THE WORLD BANK

Optimisation of Axle Loads of Commercial Vehicles

ASIAN INSTITUTE OF TRANSPORT DEVELOPMENT

Table of Contents

Abbreviations

AADT	:	Annual Average Daily Traffic
AASHO	:	American Association of State Highway Officials
BAU	:	Business as Usual
BBD	:	Benkelman Beam Deflection
BC	:	Bituminous Concrete
BM	:	Bituminous Macadam
BOT	:	Build, Operate and Transfer
DBM	:	Dense Bituminous Macadam
EPS	:	Existing Pavement Sections
ESAL	:	Equivalent Single-Axle Load
EU	:	European Union
GVW	:	Gross Vehicle Weight
HDM-4	:	Highway Development and Management
IRI	:	International Roughness Index
MV Act	:	Motor Vehicle Act
NBFCs	:	Non-Banking Finance Companies
NH	:	National Highway
NHAI	:	National Highways Authority of India
NHDP	:	National Highway Development Project
OECD	:	Organisation for Economic Cooperation and Development
R-BC	:	Renewal Bituminous Concrete
R-SDBC	:	Renewal Semi-Dense Bituminous Concrete
RUCS	:	Road User Cost Study
SDBC	:	Semi-Dense Bituminous Concrete
SH	:	State Highway
VDF	:	Vehicle Damage Factor
VDF	:	Vehicle Damage Factors
WIM	:	Weigh-in-Motion

Executive Summary

There is a strong correlation between pavement design standards and carrying capacity of the vehicles due to static and dynamic forces generated in the course of the movement of the vehicles. It is because of this correlation that countries prescribe maximum permissible gross vehicle weight and maximum allowable axle loads. While such norms have been laid down in India also, these are quite liberal in relation to the road pavement strength.

The currently permissible axle load is 10.2 tonnes although most of the roads have been designed for an axle load of 8.16 tonnes. It is, however, a rare trucker who adheres to the prescribed norms. Carrying one-and-a-half times the permissible load is commonplace. The rampant overloading results in extensive damage to the road network which is already under stress.

The gross vehicle weight (GVW) and maximum safe axle weight of different types of vehicles are notified by the central government under Section 58 of the Motor Vehicles Act. The latest notification in this regard was issued in October 1996. It allows a front single axle load of 6 tonnes with single tyres and a rear single axle load of 10.2 tonnes with twin-mounted tyres. Tandem and multiple axles fitted with additional tyres are allowed higher tonnage. Restrictions on the front axle load apply primarily because the vehicle has to meet the requirements of steering torque.

There are several possible basic vehicle wheel and axle arrangements: single wheel, dual wheel; single axle, tandem axle and tridem axle. Their number and configuration greatly influence the dynamic loads transmitted to the road surface. It is for this reason that multiple axles can carry much greater payloads for given strength of road pavement. The wheel tyres are equally crucial in controlling the stress on the pavement through their pneumatic properties to envelop and absorb disturbances, spread the wheel load over an acceptable area of the pavement surface, and provide vertical springing.

The Indian standards do not differentiate between a driven and non-driven or steered axle. The European standards, however, make such a distinction. Thus in their case, the permissible axle load is 11.5 tonnes for single-driven axle and 10 tonnes for single non-driven axle, irrespective of the number of tyres. An additional tonne per axle is permitted if the same is fitted with pneumatic or equivalent suspension. As the

situation stands, majority of trucks in India are fitted with steel leaf-spring suspensions, which produce lower damping of dynamic loads.

Load equivalency factors have been devised to measure the relative damaging effects of different types of loadings on pavements. The concept of an equivalent single-axle load (ESAL) is used to measure these effects. By convention, an 18,000-pound (8.16 tonnes) single axle is treated as one ESAL. The equivalency relationship is expressed in the form of a 'power law', generally known as the 'fourth power law'.

It is important to note that the equivalency relationship may vary from country to country on account of specific local conditions. Deviations from the fourth power law would significantly modify the vehicle damage factors. (This has been explained in Chapter 3 with a relevant case study.) Therefore, the vehicle damage factors used in any analysis should reflect as far as possible the ground conditions in the related country.

It is well recognised that the use of improved vehicle technology offers great potential for reducing pavement costs related to heavy vehicle use. This brings out the need for research in various aspects of interaction between vehicle design and road surface, an area that has so far been neglected. It is well known that Indian trucks are a product of an outdated technology – two-axle rigid trucks fitted with steel leaf-spring suspension.

