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Performance comparison of waste plastic modified versus conventional bituminous roads in Pune city: A case study

Arjita Biswas[a,*], Amit Goel[a], Sandeep Potnis[b]

[a] National Institute of Construction Management & Research (NICMAR), Pune, India
[b] MIT World Peace University, Pune, India

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ABSTRACT

Scarce resources in a developing country like India calls for the optimal use of the road infrastructure using scientific pavement management tools. In the process of finding ways for modifying the traditional methods of making bituminous roads, the use of waste plastic as a substitute to a certain percentage of bitumen is a promising alternative. Gradual deterioration of road infrastructure is a major concern. A vast amount of condition assessment data must be collected to identify the major defects and their causes, to plan for an optimum maintenance alternative. This study evaluates the deterioration rates of waste plastic modified bituminous roads (also called plastic roads) as compared to normal bituminous roads in the metro city of Pune, India. Measurement of deterioration is done with field tests and distress surveys. Ranking of distress parameters was done using Analytic Hierarchy Process (AHP) where the relative importance (on Saaty's scale) assigned to each parameter in the hierarchy was given by the experts (transportation professionals). AHP was implemented using the MATLAB package. The study reveals that the deterioration rate for plastic roads is slower as compared to conventional bituminous roads.

1. Introduction

The environmental issues with waste plastic are known to all of us. To cater to these issues many researchers from different fields are continuously working on different options of efficient re-use of different forms of plastic. Plastic roads are bituminous roads using waste plastic in the wearing course and are now widely used in India. With the Indian Road Congress (IRC) bringing out a code of specifications on plastic roads (IRC SP: 98 -2013) [21], many agencies are coming forward to implement plastic roads in India as it is a sustainable method and also the need of the hour. The Ministry of Road Transport & highways, India has embarked upon a mission for utilizing waste plastic in a big way. India already has over 100,000 km of roads made of waste plastic, with more regions getting engulfed in this with time.

1.1. Use of waste plastic in road construction

The use of shredded waste plastic bags in the bituminous flexible roads has been gaining popularity over the years throughout the globe. Indian scientist and Professor, R. Vasudevan reported the technology in 2004 [2], to reuse the waste

* Corresponding author.
E-mail addresses: abiswas@nicmar.ac.in (A. Biswas), amitgoel@nicmar.ac.in (A. Goel), Sandeep.potnis@mitwpu.edu.in (S. Potnis).

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plastic bags in the construction of bituminous roads which not only solves the problem of dumping or incinerating them but also provide a better-quality pavement. R Vasudevan's technology is being applied by various countries across the globe.

Various reported works [3,5–7,13,17] proposed that plastic roads can be better as compared to normal bituminous roads in terms of their deterioration rate. However, field tests reported are very few. The study carried out by [6] postulated that an addition of 8.0 % by weight of processed plastic for the preparation of modified bitumen, results in a saving of 0.4 % bitumen by weight of the mix or about 9.6 % bitumen per cubic meter of BC mix.

A recent 2014 study [1] reported the use of the most environmentally hazardous form of plastic polyvinyl chloride (PVC) as a modifier up to a level of 3% and 5% of bitumen in making a bituminous product for paving application. Through various trials, the author proved that PVC waste can be used safely only when it makes a homogenous blend with bitumen at a temp of 160 °C. The strength and stability of the bituminous mix increased after the incorporation of PVC pipe waste, increased resistance to permanent deformation of the pavement was also observed. A 2016 study [3] demonstrated the probable use of High-density polyethylene (HDPE) for road construction in Ghana. Experiments resulted in an increased softening point, decreased penetration value whilst enhancing the overall dynamic and absolute viscosities of the binder. The study has also revealed that waste plastic modified bitumen conveys great potential as an alternative recycling method for plastic waste management in Ghana, as well as a non-traditional, modified binder for road construction. Plastic roads with similar techniques are being built in Indonesia using a plastic-asphalt mix in many areas including Bali, Surabaya, Bekasi, Makassar, Solo, and others [22]. Plastic roads were also constructed by Dutch company Volker Wessels for cyclists in Zwolle, in the northeast part of the Netherlands [22].

