EFFECT OF COMMERCIAL TRAFFIC OVERLOADING ENFORCEMENT ON PAVEMENT PERFORMANCE

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ABSTRACT

Most of the modern truck engines are capable of hauling much heavier loads than the legal upper limit. Therefore the truck owners and operators have a tendency to overload these trucks enabling them to get more returns for the same investment and manpower. One of the major factors affecting pavement life is the magnitude and frequency of the wheel load repetitions imposed on the pavement structure. In order to maintain the heavy gross vehicle weight and still stay within the legal axle load limits, the trucking industry has devised the multiple axle configurations, which include rear tandem axle trucks.

In the present study, Hospet – Sandur section of State Highway No. 49 (about 27 Km) of Karnataka (India), one of the major traffic corridors has been considered to assess the effect of overloading on the design and performance of pavements. From Axle load survey data the Vehicle Damage Factors (VDF) were calculated. Using the traffic and other engineering data, pavement performance has been evaluated for proposed flexible Pavement. In order to study the effect of enforcement of overloading, an attempt has been made to evaluate the pavement performance after converting the overloaded axles to tandem axles / equivalent standard axle trucks. The results have been applied to assess the benefits in maintenance management by doing the pavement performance / life analysis using deterioration models and performance criteria established for Indian conditions.

It is observed from the study, that the percentage of overloading of commercial vehicles is very high, which result in greater extent of damage to the pavement, thus reducing the serviceable life of pavement. From analysis, it is observed that the rate of the growth of deterioration is less when enforcement is implied. It implies that there is necessary to strengthen the pavements much earlier with the present trend of overloading when compared with the enforcement situation, wherein the tandem axles / equivalent standard axle trucks are used to reduce the overloading effect. Hence, there is a need for an early maintenance in order

to retain the structural integrity of the pavement which results in higher life cycle costs. The benefits in terms of lower maintenance cost are evident in case of overloading enforcement, with a lower Life Cycle Cost. It is recommended that the strict enforcement is necessary on axle load limit and introduction of multi-axle trucks, including tandem axle trucks to optimize the total transportation cost of the highway system.

1. INTRODUCTION

There are many factors which affect the design and maintenance of pavements. These factors include gross load, tyre pressure, type of load, number of wheels and type of wheel configuration, number of repetitions, subgrade properties, moisture content, environmental conditions, temperature, type of material used in pavement construction, etc. Commercial vehicles especially Trucks are the major consumers of the Road network, applying the heaviest loads to the pavement. Truck loads are transferred to the pavement through various combinations of axle configurations depending on the truck type. Tandem and Tridem axles have more wheels than do single axles and so they can carry a heavier load while introducing the same magnitude of stress on the pavement. Hence, knowledge of axle loadings and spectrum of axle loads of vehicles using a road system is necessary in the development and application of realistic pavement design and maintenance procedure.

Structural damage to a road is caused almost exclusively by commercial vehicles expected to use it during its life. As observed in most of the developing countries, over loading of trucks in India also has assumed menacing proportions, endangering the pavement stability and road safety (MOT, Govt. of India 1992). Overloading is restored to by transport operators to economize in the cost of operations, resulting in axle-loads generally much higher than the standard prescribed limits. In the whole, the pavement of existing highways are grossly inadequate (structurally) to bear the rise in axle loads, keeping in view the fact that in some cases the damage caused to pavement by the heaviest 10% of the vehicles in the traffic stream by far greater than the total damage caused by the remaining 90% put together (*MOST, Govt. of India, 1994*).

1.1 Need for the Axle Load Survey

One of the most important tasks of highway officials and engineers is the maintenance of deteriorating existing highway systems. The deterioration of the highway network is augmented by the continued growth of traffic and the accompanying increase in vehicle size and gross weight in an attempt to improve the energy savings and economic efficiency of the transportation system. However, an increase in axle loads causes severe damage to the pavement system and accelerates its rate of deterioration by many folds. In order to maintain the legal axle load limits, the trucking industry has devised multiple axle configurations.