The key issue is the interface between regulatory stability and technological change. It is often the case in India, not just in trucking but in a swathe of other areas as well, that standards have a tendency to be set in stone. The result is a sort of technological freeze. Recent trends in vehicle technology underscore the need for legislation aimed at promoting the road-friendliness of heavy vehicles.

An environment has to be created where the industry begins to look for technological solutions to enhance overall transport capacity and productivity. These include provision of road-friendly suspension systems, multi-axles, power steering, improved tyres, etc. Technological upgradation would help not only to increase the payload of the vehicles but would also reduce the stress on the road surface. This would, in turn, enhance private gain while promoting public good.

A set of incentives is also needed to encourage manufacture of vehicles with more axles and road-friendly fitments. These incentives would basically be in terms of pricing and specific tax differentials both at the manufacturing and operational stages. Vehicles fitted with air suspensions should be given duty exemptions as an incentive to the operators. Differential charges can be set for vehicles with more axles that cause less road damage.

With the object of finding out the optimal axle weight at which the total transport costs (road user costs plus the road agency costs of maintenance and rehabilitation) are minimised, we have studied the life-cycle costing of pavement performance under varying axle loads over a 15-year period. The analysis has been carried out for two sample road sections (one a national highway and the other a state highway) under prevailing operational conditions with regard to road surface, traffic levels and their composition. The exercise has brought out the following broad conclusions:

(i) The total transport costs are minimised at an axle load of 11 tonnes, as against the prescribed limit of 10.2 tonnes in the case of sample road sections both from the national and state highways.

(ii) Higher dynamic loads cause higher rates of pavement deterioration. For example, increase in axle load from 10 to 13 tonnes for a two-axle truck plying on Sirhind-Morinda-Ropar stretch results in a two-fold increase in the vehicle damage factor (VDF). In the case of a multi-axle truck, the increase in VDF is much less for the same volume of traffic.

(iii) Reduced rates of pavement deterioration lead to significant reductions in total costs, arising mainly from vehicle operating costs, while increased rates of deterioration lead to significantly increased costs, arising from the same source.

(iv) There is no benefit in total costs in allowing the network to deteriorate beyond a value of 6 in the international roughness index (IRI) or an overall pavement distress level of 25 percent of the damaged area.

(v) The BAU (business-as-usual) scenario, meaning rampant overloading of commercial vehicles, results in the maximum increase in total costs in the considered axle load spectrum.

(vi) The pavement performance life is shortened by as much as 40 percent in the case of BAU scenario in comparison with the operational life available at an axle load of 10 tonnes

The road network presently suffers from a host of deficiencies in terms of capacity, pavement thickness, distressed bridges, etc. Most of the national highways are single or two-lane except for those being upgraded under the NHDP (National Highway Development Project). About 28 percent of state highways are two-lane while the rest are single or intermediate lane.

Approximately 80-90 percent of the national and state highways are suitable for a standard axle load of 8.16 tonnes and are not structurally adequate for the permissible axle loads of 10.2 tonnes. Over 50 percent of the national and state highways and a still higher percentage of other roads are in bad condition.

Massive investments are needed to strengthen the network for the currently prescribed axle loads. It is, therefore, premature to revise upwards the axle load limit for commercial vehicles. Under the circumstances, effort should be made to legislate for road-friendly vehicles which can carry higher loads with minimum distress to road pavement. It may be mentioned that the additional investments required for an axle load of 11 tonnes would be only marginal once these highways are upgraded and strengthened to withstand the currently prescribed axle load limits.

In view of the excessive overloading of vehicles, the latest guidelines of the Indian Roads Congress provide for designing of roads on the basis of prevailing axle-load spectrums. This is leading to non-uniformity in road design because different road sections would show different axle-load spectrums resulting in different vehicle damage factors. There is need to bring in uniformity in design of pavements across the road network.

Overloading of vehicles beyond permissible limits is an offence under the Motor Vehicles Act 1988. The statutory provisions in this regard are set out in Sections 113, 114, 194 and 200 of the Act. The offence is punishable with a minimum fine of Rs.2,000 and an additional amount of Rs.1,000 per tonne of excess load together with the liability to pay charges for off-loading. The offence is, however, compoundable under Section 200 by paying compounding fees as specified by the state governments.