In 2019, Agyeman et al. [4] conducted a succession of laboratory tests on different waste plastic materials from various industrial sources in the probable use of road construction materials like paver blocks, etc. The results indicate that both low and high plastic specimens had better compressive strength as compared to a non-plastic specimen.

As per a recent news report [22], The United Kingdom also announced that it will invest £1.6 million for the trial of plastic road technology, in collaboration with an asphalt enhancement company, that will implement technology developed by R. Vasudevan with some of the secret compounds to make roads last longer. It is currently being implemented in cities like Gloucester, London, and Durham.

1.2. Monitoring the performance of bituminous roads

For effective maintenance planning and resource allocation, the Prediction of the pavement distress index(DI) is necessary on a network scale [16].

Sarfaraz, Ahmed [12] prioritized pavement maintenance activities, based on the Pavement Management system and these methods vary from simple ranking to complex optimization.

The authors [18] developed a model for predicting the deterioration of the Pavement Condition Index (PCI), calibrating its parameters based on the pavement structural factors such as structural number, asphalt layer thickness, subgrade strength, and environmental conditions.

2. Methods

During December 2016 and January 2017, various roads of Pune city were overlaid with a bituminous mix containing shredded waste plastic by 8% of the weight of the mix. This study compares the in-service performance of these plastic roads with similar traffic conventional bituminous roads, laid during the same period time, in terms of their deterioration rates. The study is restricted to the city of Pune, Maharashtra, India. To fulfill this objective, the following methodology is adopted (Fig. 1).

First, the national and international journals, news articles, websites were referred to understand the plastic roads, its implementation, and the pavement management system.

To carry out research work in the Pune city, the study area was selected, the criteria for which are discussed in the latter part of the paper.

Basic Inventory data was collected and the Filed test, pavement distresses and Pavement Condition Index (PCI) calculations were carried out.

The questionnaire was prepared to circulate among the Filed professionals and experts in the field to give rating for AHP Model. AHP model was analyzed through MATLAB coding and prioritization of roads was the outcome based on the distresses parameters.

2.1. Analytical hierarchy process method (AHP) in pavement management

The Analytical hierarchy process (AHP) is one of the multi-criteria decision-making methods (MCDM) used to scale and quantify measurements. The first step is the formation of the problem components (hierarchy); the second phase of the AHP is the evaluation which is based on the concept of paired comparisons. For project-level evaluations where a few sections are to be considered simultaneously, AHP is an effective analysis method.

The authors [8] presented a rational approach using AHP for prioritization of highway sections for maintenance based on present highway conditions, future highway conditions, and the highway importance. Abdurrahman et al. [9] considered the requirement of a ranking procedure to optimize the limited funds available for road maintenance. Apart from the technical

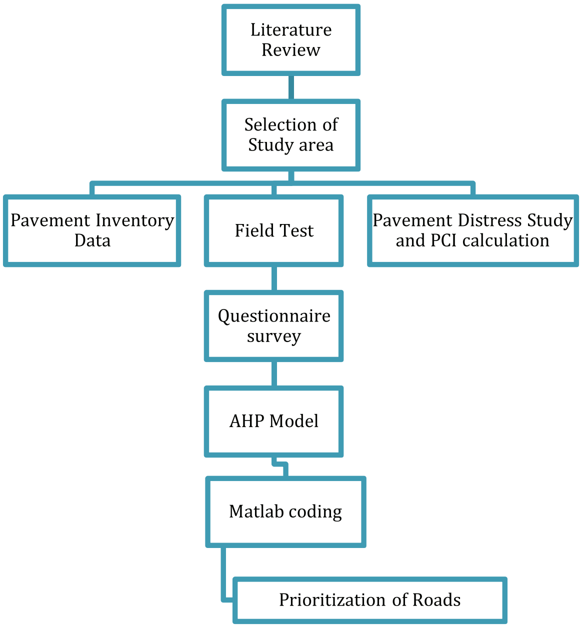

Fig. 1. Methodology of the study.