To reduce the effect of overloading and at the same time to reap the benefits of reduced transportation cost, it is necessary to impose the axle load regulations for the commercial trucks. There is a need to conduct the axle load studies on the highway system to understand the extent of loading as well as percentage of different axle configuration of commercial trucks. The spectrum of axle loads and resulting vehicle damage factors are necessary in designing the rehabilitation measures. Since in most of the cases the legal load limits will exceed due to overloading, there is a need to study the effect of enforcement of axle load restrictions in reducing the damaging effect on pavement with high gross weight of commercial trucks.

1.2 Permissible Axle Loads in India

The policy at National level for the road system in India with regard to the Registered Laden Weight (RLM) limit (*MOT, Govt. of India 1992*) was as follows:

i) Maximum Single Axle Load (with 2 Tyres) – 60 KN (6.0 T)
ii) Maximum Single Axle Load (with 4 Tyres) – 102 KN (10.2 T)
iii) Maximum Tandem Axle Load (with 8 Tyres) – 180 KN (18.0 T)

1.3 Objective and Scope

The main objectives of the present study are

(i) To determine Vehicle Damage Factors (VDF) from the axle load spectrum data
(ii) To assess the effect of overloading on pavement performance, and
(iii) To study the benefits due to the enforcement of Axle load regulation in terms of pavement performance.

The axle load survey was carried out on a Road section of SH 49 from Hospet to Sandur in the State of Karnataka, India. The data were analyzed to compute the extent of overloading and the resultant vehicle damage factors. The analysis was carried out for Case I: by considering the actual field data directly; and for Case II: by converting the overloaded axles in to allowable standard axles i.e. the axle loads that are more than the allowable limits have been restricted to allowable limit and the excess loading has been converted to additional truck traffic with allowable axle load limits. Even though the Truck traffic volume increases in Case II to transport the same quantum of goods as of in Case I, all the axle loads are within the allowable axle load limits. Equivalency factors provided in IRC: 37-2001 were used in the analysis. The damaging effect due to overloading was computed using the vehicle damage factors obtained. The results have been applied to assess the structural conditions of pavement.

2. LITERATURE REVIEW

2.1 Equivalent Wheel Load Factor (EWLF)

The nature of highway traffic loading and climatic environment is such that any point within a pavement structure is subjected to a diverse and almost infinite spectrum of stresses and strains. Traditionally the design of flexible highway pavements has followed the so called “Fixed Vehicle” approach where in the pavement thickness is expressed as a function of the number of repetitions to failure of a standard vehicle for various subgrade support values. Since the traffic on highway pavements is wide spectrum of wheel loads, it is essential to convert this heterogeneous traffic to an equivalent homogeneous traffic in terms of a chosen standard vehicle. One means of achieving this objective is through the use of Equivalent Single Wheel Load (ESWL) factors (S*pecial Report 22, HRB, 1995*). However, one of the major limitations of theoretically evaluated ESWLF is that it is almost independent of the load magnitude whereas the failure mechanism in a given pavement structure is strongly dependent on the magnitude of load. Further, the ESWLF concept in its present form may not account for the cumulative nature of the damage process. Hence, there arises a need for a methodology by which it is possible to consider the pavement distress as the criterion of equivalency and account for the cumulative process of damage. The concept of Equivalent Wheel Load Factor (EWLF) was a consequence of research in this direction (*MOST, Govt. of India, 1994*).

2.2 The Vehicle Damage Factor (VDF)

The Vehicle Damage Factor (VDF) is an important indexing factor for characterizing the traffic loading for a road. The VDF can easily be computed from the axle load data by the following formula, provided sufficiently large and fairly distributed sample of vehicles are included in the axle load survey.

$$\text{VDF} = \text{Total EAL} / \text{Number of vehicles weighed} \qquad (1)$$

Where total EAL = ∑ No. of axles in each weight class x load Equivalency factors of the weight class.