The existing legal provisions fail to provide adequate deterrence to overloading and indeed in some ways offer positive incentives to cheat. The Act does not provide for any punishment for abetment of the offence. It is well known that transport companies and consignors freely abet in the loading of goods vehicles in excess of the prescribed limits. Crucially, language of some of the existing provisions is vague and prone to varying interpretations. Various states have taken advantage of this discrepancy to interpret these provisions in ways that do not maximise social utility.

Schemes like issue of special tokens in some states whereby overloading is permitted on payment of compounding fees legitimise an illegal action on payment of a premium. Pay and offend cannot be the guiding spirit of state policy. The compounding of the offence also does nothing to improve safety on roads since overloading beyond permissible limits constitutes a safety hazard.

There is no reliable data available at the all-India level on the earnings from the special token schemes. However, based on the data furnished by the state governments of Rajasthan and Uttar Pradesh, and assuming that only 20 percent of the trucks availed of special token schemes or were brought to book during the course of checks in the year 2002-03, this works out to an earning potential of Rs.20,500 crore at all India level. The private gain is a multiple of this figure. The indicative numbers are a pointer to the deep malaise in the system.

In the light of the apparent shortcomings, the provisions of the Motor Vehicles Act relating to overloading need to be amended. The proposed amendments with specific formulations in this regard are set out in Chapter 4. In order to ensure the smooth and socially consistent application of the law, it is necessary that the law should not only be simple and enforceable, but it should also adopt the principle of third-party regulation and adjudication.

While imposing fines and offloading of goods are necessary punitive measures, the more long term and permanent solution would require a restructuring of the trucking business and overcoming of the prevailing technological impasse. Overloading could be greatly reduced if there is a movement away from single-truck firms to those owning a minimum fleet of 10-12 trucks because in that case there would be a strong incentive at the firm level to keep all the assets in use rather than overload just a few. The larger firms would also be able to phase out the two-axle goods vehicles at least on the long haul sections.

Enforcement of punitive measures requires an array of weighbridges to weigh the loaded vehicles and adequate godown space for storage of unloaded excess cargo. Presently, the number of weighbridges is not sufficient and godown space is not available for storage of off-loaded excess cargo. The truckers take advantage of this situation, so also the enforcement agencies. Thus, a self-serving nexus has come into existence between the operators and the state agencies

To facilitate enforcement, adequate number of weigh-in-motion (WIM) and static weighing stations need to be set up on the highways. A beginning in this regard should be made on the national highways where the NHAI should set up the required infrastructure and also provide suitable space for removal of excess cargo at the risk and cost of the transport operators. It is also necessary that BOT operators be vested with powers to enforce the provisions of the Motor Vehicles Act.

Chapter 1

Axle Loads and Road Pavement

1. There is a strong correlation between pavement design standards and carrying capacity of the vehicles due to interaction between wheel loads and road surface. It is because of this correlation that countries prescribe maximum permissible gross vehicle weight and maximum allowable axle loads. While such norms have been laid down in India also, it is a rare trucker who adheres to these norms. Here, carrying one-and-a-half times the permissible load is commonplace and, sometimes, some dare devils even carry twice the permissible load. The container revolution has further added to the problem because large containers are often moved on two-axle trucks, regardless of the load.

2. This situation results in several negative externalities, but the chief one is the huge damage to the road network, of which only 10-20 per cent is suitable even for the existing prescribed axle loads. In other words, it is overloading which causes damage to as much as 80 per cent of the network. There is also the threat to traffic safety, not to mention the operative life of the vehicles, which gets sharply reduced.

3. Overloading takes place because of two reasons: it is profitable to overload and there is hardly anyone to effectively prevent the truckers from overloading. The first is an economic-cum-technological problem. The second is a legal-cum-enforcement problem. Clearly, if overloading is to be tackled, both these problems will have to be addressed. The discussion that follows deals with the technological issues. The next chapter (Chapter 2) addresses the legal aspects and the measures required to facilitate enforcement.

4. The gross vehicle weight (GVW) and maximum safe axle weight of different types of vehicles are notified by the central government under Section 58 of the MV Act. In exercise of these powers, Government of India laid down in the early 1950s that maximum safe laden weight and safe axle weight of each axle of the vehicle shall be as per the rating fixed by the manufacturers. In 1959, the Ministry of Road Transport and Highways (erstwhile Ministry of Surface Transport) permitted an *ad hoc* increase of 25 per cent over the axle weight and gross vehicle weight of commercial vehicles certified by the vehicle manufacturers. Many of the trucks plying on the roads then had a certified GVW of about 10 tonnes.