factors, other non-technical factors such as political intervention also play a significant role in determining priority, the authors suggested a widespread assessment framework that enables considering several technical and non-technical factors into consideration. Analytic Hierarchy Process (AHP) was used to evaluate the roads for approved criteria. Their work established the developed analytic hierarchy process (AHP) model works suitably and produces satisfactory results as well as providing precise decisions. Akash C. Prakasan [10] used the Analytic Hierarchy Process (*AHP*) for developing a priority ranking model for the maintenance of urban roads by selecting 21 urban road sections near Delhi, India. A Software named AHPM (Analytic Hierarchy Process Model) was developed using MATLAB for flexible pavement [11]. Ahmed et al. [12] suggested that an objective-based AHP method is more suitable for the prioritization of pavement maintenance of roads.

Hongmei Li [14] proposed an Analytic Hierarchical Process (AHP) theory-based method to determine the weight of the decision-making influence factors, considering their relative significance and generating an overall ranking for each road section. Other soft computing techniques can also be used in Pavement management system [15].

3. Data collection

3.1. Selection of study area

For the present study, a total of ten city roads of Pune in Maharashtra, India were selected. The criteria for selection were five plastic roads and five normal bituminous roads which were overlaid between December 2016 and January 2017 with similar cross-section and similar traffic conditions. All selected roads were within a periphery of 10−12 km to neglect the impact of age, traffic, and environmental parameters. The Pavement inventory data collected in this study includes the details about the road sections, road name, carriageway width, length of the road, crust thickness.

3.2. Field tests – field distress surveys

To study the deterioration parameters of flexible pavement the following studies were carried out which can fairly accurately predict the conditions of roads:

3.2.1. Benkelman beam deflection test (BBD)

Test method reference: TRRLReport 833 [19]. BBT is used to determine the viscoelastic property of the bituminous layer. The tolerance value for a good bitumen road lies between 0.5-1. (Fig 2).

3.2.2. Skid resistance

Skid resistance is the force developed when a tire that is prevented from rotating slides along the pavement surface. Skid resistance is measured in the form of friction measurements such as a friction factor or skid number. The surface texture of the road layer determines the skidding nature of a road, mainly in wet conditions.

Fig. 2. BBD Test.

The skid resistance of the road is determined as a skid number and compared with the reference value. Lower the skid number higher is the skid resistance. An approved skid number is < 65 for a well-performing road. We have used a Stanley pendulum skid resistance tester (Fig. 3).

3.2.3. Roughness test by bump integrator

Roughness is a significant pavement characteristic as it affects not only vehicle delay costs but also ride quality, fuel consumption, and maintenance costs. Roughness data are collected using towed fifth wheel bump integrator running at a speed of 32 km/hr on selected stretches (Fig. 4). The ROMDAS® Bump Integrator (BI) for measuring road roughness is a response-type roughness meter. This is a mechanical instrument that measures the relative displacement of a vehicle's

Fig. 3. Skid resistance using Stanley pendulum.

Fig. 4. Roughness test by Bump Integrator.

suspension concerning the body of the vehicle. The BI readings are used to analyze the linear profile and calculate the 'roughness' of a road's surface in mm/km.

From Bump integrator readings, readings can be converted to IRI as per IRC SP-16-32004 (Annexure 1):

$$IRI = 0.0032\ (BI)^{0.89}$$

where, IRI = International Roughness Index (m/km)
B I = Average Roughness by Bump Integrator (mm/km)

4. Data analysis

A visual condition survey was done for all the roads selected. Each road was divided into sections of 50 m each. Four types of distresses viz. Cracking, Ravelling, Potholes, Rut depth were finalized by Delphi Technique with field experts for calculation of the Pavement condition index (PCI). The above four parameters selected are major distresses for predicting the deterioration of bituminous roads in Indian conditions especially for urban city roads.

4.1. Estimation of Pavement Condition Index (PCI)

The pavement condition index (PCI) was estimated by using the Indian Road Congress (IRC) code (IRC 82- 2015) [20] for the calculation of distresses of both the types of pavement sections. The primary input for the method is the percentage contribution of each type of distress in each subsection (50 m).