An equivalency is simply a convenient means for indexing the wide spectrum of actual loads to one selected value. One of the most important and useful products of the AASHO Road test was the development of a relationship characterizing the relative damaging effect of varying axle loads on pavements in terms of the equivalent 8.2 tonnes single axle load. The relationship sometimes referred to as 'fourth power' rule has subsequently been verified by the studies reported by several agencies in different countries. The rule states that the damage power of an axle load increases roughly as a fourth power with the weight of an axle i.e. any single axle load less than 8200 kg is some fractional EAL, whereas any greater single load is some multiple of EAL.

The damaging factors for different configurations are based on the ratio of strain at any given load to strain under 82 KN load (B*illy Conor 1982*). It is obvious that, whenever possible, the use of additional axles should be encouraged, especially in lieu of overweight permitted. The load equivalency factors based on the 'fourth power' rule published IRC: 37-2001 are tabulated in Table 1 (*Indian Roads Congress, 2001*). Once VDF is obtained from a particular axle load survey for a region, the same can be used to convert the traffic volume data into number of EAL. However, care should be taken that flow conditions of traffic remain same for which the VDF is obtained, and the VDF value should be regularly updated by conducting fresh axle load surveys

Table 1: Axle Load Equivalency Factors

Gross Axle Weight (kg)	Load Equivalency Factors		Gross Axle Weight (kg)	Load Equivalency Factors	
	Single Axle	Tandem Axle		Single Axle	Tandem Axle
900	0.0002	0.0000	19051	27.70	2.61
1810	0.002	0.0002	19958	33.00	3.16
2720	0.009	0.001	20865	39.30	3.79
3630	0.031	0.003	21772	46.50	4.49
4540	0.080	0.006	22680	55.00	5.28
5440	0.176	0.013	23587	-	6.17
6350	0.35	0.024	24494	-	7.15
7260	0.61	0.043	25401	-	8.20
8160	1.00	0.070	26308	-	9.40
9070	1.55	0.110	27216	-	10.70
9980	2.30	0.166	28123	-	12.10
10890	3.27	0.242	29030	-	13.70
11790	4.48	0.342	29937	-	15.40
12700	5.98	0.470	30844	-	17.20
13610	7.80	0.633	31752	-	19.20
14520	10.00	0.834	32660	-	21.30
15420	12.50	1.08	33566	-	23.60
16320	15.50	1.38	34473	-	26.10
17230	19.00	1.73	35380	-	28.80
18140	23.00	2.14	36288	-	31.70
Note: Equivalency factors for Tridem axle loads have been calculated using the 4^{th} power rule considering 48 kips (21.7 KN) as a standard tridem axle load.					

3. FIELD STUDY

3.1 Project Road

The Government of Karnataka (GOK) proposes to embark on a major program to improve State Highways (SHs) through Public-Private Participation (PPP) initiatives. Towards this end, the Infrastructure Development Corporation (Karnataka) Limited (iDeCK) has been assigned the task of managing the study and preparation of the project, with support from the Karnataka Road Development Corporation Limited (KRDCL), with the aim of inviting PPP bids

The proposed widening from intermediate lane to 4 lane divided carriageways for SH-49 section from Hopset to Sandur of 27.275 km long will provide the safe movement of heavy iron bearing traffic moving from mines situated in and around Sandur. As the area is covered by iron ore mines there is a lot of movement of heavy trucks in and around the area. At present, the truck movement was using narrow road section of 5.5 m wide, with frequent traffic blockade due to bad condition and accident-prone locations. Present pavement condition is fully deteriorated with deep potholes, depressions and disintegrated blocks resulting in unsafe movement and inconvenience for the commuters. The proposed improvements to the Hospet - Sandur Road section will not only provide a good quality road but also provides a pollution free environment to the people of Sandur.

3.2 Preparation for Field Works for Axle Load Survey

Axle Load survey was carried out at the selected location wherein larger sample size of the trucks have been weighed. At this selected survey location, arrangements were made for the installation of the weighing pads by cutting a pit at the shoulder at the edge of the pavement. The top surface of the weighing pad was kept in level with the road surface. The survey was conducted for both up and down directions. The locations of the two pads on both sides of the highway were staggered in such a way sufficient length of carriageway was available for uninterrupted movement of vehicles not required to be stopped for weighing.

