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Application of Artificial Neural Network (ANN) Methodology in Conducting Life Cycle Cost Analysis (LCCA) For Roads

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ABSTRACT: This research explores the application of Life Cycle Cost Analysis (LCCA) in road infrastructure planning, specifically focusing on the comparison between concrete and bituminous pavements. The study employs MATLAB software to predict maintenance costs and assess economic viability over a 40-year period. Results indicate that concrete pavements, particularly rigid options, offer significant economic advantages over flexible bituminous surfaces. Despite an initial higher construction cost, rigid pavements demonstrate lower life cycle costs due to reduced maintenance expenses. The flexibility values derived from the analysis, such as 0.993 for flexible and nearly 1 for rigid pavements, highlight the economic benefits of long-term investment in concrete infrastructure. Moreover, the study emphasizes the role of LCCA in optimizing investment decisions by considering factors beyond construction costs. It underscores the importance of incorporating geological, environmental, and technological considerations into road material selection. The findings suggest that informed decision-making, facilitated by artificial neural network methodologies like MATLAB, can lead to sustainable infrastructure development and efficient resource allocation. This research contributes to enhancing the longevity and performance of road networks through evidence-based planning and cost-effective material choices.

KEYWORDS: Life cycle cost analysis (LCCA), Life cycle cost (LCC) Road engineering, Life cycle thinking; Net present value; Equivalent uniform annual cost

I. INTRODUCTION

The study presents the use of Life Cycle Cost Analysis (LCCA) for rigid pavement, which is an economical technique for comparing options to find the most cost-effective solution. This research evaluates the life cycle costs of masonry and bitumen pavements, offering an advantageous option. With a growing emphasis on sustainability, the road industry faces the challenge of integrating sustainable practices. However, achieving sustainability while ensuring durability requires significant investments. Due to limited funding, agencies are increasingly interested in assessing future costs over extended periods. To address budget constraints, agencies need rigorous decision-making methodologies that provide insights into the long-term economic viability of investments. LCCA is one such methodology, which evaluates the economic impact of an asset's life cycle while considering its durability. LCCA requires a comprehensive identification of all materials and processes used at each phase. However, its practical application depends on various factors, such as the availability of credible data, understanding of structural characteristics and material properties, modeling deterioration to predict pavement condition, and guidelines for estimating user costs. There is a lack of consistency in system boundaries and input parameters among different LCCA models, making them difficult to link. Some suggest a hybridized eco-efficiency analysis that combines LCA and LCCA, while others propose an LCCA based on optimizing performance and available funds. A new probabilistic simulation optimization LCCA has also been proposed, which considers the uncertainty of input parameters.

1.1 Life Cycle Cost Analysis of Road

Roads are among the most important public assets in all countries. Road improvements bring immediate and sometimes dramatic benefits to road users through improved access to hospitals, schools, and markets; improved comfort, speed, and safety; and lower vehicle operating costs for these benefits to be sustained, road improvements must be followed by a well-planned program of maintenance. LCCA is a process of evaluating the economic performance of a structure over its entire life. LCCA is especially useful when project alternatives that fulfil the same performance requirements, but differ with respect to initial costs and operating costs, have to be compared in order to select the one that maximizes net savings. LCCA for road is required because roads, and means of transport, make a crucial contribution to economic development. Poorly maintained roads constrain mobility, significantly raise vehicle operating costs, increase accident rates and their associated human and property costs, and are needed to be deal.

To reduce the overall cost of the road right from construction cost to its repair cost the high quality material constructions with regular preventive maintenance is required Preventive Maintenance: Work undertaken that preserves the existing pavement, retards future deterioration, and improves the functional life without substantially increasing the structural capacity. Neglected roads steadily become more difficult to use, resulting in increased vehicle operating costs (more frequent repairs, more fuel use) and a reluctance by transport operators to use the roads. This imposes a heavy burden on the economy: as passenger and freight services are curtailed, there is a consequent loss of economic and social development opportunities.

1. The Life Cycle of a Road

The general life cycle of a road is presented in Fig. This diagram differentiates two approaches for material flows. The first approach is linear, represented by phase 1 raw materials extraction until phase 5B landfill or 5C energy recovery after incineration, which considers material flows where new virgin materials are required after the end of life (EOL) of the previous system. The second approach is circular, represented by phase 1 raw materials extraction until phase 5A recycling, which has the goal to utilize products at the highest value of all time and takes into account material flows where primary materials are saved due to recycling and reuse of waste products after the EOL of the previous system.

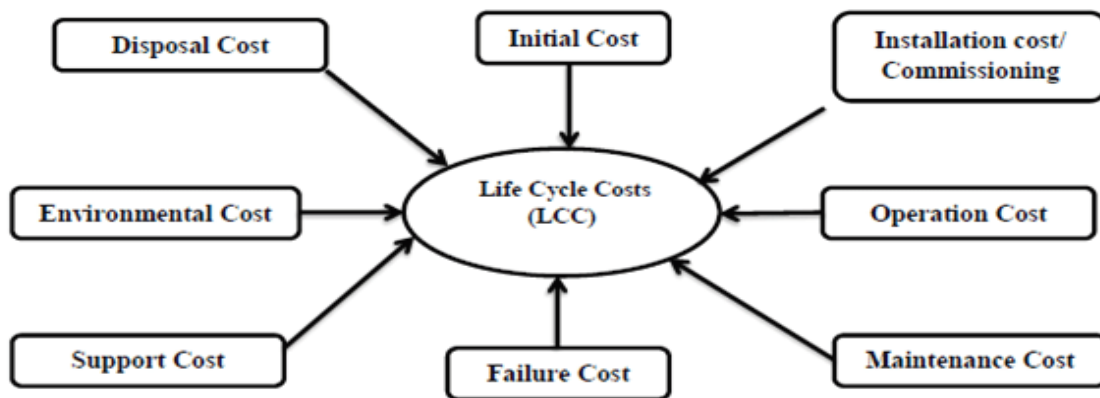


Figure No.1 Life cycle of a road

Whether recycling or reuse is preferred over the use of new materials depends on the impact of multiple factors. For example, the difference in transportation distances, the impact of the recycled or reused materials on the durability of the new product and the impact of the recycling or disposal processes. Hence, including all the different life cycle phases is important for the sustainability assessment of alternatives. Therefore, the following part of the paper will describe all the different life cycle phases of a road and important cost components which should be considered.