Therefore, the estimation of this percentage contribution of each type of distress in each subsection involves the following steps:

1 Diagnosing and measuring a similar type of distress in each subsection.
2 Estimating the percentage contribution of a similar type of distress to the total area of the subsection in each subsection.

PCI value for each subsection is estimated based on the percentage contribution of each distress from the total area of each subsection as per the guidelines suggested by the IRC:82-2015. Default weights (Table 2) as per IRC [20] have been assigned for each type of distress to estimate the final PCI value from the calculated percentage contribution of each distress. Table 1 shows the recommended typical PCI rating scale of 0–3 for a range of each distress of major district roads (MDR), other district roads (ODR), and Village Roads (VR). Areas of each distress were measured physically on the road and its

Table 1
PCI calculation by IRC method.

Distresses	Poor	Fair	Good
Cracking	More than 15 %	5%-15 %	Less than 5%
Raveling	More than 10 %	5%-10 %	Less than 5%
Pothole	More than 0.5 %	Less than 0.5 %	Nil
Settlement/Depression	More than 5%	1 %–5 %	Less than 1%
Rut depth mm using 3 m straight edge	More than 10 %	5%-10 %	Less than 5%
Rating	1	1.1–2	2.1–3
Condition	**Poor**	**Fair**	**Good**

Source: Table 5.3 Pavement Distress Based Rating for Urban Roads IRC:82–2015 (Page: 5)

Table 2
Weighted Multiplying factor.

S.No.	Parameter	Weightage(fixed) Multiplying Factor
1	Cracking	1.0
2	Raveling	0.75
3	Pothole	0.5
4	Shoving	1.00
5	Patching	0.75
6	Settlement	0.75
7	Rut depth	1.00

Table 3
Sample calculation of PCI for a section.

	Road near Tathwade garden (Plastic Road)				Area of Road= Width - 6m Length -250m			
Chainage	Distresses	Area	Condition %	Condition	Rating	FMF	WRV	PCI
50-100	Cracking	5	1.667	Good	2.6	1.00	2.60	2.25 Good
	Ravelling	3	1	Good	2.6	0.75	1.95	
	Pothole	0.16	0.053	Good	2.9	0.50	1.45	
	Rut depth mm using 3m straight edge	0	0	Good	3.0	1.00	3.00	

FMF= Fixed Multiplying factor for Urban Roads as per IRC 82-2015
WRF= Weighted Rating Value

FMF = Fixed Multiplying factor for Urban Roads as per IRC.82-2015
WRF = Weighted Rating Value.

density was found out as condition percentage. For example, if the cracking area is less than 5%, the condition is good and the rating can be given between 2.1–3 as per Table 1. Based on the judgment of the surveyor it is rated within the range.

Likewise, for each subsection condition of road and PCI is calculated, the mean PCI value is estimated for each pavement section from the estimated PCI value for each subsection of the selected pavement section.

For the calculation of the weighted rating value of an individual parameter, the following fixed weights have been assigned as per the given table.

Example: In the table below (Table 3) calculation of PCI for one section, 50 m length (50−100 m chainage) is shown for a selected road. A section is thoroughly evaluated for different types of distress as listed in the table below viz. cracking, potholes, etc. and the area of each distress is measured and it is divided with the area of road section considered to calculate condition percentage. From the percentage of condition, a rating is given as per Table 1 and the judgment of expert surveyor. Weighted/Fixed modifying factor (FMF) is assigned as per Table 2 and Weighted Rating Value (WRV) is calculated for each type of distress by multiplying Rating and FMF. The average of WRV is the PCI for that road section.

Similarly, PCI for each section of the road is calculated and it is averaged out to find the PCI for the selected road to predict the condition of the road.

4.2. Compiled data

The underlined two tables (Tables 4 and 5) tabulate the results of field studies and physical distress studies for Plastic roads and normal bituminous roads. Each road is given a specific code number for running the Analytic Hierarchy Process (AHP) Model.