3.3 Measurement of Wheel Loads

The portable wheel weight measuring equipment was used for the measurement of wheel loads. The size of the weighing unit permitted only one single or twin tyre assembly to be weighed at a time. Each vehicle to be weighed was aligned on to the unit and stopped with the wheel being weighed at the centre of the top plate. The vehicle was stopped just long enough for the reading on the display unit to get stabilized. The same procedure was repeated with the next level.

Assuming the load on each axle as evenly distributed, the axle load was taken as twice the wheel load. Due to the requirement of stopping a vehicle for weighing, there was no possibility to weigh all the commercial vehicles passing through the survey site and hence the vehicles were weighed on a sample basis. While the vehicles were being weighed, information about the axle-type was also recorded.

4. AXLE LOAD ANALYSIS

In the present study, the axle load analysis was carried under two cases; Case 1 was using the actual data from the field and Case 2 was by converting the overloaded axles in to allowable standard axles i.e. the axle loads that are more than the allowable limits have been restricted to allowable limit and the excess loading has been converted to additional truck traffic with allowable axle load limits

4.1 Computation of Vehicle Damaging Factor using Field Data

The axle load data collected from the survey site was classified into groups based on axle type viz., singe axles, tandem and Tridem axles. Each group was again classified into intervals of 2 tonnes (2 KN). Frequency of each class interval was computed. Midpoint values of each weight class have been considered for obtaining the Equivalency factors for respective weight class. Frequencies of each weight class were multiplied with the respective equivalency factors to obtain Equivalent Single Axles (ESA) in terms of 8.2 tonne (82 KN) single axle load. Summation of all Equivalent Standard Axles (ESA) gives the total damaging effect for that site. By knowing the number of vehicles weighed and total damaging effect, Vehicle Damage Factors (VDF == Total ESA / No. of Vehicles Weighed) were computed for each class of commercial vehicles and presented in Table 2.

Table 2: VDF values from the Axle load survey data

Vehicle Details	Class of Vehicle			
	LCV*	Trucks		
		2 Axle	3 Axle	Multi Axle
Nos. weighed	33	391	920	55
Nos. observed	50	694	1115	65
Sample Size (%)	66	56	83	85
VDF Value	0.01	10.01	12.73	3.44

*LCV – Light Commercial Vehicle

4.2 Computation of Vehicle Damage Factors after Converting Overloaded Axles

The axle load data collected from survey site was classified similarly as done in previous case. After classifying the axles into single axles, tandem axles and tridem axles, the axles which were exceeding the legal axle load limit of 10.2 tonnes, 18.0 tonnes and 22 tonnes respectively were restricted to maximum allowable limits, assuming that the excess load would be transferred through the additional vehicles with the maximum allowable axle loads. For analysis purpose excess axle loads have been distributed within the same classification group of vehicles. The frequency of each class interval was calculated and multiplied with the equivalency factors to get the equivalent standard axles (ESA) in terms of 8.2 tonnes (82 KN) load. The summation of ESAS of all classes gives the total damaging effect. The modified vehicle damage factors (Modified VDFs) and were computed using the total damage effect, number of vehicles weighed and presented in Table 3.

Table 3: Modified VDF values after converting the Overloaded Axle loads to Allowable Axle loads

Vehicle Details	Class of Vehicle			
	LCV*	Trucks		
		2 Axle	3 Axle	Multi Axle
Nos. weighed	33	391	920	55
Actual VDF Value	0.01	10.01	12.73	3.44
Nos. increased to transport the excess loads	0	99	297	6
% increase	0	25	32	11
Modified VDF Value	0.01	1.82	1.89	1.88

*LCV – Light Commercial Vehicle

5. APPLICATION OF THE STUDY

5.1 Assessment of Traffic Loading

A well compacted pavement section or one which has been well conditioned by traffic, deforms elastically under each wheel load application such that when the load moves away, there is an elastic recovery or rebound deflection of the deformed pavement surface. This is the basic principle of deflection method of pavement evaluation (*Khanna S.K., and Justo, CEG 1991*). The amount of pavement deflection under a design wheel load or its rebound deflection on removal of this load is a measure of the structural stability of the pavement system. Larger rebound deflections indicate weaker pavement structure which may require earlier strengthening or higher overlay thickness.