2. Raw materials extraction

A holistic consideration of the LCCA of a road's life cycle commences with the cost of raw materials extraction, acquisition and/or production of primary materials such as aggregates, fillers, sand, bitumen, cement, water and additives. This should include all the processes involved in acquiring (e.g. extracting and mining), processing (e.g. refining and crushing) and transporting road materials. The costs associated with this phase arise from the use of equipment, materials, energy, labor, and transportation of materials to the production plant. In most cases, all the cost components are grouped into a material unit price. However, distances between materials sources and production plants

can significantly affect the cost of materials, especially when secondary waste materials are being recycled and compared with primary materials. In addition, the transportation type can also have a substantial effect on the cost of the materials. This makes it difficult to differentiate costs if a unit price is used when other transport distances or types are considered for other alternatives. Therefore, for a detailed LCCA, the cost of transportation should be settled separately from the material cost.

3. Mixture production

The production of bitumen or cement-bound mixtures is according to several authors one of the main contributors to the total LCC due to the high amount of energy that is needed for drying, heating and mixing the different materials. The energy consumption during production also has a strong link with the impact of the material extraction phase. For example, when primary aggregates for asphalt production are being saved due to the use of reclaimed asphalt pavement (RAP), a second burner often needs to be installed for drying RAP. Consequently, the energy cost during the production will increase, while the material cost decreases. Vice versa, when the energy consumption is lowered, for example, when the temperature is decreased to produce warm mix asphalt instead of hot mix asphalt, an additive is used. This additive is an extra material which increases the material cost but decreases the energy cost during production. Other cost components that are associated with this phase are the costs for handling the materials at the production plant, equipment, emission permits, labor, taxes, licensing and operation permits.

4. Road construction

Road construction comprises diverse processes and associated equipment requirements for initial construction works. First, the unbound materials, bitumen or cement-bound mixtures and equipment must be transported to the construction site. Afterwards, construction can begin, which can include (but is not limited to) the following aspects: clearing of the site, excavating, treating the base or foundation with cement or lime and compacting it, constructing and compacting the different road layers, and integrating the different ancillary road facilities (e.g. lighting and signs). The associated costs include transportation, safety measurements, construction machinery or equipment (i.e. fuel consumption, mobilization, demobilization, insurance, taxes, interest depreciation and licenses), storage on site and labor (i.e. wages, contractual benefits). Additionally, road users incur extra costs due to construction. These costs can be significant and should be included in the analysis. They include VOC, a higher possibility for AC due to more narrow lanes and work zone delay costs (WZDC) due to time loss.

5. Use phase and maintenance

The use phase accounts for the interactions between vehicles, the pavement surface condition and the pavement performance over its service life. The road user costs associated with this stage consist of fuel consumption, tire wear, vehicle maintenance and vehicle depreciation due to mileage. Road durability and performance is affected by climatic factors (e.g. temperature) and human induced activities (e.g. traffic load and initial design), consequently causing deterioration. Therefore, maintenance is needed to lower the road's deterioration speed. Maintenance and rehabilitation (M&R) are a set of preventive and reactive works that are performed at different periods throughout the service life of the road to enhance the overall performance and maintain its serviceability. If there is excessive deterioration, rehabilitation is required to restore the pavement to its former condition.

In general, three types of M&R can be identified. Preservation is applied when the road is still in good condition. This treatment extends the road's service life without increasing its structural capacity, which makes this treatment relatively simple and inexpensive. However, preservation treatments must be applied before deterioration starts which results in a more frequent application. Examples of preservation treatments are crack filling, patching, slurry seals, chip seals, micro-surfacing and diamond grinding. Maintenance delays future deterioration and improves the road's condition without substantially increasing its structural capacity. Examples of maintenance treatments are ultrathin and thin asphalt overlays, stress absorbing membrane interlayers for concrete pavements, hot in place recycling and cold in-place recycling. Finally, when the pavement condition and structural capacity is too poor, with a high risk of structural failure, service life must be extended by applying rehabilitation treatments. Rehabilitation has the highest cost because it involves the milling or demolishing of the existent road and the reconstruction of a new one. Similar to the construction phase, the associated cost components for M&R activities may include materials, construction machinery or equipment, labor and transportation.



II. LITERATURE REVIEW

Its primary goal is to assess the overall costs of tar and concrete pavement using a technique for Life Cycle Loss Analysis (LCCA) which may help to choose pavement and enhance the pavement system. Compare the total cost for flexible and rigid pavement for 1 kilometer. Propose a better option to maintenance and repair of bituminous pavement. In order to investigate the idea of life cycle, rigid pavement and tar pavement are beneficial.