4.3. Application of analytical hierarchy process (AHP)

AHP is a technique for organizing and analyzing complex decisions and coming up with the solution that best suits the needs of the decision-makers. The hierarchical architecture of PCA in which the pavement conditions of different

Table 4
Data of Plastic Roads for AHP Model.

S.No.	Code	Name of Road	W (m)	L (m)	Overlay Thickness (mm)	BBD (mm)	Roughness, IRI	Skid resistance	PCI
1	PR1	Tathawade garden, Karve Nagar	6	250	80	1.04	4.096	50	2.350
2	PR2	Road near Vaikunth crematory	5	158	90	0.69	4.560	50	2.240
3	PR3	Koregaon Park lane no. 3	5	450	75	0.51	3.950	55	2.270
4	PR4	Rd near Arnold school, wadgaon sheri	4.5	200	90	0.57	3.950	53	2.240
5	PR5	Magarpatta City H.C.M.T.R. road	4.5	115	80	0.60	4.210	52	2.270

Table 5
Data of normal bituminous Roads for AHP Model.

S.No.	Code	Name of Road	W (m)	L (m)	Overlay Thickness (mm)	BBD (mm)	Roughness, IRI	Skid resistance	PCI
1	NR1	TathawadeUdyan, Karve Nagar	6.0	250	80	1.41	4.15	53	2.255
2	NR2	Road near Vaikunth crematory	5.0	150	90	0.75	4.90	51	2.240
3	NR3	Koregaon Park lane no. 4	5	380	75	0.96	4.15	52	2.215
4	NR4	Nr Arnold school, Wadgaonsheri	7.2	250	80	1.25	4.00	50	2.235
5	NR5	Magarpatta City H.C.M.T.R. road	4.5	115	80	0.78	4.50	54	2.270

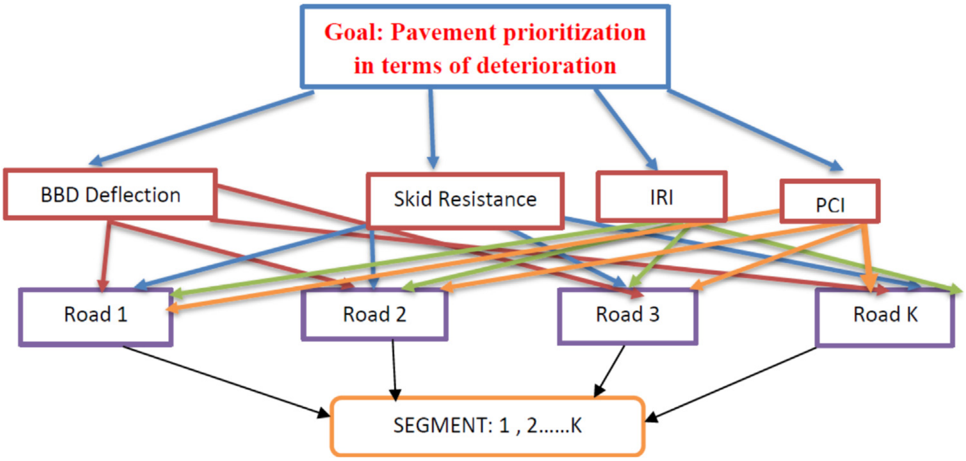

Fig. 5. Hierarchy structure for AHP Analysis.

road stretches is evaluated under different parameters. These criteria refer to a defining characteristic of pavement based on which sound decisions can be taken. In these four important pavement parameters are chosen

A= {BBD, Skid resistance, IRI, PCI}

4.3.1. Analytic hierarchical process model. (step by step)

Step 1: The initial step in the development of the model is the generation of the importance weight of each criterion. The contribution of each indicator differs from each other, which is reflected through a weight coefficient. The determination of weight coefficient corresponding to each performance indicator relies on the tradeoffs amongst performance indicators which are derived from pairwise comparison matrix $A = (a_{ij})_{mxm}$ in which m represents many performance indicators and the entry 'a_{ij}' corresponds to the ratio of the relative importance of 'ith' performance indicator to 'jth' performance indicator. Fig. 5 describes the hierarchy structure for the formation of the AHP model.