The results of present analysis have been applied to study the pavement performance and LCC analysis using HDM-4 software. The data regarding the traffic volume, lateral distribution factor (i.e. percent coverage wheel path), traffic growth rates and other details were collected to assess the Cumulative standard axles using the following equation.

$$Ns = 365 \times P \times \frac{[(1+r)^n - 1]}{r} \times VDF \times CF \quad (2)$$

Where

- P = Traffic at initial time, commercial vehicles per day
- r = Rate of traffic growth, %
- CF = Percent Coverage (75% for two lane carriageways)
- Ns = Cumulative Standard Axle load repetitions during design life in millions (MSA)
- VDF = Vehicle Damage Factor
- n = Design life in years (15 years)

For the purpose of structural design of pavement, only the number of commercial vehicles of gross vehicle weight of three tonnes (3 KN) or more and their axle loading is considered. Growth rates were arrived by considering past traffic data and socioeconomic profile of the Project Influencing Area (PIA). Details of average annual daily traffic (AADT) of commercial vehicles have been presented in Table 4.

Table 4: AADT of Commercial Vehicles (No.s) for Case I

AADT in base year 2009				
LCV*	Trucks			Total
	2 Axle	3 Axle	Multi Axle	
70	1486	1561	15	3141

*LCV – Light Commercial Vehicle

Average annual daily traffic (AADT) volume of commercial vehicles have been modified for Case II by adding the additional vehicles that were introduced to transport the excess axle loads. Details of modified AADT volume of commercial vehicles for Case II have been presented in Table 5.

Table 5: Modified AADT of Commercial Vehicles (No.s) for Case II

Details	AADT in base year 2009				
	LCV*	Trucks			Total
		2 Axle	3 Axle	Multi Axle	
Actual Traffic as per survey	70	1486	1561	15	3141
% increase in trucks to transport the excess axle loads	0	25	32	11	
Modified AADT	70	1858	2061	17	4006
*LCV – Light Commercial Vehicle					

The traffic loading was assessed for both the cases for design life of 15 years. Pavement design and structural composition had been carried out as per IRC: 37-2001 guidelines. Details of proposed pavement crust thickness for both the cases are presented in Table 6.

Table 6: Design Traffic Loading and Pavement Layer Thickness

Pavement layer Composition as per IRC 37: 2001 for design life of 15 years						
Traffic loading in million standard axles		BC (mm)	DBM (mm)	WMM (mm)	GSB (mm)	Subgrade (mm)
Case-I	142	50	160	250	200	500
Case-II	30	40	100	250	200	500
BC: Bituminous concrete; DBM: Dense bituminous macadam; WMM: Wet mix macadam; GSB: Granular sub base						

5.2 Life Cycle Cost Analysis

Life Cycle Cost Analysis (LCCA) is an engineering economic analysis tool useful in comparing the relative merit of competing project alternatives. LCCA is defined as "a process for evaluating the total economic worth of a usable project segment by analyzing initial costs and discounted future costs, such as maintenance, user costs, reconstruction, rehabilitation, restoring, and resurfacing costs, over the life of the project segment.

LCCA introduces a structured methodology that accounts for the effects of agency activities and roadways users and provides a means to balance them with the effects of construction, rehabilitation, and preservation.

LCCA process begins with the development of alternatives to accomplish the structural and performance objectives for a project. Then the schedule of initial and future activities involved in implementing shall be defined for each project design alternative and the costs of these activities are estimated. The predicted schedule of activities and their associated agency and user costs outline the projected Life Cycle Cost (LCC) stream for each alternative. Using an economic technique known as “discounting,” these costs are converted into present value and summed for each alternative and then which alternative is the most cost-effective is determined. It is important to note that the lowest LCC option may not necessarily be implemented when other considerations such as risk, available budgets, and political and environmental concerns are taken into account. LCCA provides critical information to the overall decision-making process.