5. At that point of time, an axle load of 18,000 lb or 8.16 tonnes was the accepted norm for design of roads. Even with ad hoc overload of 25 per cent, GVW of the commercial vehicles worked out to 12.5 tonnes and on a two-axle vehicle, rear-axle load came to around 8 tonnes, a situation still within the permitted road design standards. Subsequently, as the economy grew, vehicles of higher capacity began to be manufactured and this led to a demand for further increase in the axle load limits. The situation became chaotic when the individual state governments started prescribing axle load limits on their own, taking into account the vehicle weights certified by the vehicle manufacturers.

6. In 1982, the Government of India set up a Committee to deal with the whole question of axle load policy for commercial vehicles in the country. The Committee recommended that the maximum allowable axle load and GVW of vehicles should be uniform throughout the country and that while fixing the maximum allowable limits, the 25% overload permitted should be taken into account. Further, the road design parameters should be based on the maximum allowable axle loads so as to restore the much-desired consonance between the vehicles plying and the road pavement strength.

7. In 1983, based on the recommendations of the Committee, the maximum allowable axle loads were notified. These were reconfirmed in 1996 and continue to be valid till date. A copy of the notification is given as Annexure 1.1. The notification allows for three, mutually exclusive options. The choice is between: (i) the manufacturer's rating of GVW and axle weight respectively for each make and model; (ii) maximum GVW and safe axle weight of each vehicle, as specified for the relevant category; and (iii) the maximum load permitted to be carried by the tyres as specified in Rule 95 of the Central Motor Vehicles Rules, 1989.

8. It may be mentioned that Rule 95 of the Central Motor Vehicles Rules, 1989 lays down the size, ply rating and maximum weight permitted to carry on single or dual configuration of tyres. The maximum weights are in accordance with the Indian standard IS: 10914 of 1988, and for the maximum cold inflation pressures indicated therein and have been adjusted for the speed limit stipulated in the notification under Section 112 of the Motor Vehicles Act. Further, these weights are applicable subject to the condition that the axle loads do not exceed 6 percent of the permitted limits.

9. The moving vehicles transmit wheel loads to roads and bridges much higher than the prescribed axle loads. This is as a result of a variety of static and dynamic forces generated in the course of the movement of vehicles. The static component depends on the total prescribed weight of the vehicle and its axle configuration. The

dynamic component depends on the vertical dynamics of the vehicle, including factors such as suspension and tyres, the road surface's longitudinal profile and the speed of the vehicle. As a result, vertical vibrations vary above and below their static values.

10. There are several basic vehicle wheel and axle arrangements: single wheel, dual wheel, single axle, tandem axle and tridem axle. Their number and configuration greatly influence the dynamic loads transmitted to the road surface. It is for this reason that multiple axles can carry much greater payloads for given strength of road pavement. The wheel tyres are equally crucial in controlling the stress on the pavement.

11. The tyre acts through its pneumatic and mechanical properties to envelop and absorb small disturbances, spread the wheel load over an acceptable area of the pavement surface and provide vertical springing. Its performance, vis-à-vis both the vehicle and the pavement, is highly dependent on the inflation pressure and the wheel load. The tyre load and the distribution of compressive stress in the "contact patch" or "footprint" are important indicators of tyre response and of potential pavement response. Tyre performance depends critically on the selected size and inflation pressure in relation to the load carried.

12. Over the years, bias-ply tyres have been replaced with radial tyres and inflation pressures have also increased. Higher pressure reduces the size of this footprint since the weight of the wheel is distributed over a smaller area. The increased pressure hastens the wear of the road surface. Other things being equal, single tyres have more adverse effects on pavement than dual tyres since they have a larger total contact patch and apply lower compressive stresses than wide single tyres.

Box 1: Maximum Allowable Axle Load Limits in India

1950	As per rating of safe axle weight of each axle fixed by the vehicle manufacturer. Most of the trucks had a GVW of about 10 tonnes (Rear axle load of 6.5 tonnes).						
1959	1.25 times the axle weight and GVW of commercial vehicles certified by the vehicle manufacturer. Most trucks had certified GVW of 10 tonnes. As such, the allowable limit became 12.5 tonnes (Rear axle load of 8 tonnes).						
1983	Front Axle :	Single Axle	–	one tyre	–	3 tonnes	
		Single Axle	–	two tyres	–	6 tonnes	
	Rear Axle :	Single Axle	–	two tyres	–	6 tonnes	
		Single Axle	–	four tyres	–	10.2 tonnes	
		Tandem Axle	–	eight tyres	–	19 tonnes	
		Triple Axle	–	twelve tyres	–	24 tonnes	

Note: Limits notified in 1983 were reconfirmed in 1996 and are presently in force.