Step 2: **Questionnaire Survey**

To form a matrix, a questionnaire has been prepared to perform pairwise judgment between the criteria. Each performance indicator is compared against each other, determining their relative importance on a scale of 1–9. Saaty's scale.

Questionnaire sheets were sent to more than 20 field experts and Scientists working in Central Road Institutes. A total of 11 respondents gave the weightage and based on the geometric mean of the responses, a pairwise comparison of Matrix was formed which is shown below.

$$A = \begin{vmatrix} 1 & 3 & 2 & 1 \\ 1/3 & 1 & 1/3 & 1/5 \\ 1/2 & 3 & 1 & 1/2 \\ 1 & 5 & 2 & 1 \end{vmatrix}$$

Table 6
Decision Model (Results from MATLAB).

Road code	AHP score	Priority as per deterioration
PR1	. 0.1078**1**	**3**3**3**
PR2	0.0943	7
PR3	0.0856	10
PR4	0.0872	9
PR5	0.0899	8
NR1	0.1215	1
NR2	0.0984	6
NR3	0.1029	4
NR4	0.1137	2
NR5	0.0987	5

Table 7
Ranking of Roads as per deterioration.

Rank	Road Code	Name of Road	Type of Road
1	NR1	Road Near Tathawade garden, Karvenagar	Normal
2	NR4	Rd near Arnold school, Wadgaonsheri	Normal
3	PR1	Road Near Tathawade Udyan, Karvenagar	Plastic
4	NR3	Lane No 3, Koregaon Park	Normal
5	NR5	Magarpatta City H.C.M.T.R. road	Normal
6	NR2	Road near Vaikunth Crematory SM Joshi Bridge	Normal
7	PR2	Road Near Tathwade Udyan, Karvenagar	Plastic
8	PR5	Magarpatta City H.C.M.T.R. road	Plastic
9	PR4	Rd near Arnold school, Wadgaonsheri	Plastic
10	PR3	Lane No 3, Koregaon Park	Plastic

4.3.2. MATLAB for AHP

MATLAB is a multi-paradigm numerical computing environment and proprietary programming language developed by MathWorks. MATLAB allows matrix calculations, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs written in other languages. We have used MATLAB programming for evaluating the AHP score and prioritizing the ten roads selected based on the deterioration.

5. Results & discussions

After running MATLAB for the AHP model formulated based on four types of distresses and pairwise ranking of distresses as suggested by experts, decision results came out as ranking of roads based on the overall deterioration. The results are tabulated in Table 6. The higher the AHP score of the road, it is predicted that it will deteriorate early.

In Table 7, the ranking of all the roads selected for the study is presented in the ascending order of their deterioration rates.

From the results of MATLAB, it is seen (Table 7) that in the first five roads only one road is plastic. Hence, it can be concluded that the deterioration rate of plastic roads is slower as compared to normal bituminous roads.

6. Conclusion

From the pilot study conducted on ten in-service roads in the city of Pune, Maharashtra, India (having the same CVPD, and topographical and climatic conditions), it can be concluded that the addition of waste plastic to the bituminous mix has delayed the early deterioration of roads. The authors have considered major distress parameters affecting the deterioration of urban bituminous roads in the AHP model that has ranked all the roads.

In a developing country like India, where resources are scarce and efficient maintenance of bituminous roads is required every year, implementation of plastic roads can bring significant economic savings for the local authorities who spend a lot every year on pre-monsoon maintenance of city roads. The substitution of bitumen with waste plastic (8% in this study) will indirectly save on costly bitumen which in turn will make these roads further beneficial. Also, the effective utilization of the waste plastic for the preparation of the modified bitumen will result in a substantial increase in its scrap value, which otherwise is an undesirable waste material that is littered all over the urban areas.

The study will help to encourage the field engineers and local bodies to use a modified bituminous mix with waste plastic.

7. Future scope

The study can be conducted with varying traffic, environmental and topographical conditions. Cost parameters can also be estimated.

Declaration of Competing Interest

The authors report no declarations of interest.

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