The Life Cycle Cost (LCC) analysis was carried out for the project road using HDM-4 Software for widening and reconstruction of the pavement for the design life of 20 years using the surveyed axle load data i.e. actual VDF factor and resulting pavement thicknesses. In order to assess the benefits of converting overloaded axles i.e. by converting the excess axle loads into additional traffic with maximum allowable axle load limits, the LCC analysis was also carried out using the modified VDF values and resulting pavement thicknesses for the project road. From the results of HDM analysis, it is evident that the net benefits in enforcing the axle load limits are 25.3% higher when compared to the present trend of axle loads. Economic indicators and Benefit-Cost ratios for both the case have been presented in Table 7 and Table 8.

Pavement performance in terms of Roughness progression has been presented for both the cases in Figure 1 and Figure 2. Pavement performance in terms of Rutting progression has been presented in Figure 3 for both the cases. Rutting is one of the factors which indicates the structural behavior of the Flexible Pavements under the traffic loads, where as the Roughness indicates both structural and functional behavior of the Flexible Pavements.

Table 7: Results of LCC analysis in terms of Increase in Net Benefits for Case I (with actual VDF and AADT)

Base Alt: Routine/scheduled maintenance only; Amount in Rupees (Rs) in Millions; 1$ =Rs 48.6									
Alternative	Present Value of Total Agency Costs	Present Value of Agency Capital Costs	Increase in Agency Costs	Decrease in User Costs	Net Exogenous Benefits	Net Present Value	NPV/Cost Ratio	NPV/Cost Ratio	Internal Rate of Return
	(RAC)	(CAP)	(C)	(B)	(E)	(NPV = B + E - C)	(NPV/ RAC)	(NPV/ CAP)	(IRR)
Base Alt	142.23	109.96	0.00	0.00	0.00	0.00	0.000	0.000	0.000
With project	1,906.45	1,891.35	1,764.22	5,608.38	0.00	3,844.17	2.016	2.032	57.5

Table 8: Results of LCC analysis in terms of Increase in Net Benefits for Case II (with modified VDF and AADT)

Base Alt: Routine/scheduled maintenance only; Amount in Rupees (Rs) in Millions; 1$ = Rs 48.6									
Alternative	Present Value of Total Agency Costs	Present Value of Agency Capital Costs	Increase in Agency Costs	Decrease in User Costs	Net Exogenous Benefits	Net Present Value	NPV/Cost Ratio	NPV/Cost Ratio	Internal Rate of Return
	(RAC)	(CAP)	(C)	(B)	(E)	(NPV = B + E - C)	(NPV/ RAC)	(NPV/ CAP)	(IRR)
Base Alt	142.26	109.96	0.00	0.00	0.00	0.00	0.000	0.000	0.000
With project	1,524.62	1,508.89	1,382.36	6,197.96	0.00	4,815.60	3.159	3.191	79.5

