on the approach: Probabilistic vs. Deterministic.
3) Choose general economic parameters: Discount Rate, Analysis Period.
4) Establish expenditure stream for each alternative:
5) Compute Net Present Value for each alternative.
6) Compare and interpret results/ Sensitivity Analysis.
7) Re-evaluate design strategies if needed.

3.3CASE STUDY

The procedures of construction and estimates were studied from case studies done on three different roads.

1) Construction of pavements UTWT and TWT, Madhuban area at old Sanghvi ward no 59, PCMC.

2) Construction of PQC pavement road from Chaphekarchowk to bridge on Pavana River towards Thergaon. PCMC

Development of 45.00W wide road from Pune Alandi road to Dabhadewasti in PCMC area

CHAPTER 4
CONCLUSION

1) LCCA concludes that concrete pavements are more beneficial than bituminous pavements and concrete overlays can be considered as beneficial option for rehabilitation of existing bituminous pavements.

2) Based on the results of the research study, it was found out that the rigid pavement has longer service life (more than twice) than the flexible pavement. For one (1km) kilometer road length, the life cycle cost of the rigid pavement is lower by a value of 7.9 Million ETB than the flexible pavement in forty (40) year analysis period. Routine and periodic maintenance costs for the period of 40 years are 1.1 times greater than the initial construction cost of the same one kilometer stretch for flexible pavement and requires 7.3 million Birr higher for maintenance and rehabilitation as compared to rigid pavement.

3) the rigid pavement has lower maintenance and rehabilitation cost when compared with the flexible pavement. On the other hand, the rigid pavement which is wholly constructed with local materials, such as cement and aggregates without the requirements of importing construction materials from abroad. A total of $105,526.13 USD will be saved per kilometer if the road will be utilized rigid pavement as an alternative.

4) The total Net Present value for the Concrete road project is GH¢5.689 million whilst that for the asphalt road project is GH₵16.581 million. Using the average rate of return, the average rate of return for the Concrete road project is 33.123% whilst that for the asphalt road project is 41.502%. The Present Worth (PW) for the Concrete road project is GH¢58.7675 million whilst that for the asphalt road project is GH₵66.3348 million. Hence Concrete pavement is cheaper than asphalt pavement in terms of present worth.

5) Flexible pavements can be constructed and maintained quickly and hence reduces congestion. These pavements are generally black in colour which offer significant reduction in road surface glare and assist in making line markings stand out in contrast to the road. These pavements are durable, safe and long lasting compared to rigid pavement.These pavements are fully recyclable.These pavements provide smooth, safe surfaces and minimize fuel consumption. These can be easily opened and patched.

6) Bituminous pavements are commonly adopted as wearing course.The excessive binder content over an optimum value for a given mix is detrimental to the good performance of the black top pavements.A problem associated with the construction of bituminous pavements is control of viscosity of the bituminous-aggregate mixtures during mixing and compaction. These pavements are also adopted for base and binder courses, when there is a heavy traffic Different from concrete road which would require a very high cost of construction and a substantial curing period before opening to traffic, this bituminous pavement has a distinct in this respect

CHAPTER 5
REFERENCES

1. S.S.Jain, M.parida, SanjivAgarwal ‘Development of pavement management system for Indian national highway network’(2004).

2. "Co-residence, Life-Cycle Savings and Inter-generational Support in Urban China," HumanDevelopment Research Papers (2009 to present) HDRP-2009-27

3. Leanne Whiteley-Lagace, M.A.Sc., P.Eng. Andy Dalziel University of Texas at Austin that using only three strategic highway research program, TRB, 2011

4. Homer H. Johnson. Loyola University, Chicago. Search for more papers by this First published: 10 March 2008.

5. Ali and Tayabji, Zhang., “development of structural capacity indices for the network-level evaluation has generally been limited to flexiblepavements”,2003

6. PradhanMantri Gram SadakYojana under PMGSY in India (2006-2007 to 2018-2019-upto June 2018)

7. 1997Omkar et al. , 1999Omkar and Bind 1998; Omkar and Pervez 2001) and “recorded their effect on development and reproduction”

8. Virginia's Commonwealth Transportation Commissioner tasked his Chief of Technology, Research & Innovation Virginia Transportation Research Council Publication, May 2002

9. Fen Yeb, Jingfen Yuan, Dejia Zhang, ‘’ Life-cycle Cost Analysis (LCCA) on Steel Bridge Pavement Structural Composition’’2013

10. PeymanBabashamsi, NurIzziMdYusoff, HalilCeylan, NorGhaniMd Nor, HashemSalarzadehJenatabadi, ‘’Evaluation of pavement life cycle cost analysis: Review and analysis’’

11. Joao Santosa, Sara Bressib, VéroniqueCerezo, Davide Lo Presti, Michel Dauvergne, ‘’ Life cycle assessment of low temperature asphalt mixtures for road pavement surfaces: A comparative analysis’’

12. Hao Wang, ChinmayThakkar, Xiaodan Chen, ‘’Life-Cycle Assessment of Airport Pavement Design Alternatives for Energy and Environmental Impacts’’ 15 May 2016