2.1 Literature Pertaining to Topic

Table No. Study of literature review

Sr. No.	Author/s	Title of Paper	Published Year	Findings
1	Hany El-Sawah	Comparative Study In The Use Of Neural Networks For Order Of Magnitude Cost Estimating In Construction	2014	This article provides a research on the early cost estimation of the usage of neural networks (ANNs). The choice and architecture of the Neural network have a major influence on the outcomes achieved by the model and therefore its accuracy. The investigation examined both the Kernel Density Estimation (BPNN), the Stochastic Linear Regression and the GRNN as well as the regression analysis.
2	H. A. P. Audu	Sensitivity Analysis On Flexible Road Pavement Life Cycle Cost Model	2016	The examination of sensitivity is a technique used in evaluating the performance of a model. This research investigated the use of a sensitivity analysis utilising different discount rates to a created flexible life cycle cost model. The graphs generated from both the estimation method show a reduction in the life cycle cost and an increase in the alternative interest rate. These findings are essential for the economic assessment of flexible pavement and transit systems.
3	Mr. AkhaiMudassar Mohammed Shafi	Life Cycle Cost Analysis Of Road Pavements In Rural Areas	2016	This study analyses the cost of the concrete and bituminous highway in Cement. Basically, the rigid sidewalk and also the flexibility pavement are differentiated and the pavement is economically and cost-effectively identified. This is done using the life cycle costing NPV technique. This approach takes into account original investment costs and upkeep costs. Alternative pavement design may be chosen with the assistance of LCC. This reduces costs and provides extensive servicing across the roadways' design.
4	Yonas Ketema	Cost and Benefit Analysis of Rigid and Flexible Pavement: A Case Study at Chancho-Derba-Becho Road Project	2016	Due to the study findings, the overall investment of the rigid pavement was nearly twice as high, but in the long term it was discovered that the expense of elastic pavement per kilometre is 64 million ETB as much as the rigid one as a consequence of the accruing maintenance expenses during its design life. It is thus recommended that in pavement construction, Conventional Concrete Plank (PCCP) should be utilised to meet local material requirements.

III. METHODOLOGY

3.1 Life Cycle Cost Analysis Procedure

The following stages are included in the LCCA methodology:

- Initial building cost estimate.
- Maintenance estimates.
- Estimate user costs of road transport Cost of life cycle determination

In this research the costs for the building and maintenance of the pavement are estimated using the net actual life-cycle cost analysis approach. The results are computed. The calculation for cost of capital is provided by IRC SP- 30 (2009).

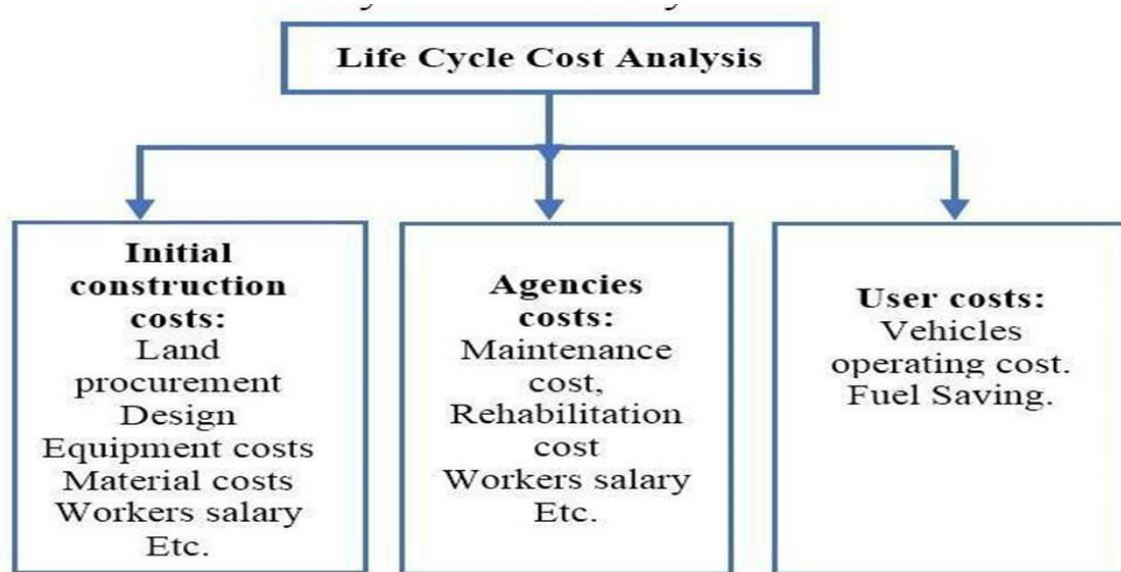


Figure No.2 LCCA

3.2 CASE STUDY DETAILS

3.2.1 TENDER PAPERS

NAME OF WORK: -

Construction of Road from Aurangabad Highway to Kolwadi Road Chari No. 14, ce Shantinagar, Holkar Nagar, S.No. 374 Gat No. 1729 to 1732 (Pai), Gat No. 387 to 367 (Pai) Runwal Nagar in Niphad Nagarpanchayat, Tal. Niphad, Dist. Nashik .Total length of project considered 47.8km