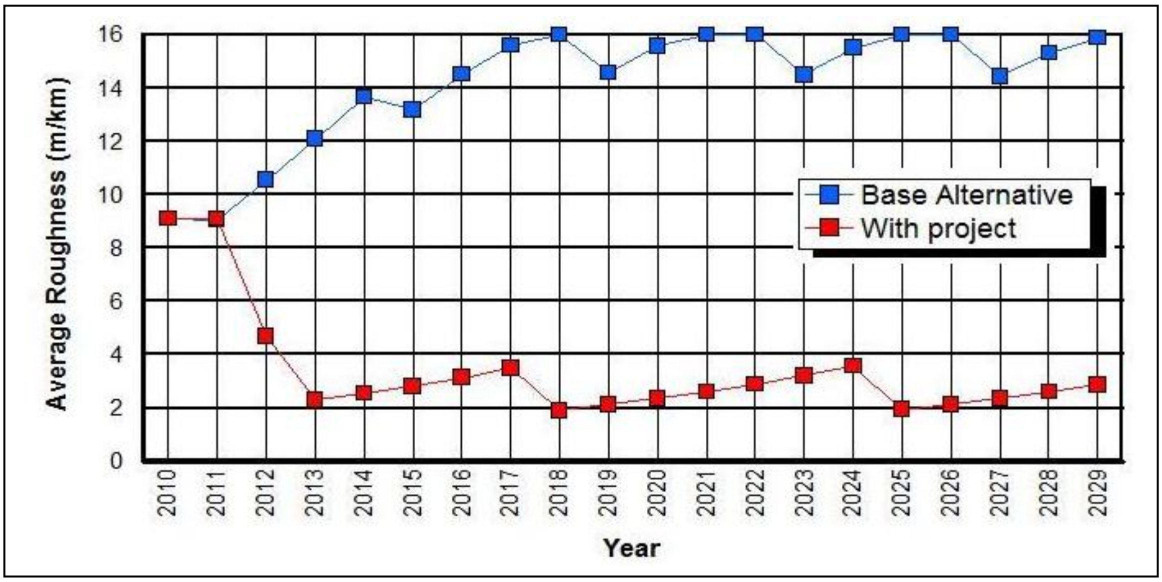

Figure 1: Pavement performance in terms of Roughness progression for Case I (with actual VDF and AADT)

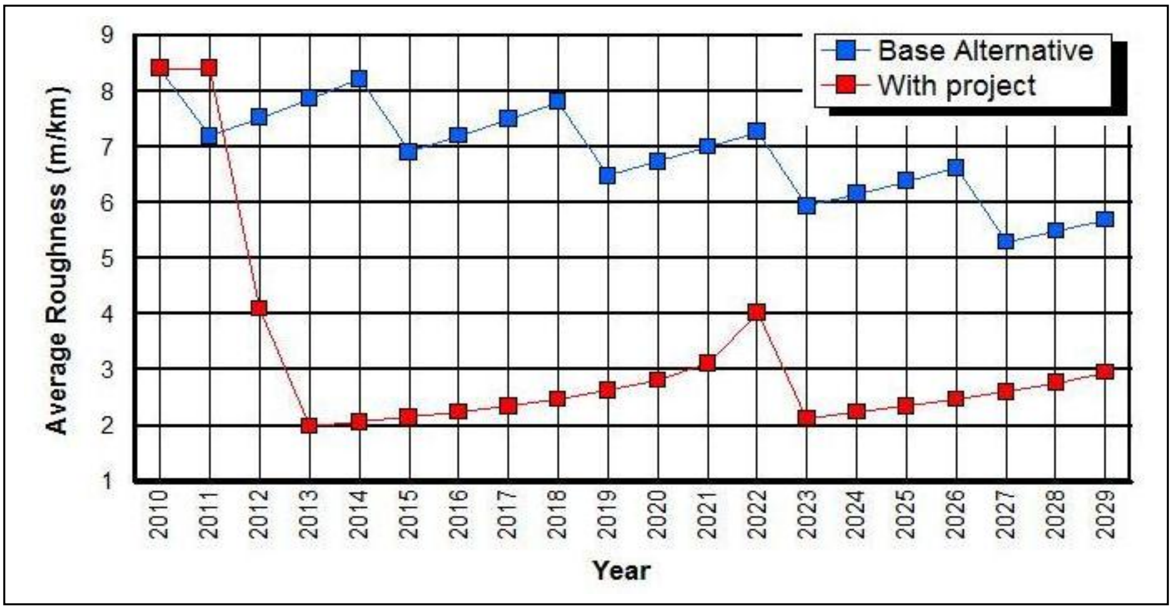

Figure 2: Pavement performance in terms of Roughness progression for Case II (with modified VDF and AADT)