13. As would be observed from Box 1, in India, the maximum allowable axle weight is 6 tonnes for single axle with single tyres, 10.2 tonnes for single axle with twin-mounted tyres, and 19 tonnes for tandem axles. This is irrespective of whether it is driven or non-driven or steered axle. Restrictions on the front axle load apply primarily because the vehicle has to meet the requirements of steering torque. Here, the freight carrying vehicles are provided with only manual steering. This arrangement entails a lot of effort on the part of the driver to steer the vehicle, particularly on curves and bends. There is also the problem of loss of control of the vehicle in case of blow-out of an overloaded steering axle tyre.

14. In the United States, gross weight limits and axle load limits are the primary mechanisms at both the federal and state levels for limiting pavement wear by different vehicles. Federal gross weight and axle load limits apply on the interstate system. In Australia, the weight of vehicles is controlled through limits on axle masses, gross mass and manufacturers' ratings. Mass limits vary with axle configuration. Limits are set to take account of the relative road wear of single, tandem and tri-axles with different tyre configurations.

15. In Europe, a Directive of the Council for the European Union (96/53) harmonises gross weight and axle load limits among EU member states, as well as the dimensions of vehicles used for goods transport. These limits balance advantages for vehicle operation against the resulting needs of road maintenance, effects on road safety, and protection of the environment. Nevertheless, the Directive does not cover vehicles transporting goods within each member state. For example, France, Belgium and Spain have maintained their weight limit for the single drive axle at a level much higher than the European limit. The Directive referred to above is given in Annexure 1.2.

16. It is worth noting that European standards differentiate between a driven and a non-driven axle. This is a significant difference, because the permissible axle load is 11.5 tonnes for single-driven axle and 10 tonnes for single non-driven axle, irrespective of the number of tyres, as against 10.2 tonnes for single axle with twin-mounted tyres. Similarly, in case of single non-driven axle with single mounted tyre, the European standards permit an axle load of 10 tonnes whereas the Indian standards permit an axle load of 6 tonnes only for the non-driven axle.

17. The suspension system of a vehicle isolates the body of the vehicle from unevenness in the road surface. It, therefore, reduces aspects of dynamic wheel loading on the road surface. Majority of trucks in India are fitted with steel leaf-spring

suspensions, which produce lower damping of dynamic loads. In comparison, use of air spring suspensions enhances the road-friendliness of the vehicle. In addition, this type of suspension improves stability, braking and tracking of the vehicle. It also distributes loads more evenly between axles and reduces the environmental impacts related to noise and vibration.

18. Research in OECD (Organisation for Economic Cooperation and Development) countries has revealed that road damage can be reduced by 20 percent through the use of well-designed air spring suspensions in place of leaf-spring suspensions on trucks. Recognising the beneficial effects of improved suspension systems, the European Community permits 1 tonne extra load per axle if the axle is fitted with pneumatic or equivalent suspension. Unfortunately, no such provision has been made in the Indian standards. The most direct policy option would be to reduce dynamic loads on road infrastructure by introducing a regulatory requirement for road-friendly suspensions.