Figure No.3 Bitumen spray



Figure No.4 Road compaction with the help of road roller



Figure No.5 Road Site



Figure No.6 Detailed Estimate



IV. ANALYTICAL STUDY

4.1 Study Aurangabad Highway to Kolwadi Road

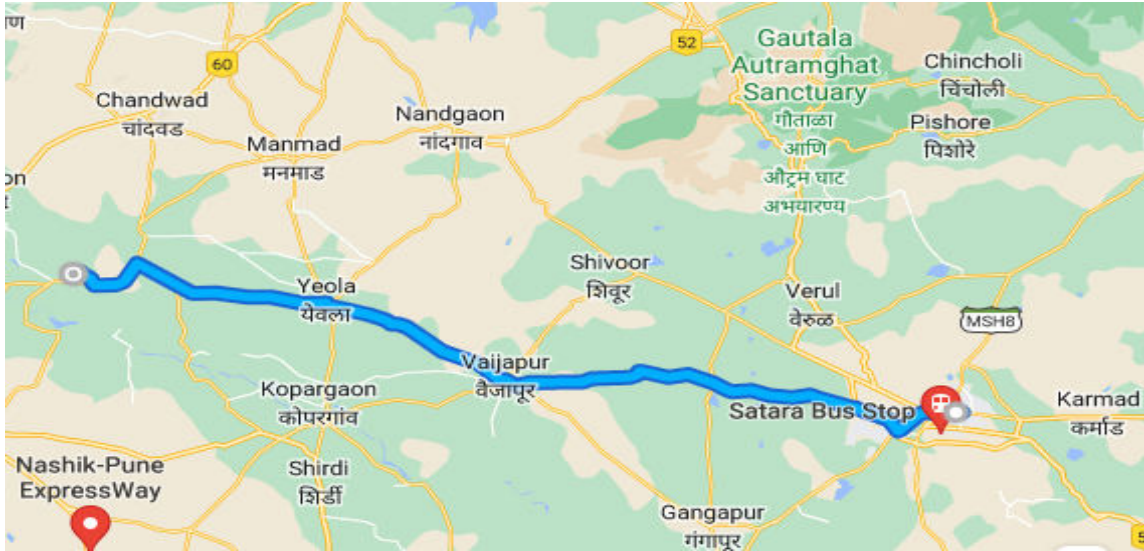


Figure No.7 Study Aurangabad Highway to Kolwadi Road

For the present case study for ANN input annual maintenance cost was required to predict future maintenance cost. Total 20 years’ data is gathered from billing engineer Mr. Amol Garole from Stup Consultant.

4.2 For Rigid Pavement

Up gradation of Package-I from Km. 0+000 to Km. 47+800 to 2 lane with paved shoulder configuration in the state of Maharashtra.

Table.2 General Abstract of Cost for Rigid Pavement

GENERAL ABSTRACT OF COST			
Length of Project -(47.80 Km)			
Bill No	Item of works	Amount (Rs. Crs.)	% of Total Cost
1	SITE CLEARANCE AND DISMANTLING	2.13	0.95%
2	EARTH WORK	41.80	18.70%
3	GRANULAR SUB-BASE	24.51	10.96%
5	CONCRETE PAVEMENT	87.47	39.13%
6	SLAB, BOX AND PIPE CULVERTS AND UNDERPASS	18.10	8.10%
7	MAJOR AND MINOR BRIDGES	8.03	3.59%
8	DRAINAGE AND PROTECTION WORKS	15.85	7.09%
9	TRAFFIC SIGNS, MARKING AND OTHER APPURTENANCES	1.81	0.81%
10	BUS BAY and TRUCK LAY BAY	1.88	0.84%



11	MISCELLANEOUS (Median work and Utilities across the highway)	5.58	2.50%
12	TOLL PLAZA	3.98	1.78%
13	MAJOR AND MINOR JUNCTIONS	8.17	3.65%
	TOTAL	223.54	
	Total project Cost Per Km (Rs. Crs.)	5.67	

4.3 For Flexible Pavement

Up gradation of, Package-I from Km. 0+000 to Km. 47+800 to 2 lane with paved shoulder configuration in the state of Maharashtra

Table.3 General Abstract of Cost for Flexible Pavement

GENERAL ABSTRACT OF COST			
Length of Project -(47.80 Km)			
Bill No	Item of works	Amount (Rs. Crs.)	% of Total Cost
1	SITE CLEARANCE AND DISMANTLING	2.13	1.05%
2	EARTH WORK	41.80	20.59%
3	GRANULAR SUB-BASE	24.51	12.07%
5	PAVEMENT	98.00	48.26%
6	SLAB, BOX AND PIPE CULVERTS AND UNDERPASS	18.10	8.91%
7	MAJOR AND MINOR BRIDGES	8.03	3.96%
8	DRAINAGE AND PROTECTION WORKS	15.85	7.80%
9	TRAFFIC SIGNS, MARKING AND OTHER APPURTENANCES	1.81	0.89%
10	BUS BAY and TRUCK LAY BAY	1.88	0.92%
11	MISCELLANEOUS (Median work and Utilities across the highway)	5.58	2.75%
12	TOLL PLAZA	3.98	1.96%
13	MAJOR AND MINOR JUNCTIONS	8.17	4.02%
	TOTAL	203.06	
K	Total project Cost Per Km (Rs. Crs.)	5.19	

4.4 Periodic Maintenance

Table.4 Periodic Maintenance (During)

Periodic Maintenance (During O&M Period)		
Appointed date as :	1-Jan-2017	
COD: (commercial operation date)	24-Jun-2018	(Construction period = 1 year and 6 months=18months = 540 days)
End of Concession:	23-Jun-2048	(Operation period 30 years)



Frequency for Periodical Renewal:		
5Years (1 st Periodical Renewal) :	24-Jun-2022	(Periodical Renewal assumed in the present analysis)
10Years(2 nd Periodical Renewal) :	24-Jun-2027	(Periodical Renewal assumed in the present analysis)
15Years(3 rd Periodical Renewal) :	24-Jun-2032	(Periodical Renewal assumed in the present analysis)
20Years(4 th Periodical Renewal) :	24-Jun-2037	(Periodical Renewal assumed in the present analysis)
25 Years (5 th Periodical Renewal):	24-Jun-2042	(Periodical Renewal assumed in the present analysis)