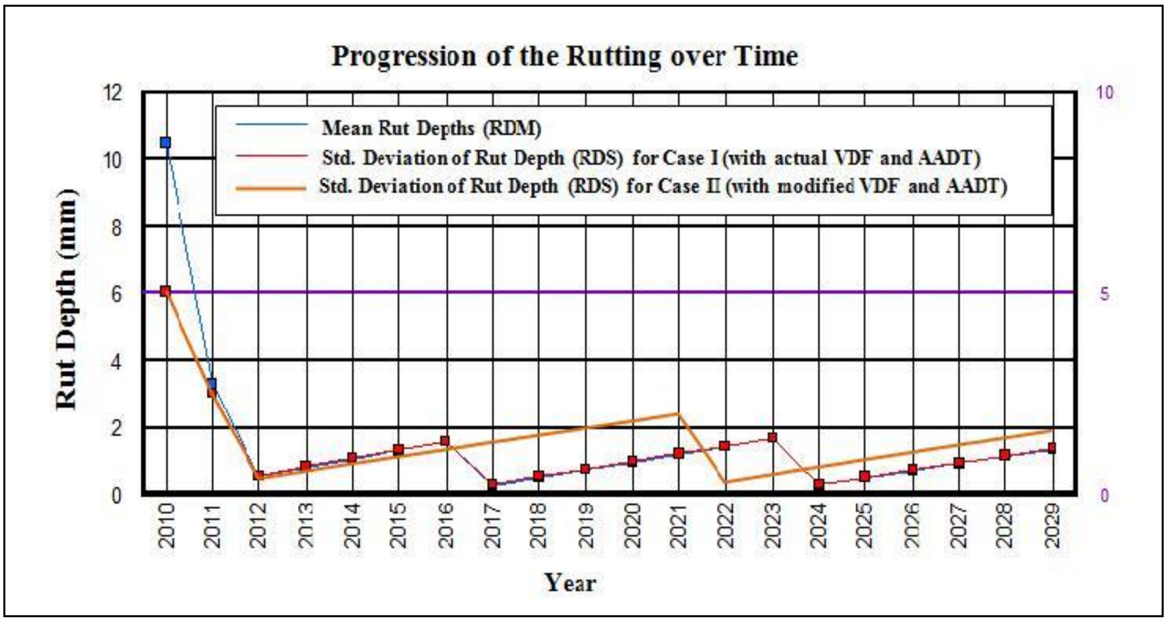

Figure 3: Pavement performance in terms of Rutting progression for both Case I and Case II

6. DISCUSSION

From the present study it can be observed that the overloading of commercial vehicles on State Highway network is very high. It is known that increase in axle loads cause considerable damage to the pavement. It can be observed from the analysis and results that the damage caused by the vehicles with overloaded axles is very high when compared to the damage caused by the vehicles with allowable axle loads. It implies that the pavement is needed to be strengthened much earlier during the design life, if the same trend of axle loads and type continues. This increases the life cycle cost as the number of overlays to be provided is more. By enforcing the limitations on overloading of vehicles i.e. either by restricting the axle load limit for all vehicles or by introducing more no. of multi axle commercial trucks for higher loading capacity, the strengthening measures can be delayed / extended so that the number of overlays and thus the life cycle cost will reduce.

7. CONCLUSIONS

The data resulted from axle load study and the analysis show that both single axles as well as tandem axles exceed their legal limits by considerable amount. This results in multiplying damage to the pavement to a greater extent.

The results of axle load data shows that the vehicle damage factors for trucks are varying from 3.4 to 12.7 which is much higher than VDF that are normally adopted in the design of pavements. The indicative VDF factors suggested by IRC vary from 1.5 to 4.5 depending on the terrain and number of commercial vehicles. Therefore, there is a need to modify the VDF values in the design of pavements for highway network, if the present extent of loading and axle type continues.

The analysis shows that by converting overloaded axles in to additional vehicles with allowable axle loading, the extent of damage can be reduced significantly. The damage to the pavement can be reduced by strict enforcement on legal axle load limits.

The multi axle (tandem and tridem) trucks with heavy loads are effective in lower life cycle costs as the number of maintenance interventions required during life cycle of a pavement are less. This is likely to result in significant increase in benefits.

The time has come to modify the policies regarding axle load limits as well as axle configurations of commercial trucks, to safeguard a pavement system as well as the total transport cost of highway system.

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