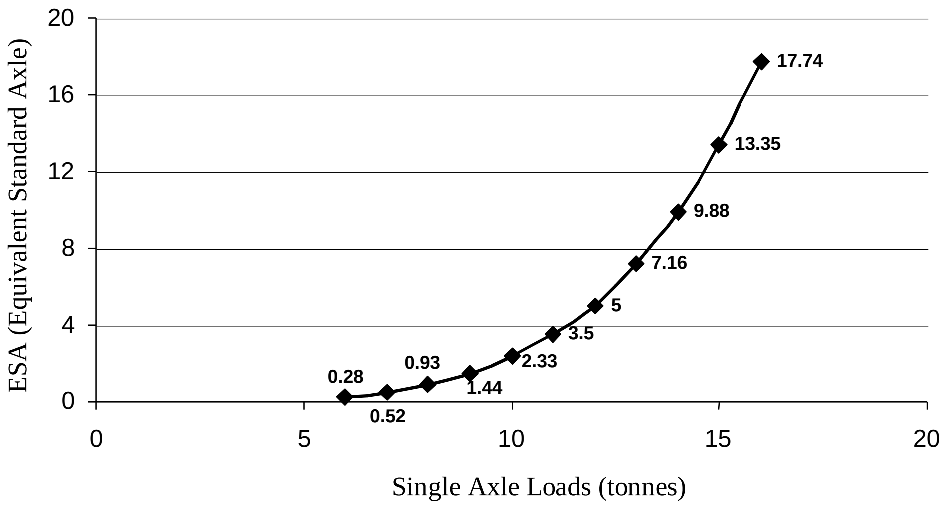
19. To take account of the magnitude and type of loads that a road will be subjected to during its design life, many attempts have been made to establish equivalency relationships between pavement performance and the magnitude of the axle load. A significant experiment in this regard was the Road Test conducted in the 1950s by the American Association of State Highway Officials (AASHO). The principal objective of the AASHO Road Test research was to establish relationships between performance, structural design (i.e., component thicknesses of the pavement structure) and loading (i.e., the magnitude and rate of application of axle loads). The original axle load equivalency concept developed from the AASHO Road Test was expressed in the form of a "power law". Because a power of 4 was obtained from an analysis of the AASHO Road Test data, the law became known as the "fourth power law".

20. Load equivalency factors measure the relative effects of different types of loadings on pavements. Pavement engineers generally use the concept of an equivalent single-axle load (ESAL) to measure the effects of axle loads on pavement. By convention, an 18,000-pound single axle is 1.00 ESAL. The ESAL values for other axles express their effect on pavement wear relative to the 18,000-pound single axle. For example, on a flexible pavement, the load-equivalence factor for a 20,000-pound single axle is about 1.5 because $(20/18)^4$ is approximately equal to 1.5. Thus, 100 passes across a pavement by a 20,000-pound axle would have the same effect on pavement life as 150 passes by an 18,000-pound axle. Equivalency factors for different axle loads are given in Annexure 1.3.

21. There are different sets of ESAL values for flexible and rigid pavements. The principal difference between these values is that tandem axles are found to have a greater effect on rigid pavements. Although ESALs increase sharply with vehicle weight, it is true that, other things being equal, a vehicle with more axles has less damaging effect on pavements. Thus, a three-axle combination with higher payload will have less adverse effect on pavements than a rigid two-axle combination.

22. The effect of a given vehicle on pavements can be estimated by calculating the number of ESALs for each axle and summing to get total ESALs for the vehicle. Based on the formula described in Annexure 1.4, equivalent standard axle factors have been computed for single axle loads – 18000 lb – and are graphically shown in Figure 1.

Figure 1: Relation between ESA and Axle Loads



23. As mentioned earlier, the relation between ESA and axle loads approximates to fourth power law. In simple terms, ESA is equal to $\left(\frac{Lj}{8.16}\right)^4$ where L_j denotes single axle load of the vehicle moving.

24. It will be seen from the above figure that the damaging power of an axle with 10 per cent overload is 1.5, with 30 per cent overload, it becomes 3.0 and with 50 per cent overload it rises to 5.0. In other words, a pavement that can last for 10 years without overloading will last for only 3.5 years with 30 per cent overload and for only 2 years with 50 per cent overload. As the overload increases, there is a sharp decline in the life of the pavement.

25. However, a comparison of vehicles in terms of ESALs would not take into account the fact that vehicles with higher weights require fewer trips to transport the same amount of freight, thereby offsetting part of the additional pavement wear caused by increased weight. To circumvent this problem, vehicles can be compared in terms of ESALs per unit of freight carried.

26. Even though static loads may be constant over the life of a pavement, in practice, the loads increase due to the effect of increasing pavement roughness on vehicle dynamics. Pavement design methods need to take account of this. Existing mechanistic pavement design methods use static wheel loads, which are assumed to be constant over the life of the pavement; dynamic wheel loads are considered only implicitly.

27. It is important, in this context, to appreciate that the fourth power law for calculating road damage, before being applied, should be critically evaluated. One of the elements of this evaluation should be technological change in vehicle manufacture. It is also important to note that the law may not apply universally because it is based on an averaging principle. However, the standard deviation from the mean value can become critical in Indian conditions. These deviations could have significant implications for the vehicle damage factors derived from the AASHO Road Test.