4.5 Schedule of Periodic Maintenance

Table.5 Table Schedule of Periodic Maintenance

Description	2022	2027	2032	2037	2042	2048
	(5 Years)	(10 Years)	(15 Years)	(20 Years)	(25 Years)	(30 Years)
Cost of Periodical Renewal with BC	151,563,741	151,563,741	0	181,442,898	181,442,898	181,442,898
Cost of Strengthening with BC and DBM		0	486,556,091	0		
Total Cost (at present rate)	151,563,741	151,563,741	486,556,091	181,442,898	181,442,898	181,442,898
	15.16	15.16	48.66	18.14	18.14	18.14

4.6 Cost for Periodical Renewal (at Present Rates for 1st, 2nd periodical slab)

Table.6 Cost for Periodical Renewal (at Present Rates for 1st, 2nd periodical slab)

Description	Unit	Qty	Rate	Amount (Rs.)
Tack Coat 2 on bituminous surface- 2.0 kg /10sqm	M ²	567,241	9.75	5,530,604
Tack Coat 1 over primed base - 2.5 kg /10sqm below DBM	M ²	567,241	9.75	5,530,604
Quantity of BC (Main carriageway 2L+PS and 4L+PS)	M ³	22,690	5267.45	119,516,628
Quantity of BC (Service Roads)	M ³	-	5267.45	-
Quantity of DBM (Main Carriageway for 2nd Periodic renewal)	M ³	-	5029.90	-
Earthwork in Shoulders	M ³	49,205	302.15	14,867,254
Thermoplastic Paint (Lane/edge marking & Arrow painting)	M ²	17,727	657.15	11,649,254
Total Cost for 1 and 2 periodic renewal with BC:				151,563,741



4.7 Cost for Periodical Renewal (at Present Rates for 1st, 2nd periodical slab)

Table.7 Cost for Periodical Renewal (at Present Rates for 1st, 2nd periodical slab)

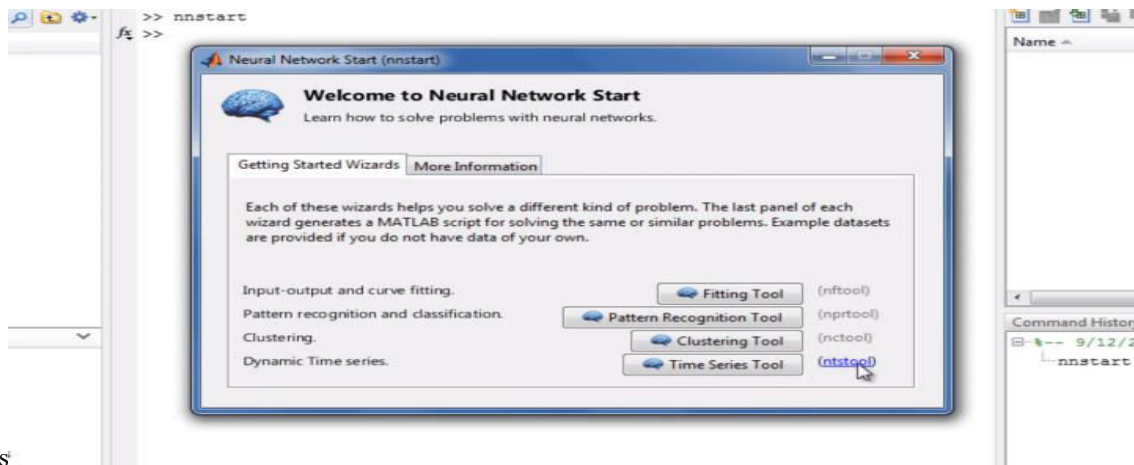
Description	Unit	Qty	Rate	Amount (Rs.)
Tack Coat 2 on bituminous surface- 2.0 kg /10sqm	M ²	567,241	9.75	5,530,604
Tack Coat 1 over primed base - 2.5 kg /10sqm below DBM	M ²	567,241	9.75	5,530,604
Quantity of BC (Main carriageway 2L+PS and 4L+PS)	M ³	28,362	5267.45	149,395,786
Quantity of BC (Service Roads)	M ³	-	5267.45	-
Quantity of DBM (Main Carriageway for 2nd Periodic renewal)	M ³	59,560	5029.90	299,582,589
Earthwork in Shoulders	M ³	49,205	302.15	14,867,254
Thermoplastic Paint (Lane/edge marking & Arrow painting)	M ²	17,727	657.15	11,649,254
Total Cost for 4,5 and 6 periodic renewal with BC:				181,442,898
Total Cost for 3rd periodic renewal with BC and DBM :				486,556,091