28. Therefore, while estimating the total transport costs, which include the vehicle operating costs and the road agency costs, the vehicle damage factors used in the analysis should reflect as far as possible the ground conditions in the country. It is well recognised that the use of improved vehicle technology offers great potential for reducing pavement costs related to heavy vehicle use. This brings out the need for research in various aspects of interaction between vehicle design and road surface, an area that has so far been neglected. Such research would require a multi-disciplinary approach embedded in devising economic and efficient solutions to the problems relating to road vehicles and pavement design.

29. Few people who have driven on Indian highways could have missed noticing the low level of technology used in the manufacture of Indian trucks. The fact is that Indian trucks use the technology of the late 1940s or that of the early 1950s. Whereas the rest of the world has moved ahead, the Indian trucking industry has lagged woefully behind. The body building industry is totally unorganised and does not come under any regulatory control. There is no uniformity in design features which vary

from state to state. Worst of all, about 90 percent of the trucks in India are two-axle rigid trucks where overloading is a common phenomenon.

30. The trucking industry here is characterized by extreme concentration in the truck manufacturer space and extreme fragmentation in the body-building space. As far as the supply side is concerned, it may be pointed out that the initial 40-odd years of industrial licensing played a major role in this area. Licensing created an insurmountable entry barrier, thus creating a virtual monopoly for the incumbent firm. It had no incentive to innovate, except by way of tinkering with axle-loads. Thanks to the size of the country, the two licensed producers quickly – if informally – divided among them the country into two zones. As such, there has hardly been any change in the situation.

31. The foregoing discussion suggests that if there is to be meaningful technology upgradation in the trucking industry, two pre-conditions will have to be met. First, the existing duopoly/oligopoly will have to give way to a more competitive industry in which there are at least half a dozen producers of trucks. Second, on the demand side, the cost structure of the industry will have to change in such a way that trucking firms begin to look for technological solutions for increasing their profitability. Of course, the significance of the role of the state in laying down proper standards also cannot be overemphasised.

32. Therefore, the key issue is the interface between regulatory stability and technological change. It is often the case in India, not just in trucking but in a swathe of other areas as well, that standards have a tendency to be set in stone. The result is a sort of technological freeze. Recent trends in vehicle technology underscore the need for legislation aimed at promoting the road-friendliness of heavy vehicles. An environment has therefore to be created where the industry begins to look for technological solutions to enhance overall transport capacity and productivity. These include provision of road-friendly suspension systems, multi-axles, power steering, improved tyres, etc. Such a step would help to increase not only the payload of the vehicles but would also reduce the stress on the road surface. This would, in turn, improve private gain while maintaining public good.

33. A set of incentives is also needed to encourage vehicles to use more axles and road friendly fitments. These incentives would basically be in terms of pricing and specific tax differentials both at the manufacturing and operational stages. For example, at the manufacturing stage, two-axle trucks should attract higher duties as

compared to three-axle trucks. Similarly, vehicles fitted with air suspensions should be given duty exemptions as an incentive to the operators. At the operational stage, the use of pricing differentials could be extended to the levy of toll charges/user fees. Differential charges can be set for vehicles with more axles that cause less road damage.

Annexure 1.1

THE GAZETTE OF INDIA: EXTRAORDINARY
[Part II – Sec.3(ii)]

MINISTRY OF SURFACE TRANSPORT
(TRANSPORT WING)
NOTIFICATION
New Delhi, the 18th October, 1996

S.O. 728(E) – In exercise of the powers conferred by sub-section (1) of section 58 of the Motor Vehicles Act, 1988 (59 of 1988), and in supersession of the notification of the Government of India in the Ministry of Surface Transport, No. S.O. 479(E), dated the 4th July, 1996, the Central Government hereby specifies that in relation to the transport vehicles (other than motor cabs) of various categories detailed in the Schedule below, the maximum gross vehicle weight and the maximum safe axle weight of each axle of such vehicles shall, having regard to the size, nature and number of tyres and maximum weight permitted to be carried by the tyres as per rule 95 of the Central Motor Vehicles Rules, 1989, be –

(i) vehicle manufacturers rating of the gross vehicle weight and axle weight respectively for each make and model as duly certified by the testing agencies for compliance of rule 126 of the Central Motor Vehicles Rules, 1989, or

(ii) the maximum gross vehicle weight and the maximum safe axle weight of each vehicle respectively as specified in the Schedule below for the relevant category, or