4.8 LCCA Using ANN

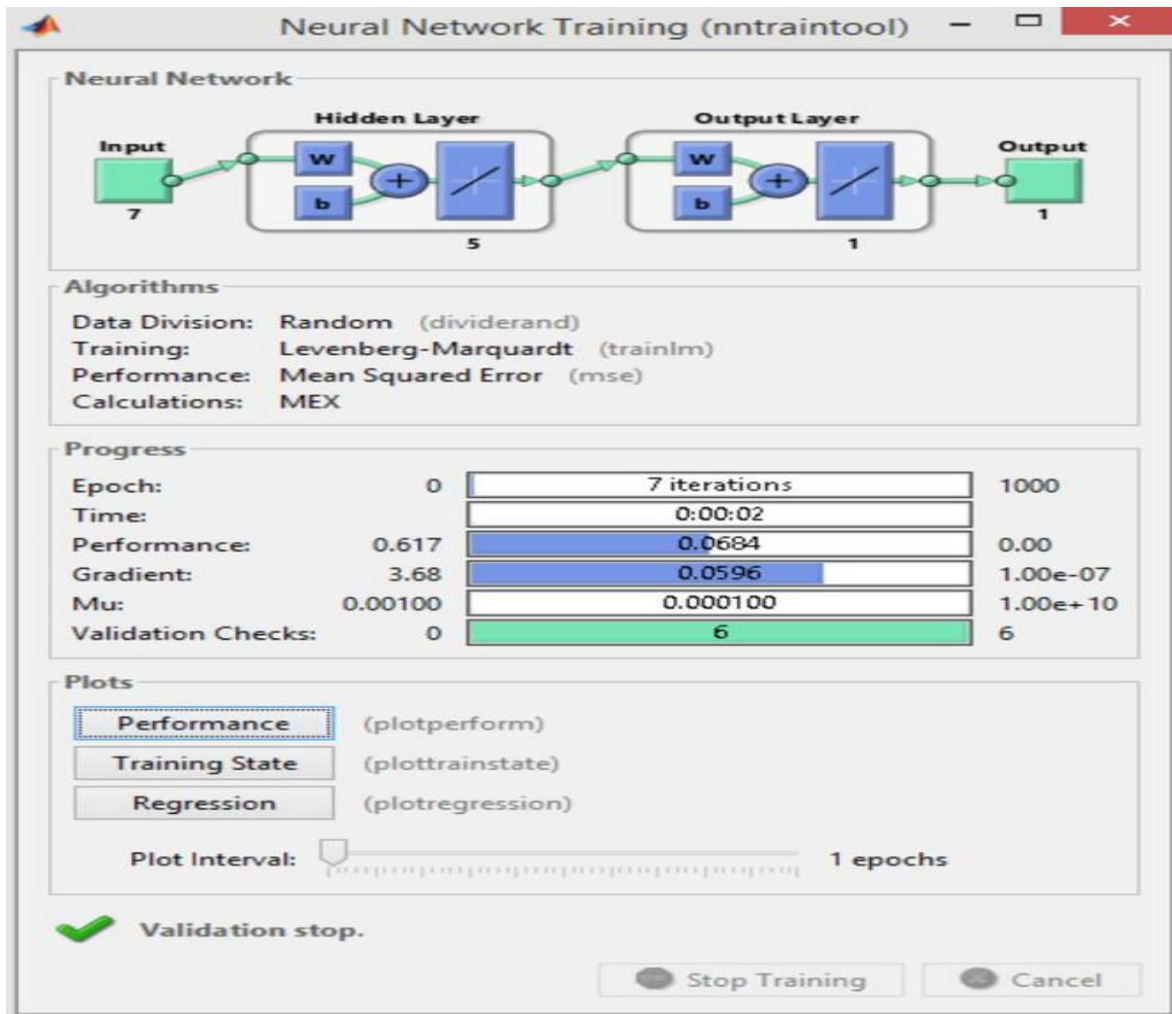
The project specifics are presented in the chapter step by step. This chapter covers the technique used in developing the MATLAB software modelling of an artificial neural network (ANN). The chapter comprises of findings and reports from different tools, i.e. the confusion and graphical presentation features of the receiver, for creation of a mathematical pattern.

4.9 Experimental Results and Discussion for Study area 1

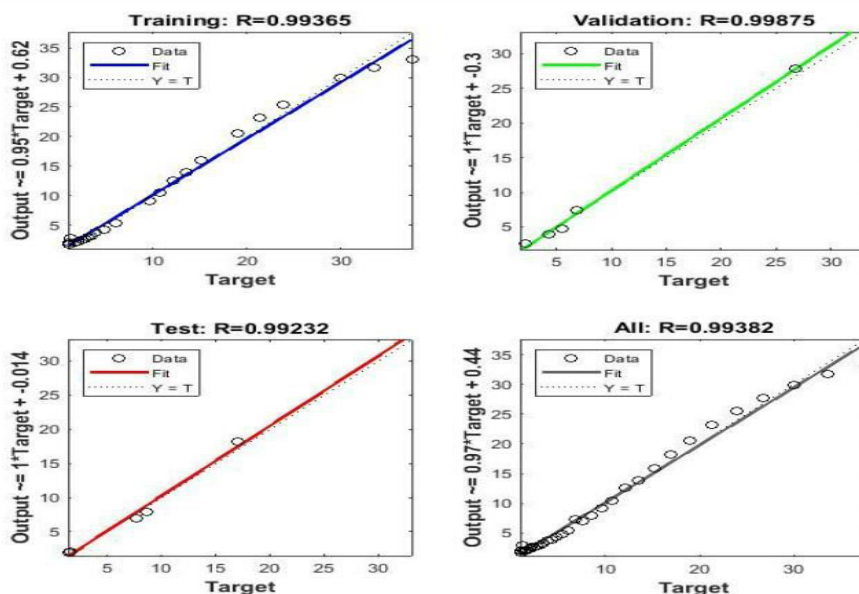
- ANN toolbox consists of several implemented NN algorithm
-



Gives time (in terms of days)

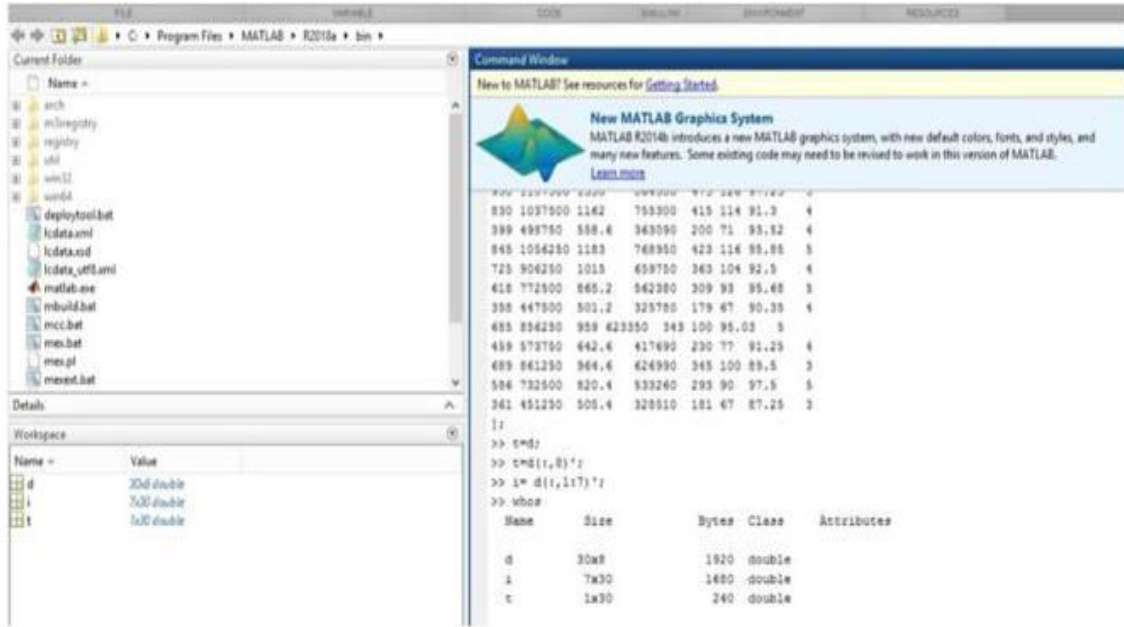


• LCCA Results in MATLAB for Flexible pavement



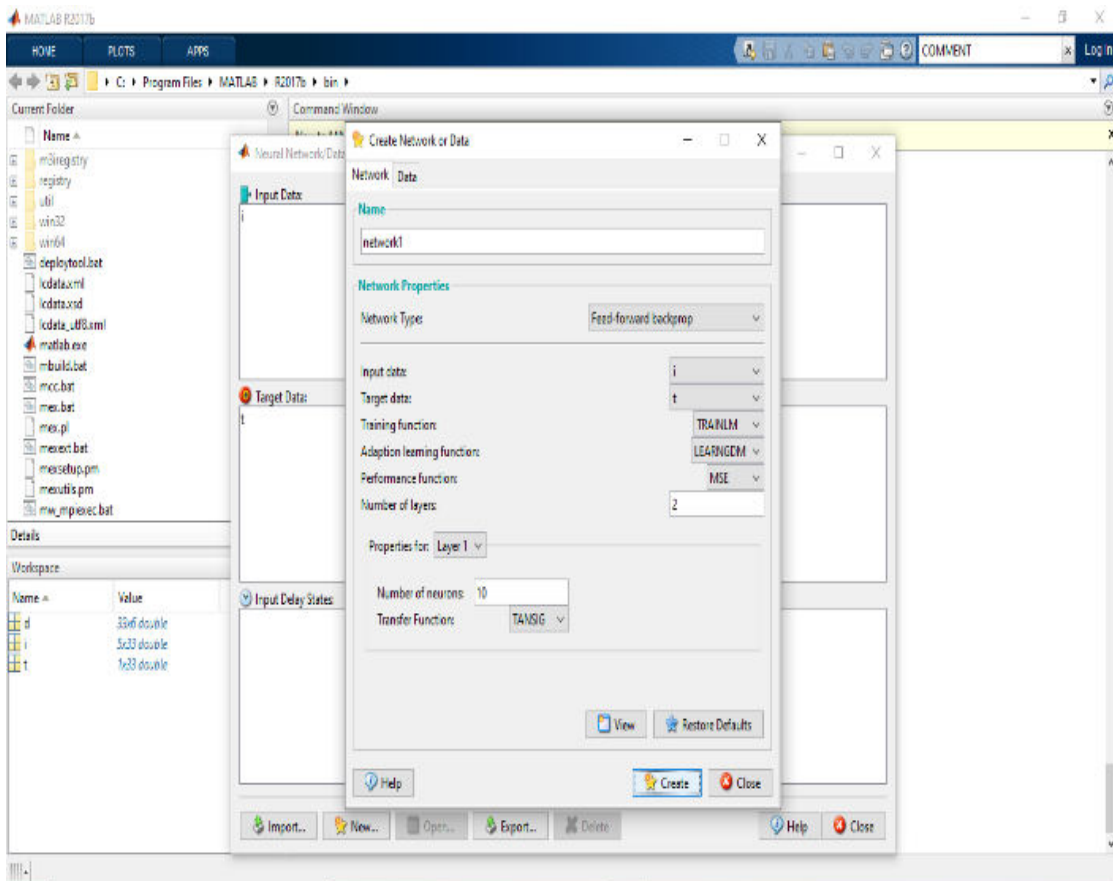


- MATLAB Graphically results for LCCA

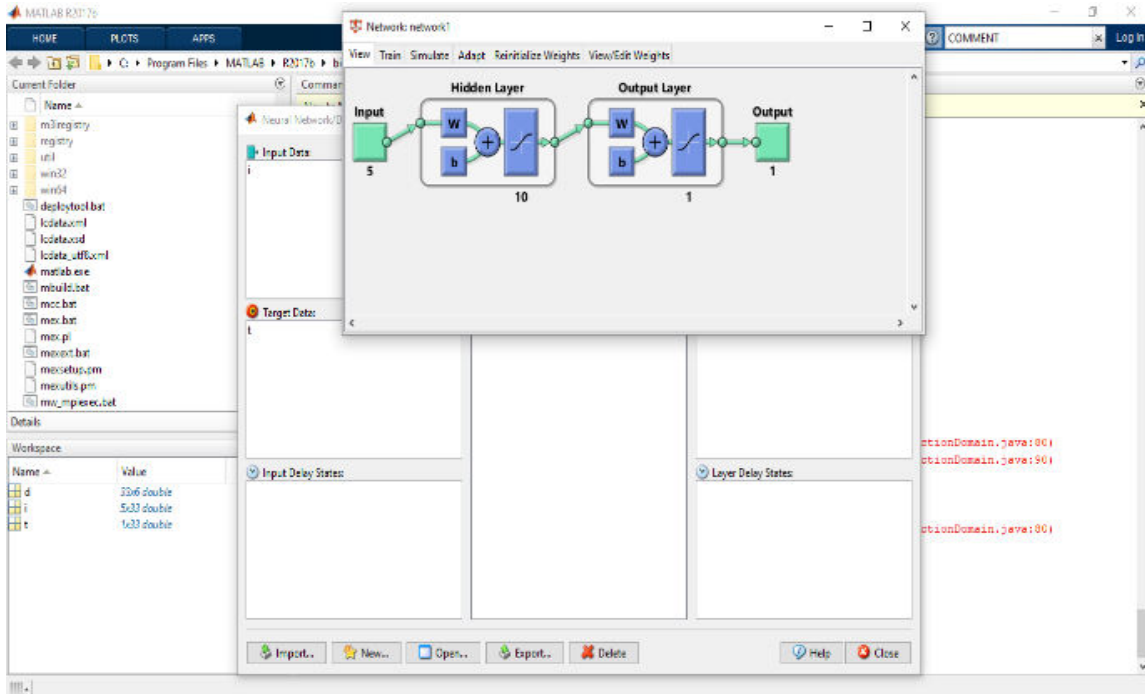


4.10 Experimental Results and Discussion for Rigid Pavement

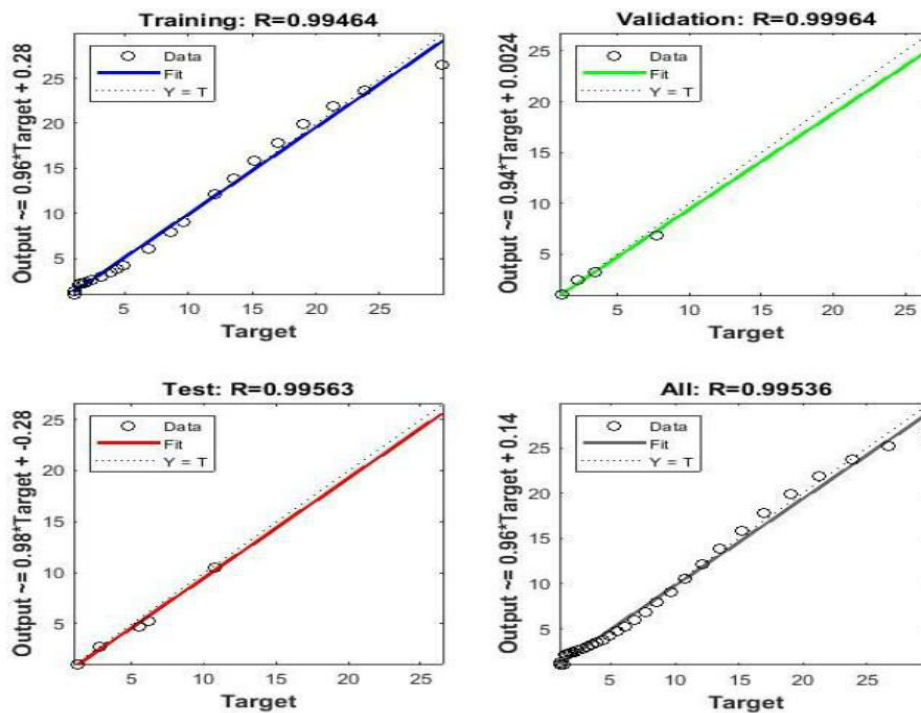
- Create network Data



- Gives time (in terms of days) as input.



- LCCA Results in MATLAB for rigid pavement



V. CONCLUSION

The research findings suggest that concrete pavement emerges as a favourable option over bituminous pavement, with concrete overlays presenting a viable alternative for rehabilitating existing bituminous surfaces. Utilizing MATLAB

software, the study predicts a flexibility value of 0.993 for flexible pavements and nearly 1 for rigid pavements, indicating a narrower range for periodic maintenance costs (R). Moreover, the research reveals that rigid pavements exhibit longer operational lifespans compared to their flexible counterparts. Over a 40-year analytical period, the life cycle cost for a kilometers of rigid pavement is notably lower than that of flexible pavement, amounting to 64 million ETB. Despite an initial construction cost premium of 10.08%, rigid pavements prove economically advantageous due to reduced routine maintenance expenses. Flexible pavements, however, offer benefits in terms of rapid construction and maintenance, congestion reduction, and aesthetic considerations. Life cycle cost analysis (LCCA) performed using MATLAB software further confirms the economic superiority of rigid pavements, with cost differentials favouring rigid options by 6.83%. These findings underscore the importance of employing LCCA in road project planning to optimize the balance between investment and maintenance costs, ensuring long-term cost efficiency and sustainable infrastructure development. Additionally, the decision-making process for selecting road materials extends beyond costs to encompass geological factors, construction duration, environmental impacts, technological considerations, and political aspects, highlighting the multifaceted nature of infrastructure planning. Ultimately, conducting LCCA for various repair options enables informed decision-making, facilitating efficient allocation of resources and enhancing the longevity and performance of road networks.

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