(iii) the maximum load permitted to be carried by the tyre(s) as specified in the rule 95 of the Central Motor Vehicles Rules, 1989, for the size and number of the tyres fitted on the axle(s) of the relevant make and model, whichever is less:

Provided that the maximum gross vehicle weight in respect of all such transport vehicles, including multi-axle vehicles shall not be more than the sum total of all the maximum safe axle weight put together subject to the restrictions, if any, on the maximum gross vehicle weight given in the said Schedule:-

SCHEDULE

	Transport Vehicles Category	Max GVW Tonnes	Maximum Safe Axle Weight
I.	**Rigid Vehicles** (i) Two Axle One tyre on front axle Two tyres on rear axle	 9.00	 3 tonnes on Front Axle 6 tonnes on Rear Axle
	(ii) Two Axle Two tyres on each axle	12.0	6 tonnes on Front Axle 6 tonnes on Rear Axle
	(iii) Two Axle Two tyres on front axle and four tyres on rear axle	16.2	 6 tonnes on Front Axle 10.2 tonnes on Rear Axle
	(iv) Three Axle Two tyres on front axle and Eight tyres on rear tandem axle	25.0	 6 tonnes on Front Axle 19 tonnes on rear tandem axle
II.	**Semi Articulated Vehicles** (i) Two Axle Tractor Single Axle Trailer Tractor: 2 tyres on front axle 4 tyres on rear axle Trailer: 4 tyres on single axle	26.4	 6 tonnes on Front Axle 10.2 tonnes on Rear Axle 10.2 tonnes on single trailer axle
	(ii) Two Axle Tractor Tandem Axle Trailer Tractor: 2 tyres on front axle 4 tyres on rear axle Trailer: 8 tyres on tandem axle	35.2	 6 tonnes on Front Axle 10.2 tonnes on Rear Axle 19 tonnes on tandem axle
	(iii) Two Axle Tractor Three Axle Trailer Tractor: 2 tyres on front axle 4 tyres on rear axle Trailer: 12 tyres on 3 axle	40.2	 6 tonnes on Front Axle 10.2 tonnes on Rear Axle 24 tonnes on 3 axle
	(iv) Three Axle Tractor Single Axle Trailer Tractor: 2 tyres on front axle 8 tyres on tandem axle Trailer: 8 tyres on single axle	35.2	 6 tonnes on Front Axle 19 tonnes on Rear Axle 10.2 tonnes on single axle
	(v) Three Axle Tractor Tandem Axle Trailer Tractor: 2 tyres on front axle 8 tyres on tandem axle Trailer: 8 tyres on tandem axle	44.0	 6 tonnes on Front Axle 19 tonnes on Rear Tandem Axle 19 tonnes on tandem axle

III.	**Truck Trailer Combinations** (i) Two Axle Truck Two Axle Trailer Truck: 2 tyres on front axle 4 tyres on rear axle Trailer: 4 tyres on front axle 4 tyres on rear axle	36.6	 6 tonnes on Front Axle 10.2 tonnes on Rear Axle 10.2 tonnes on Front Axle 10.2 tonnes on Rear Axle
	(ii) Three Axle Truck Two Axle Trailer Truck: 2 tyres on front axle 8 tyres on rear tandem axle Trailer: 4 tyres on front axle 4 tyres on rear axle	45.4 (restricted to 44.0 tonnes)	 6 tonnes on Front Axle 19 tonnes on Rear Tandem Axle 10.2 tonnes on Front Axle 10.2 tonnes on Rear Axle
	(iii) Two Axle Truck Three Axle Trailer Truck: 2 tyres on front axle 4 tyres on rear axle Trailer: 4 tyres on front axle 8 tyres on rear tandem axle	45.4 (restricted to 44.0 tonnes)	 6 tonnes on Front Axle 10.2 tonnes on Rear Axle 10.2 tonnes on Front Axle 19.0 tonnes on Rear Tandem Axle
	(iv) Three Axle Truck Three Axle Trailer Truck: 2 tyres on front axle 8 tyres on rear tandem axle Trailer: 4 tyres on front axle 8 tyres on rear tandem axle	54.2 (restricted to 44.0 tonnes)	 6 tonnes on Front Axle 19 tonnes on Rear Tandem Axle 10.2 tonnes on Front Axle 19.0 tonnes on Rear Tandem Axle

[F. No. RT-11021/11/95-MVL]
K. R. BHATI, Jt. Secry

Annexure 1.2

Permissible Maximum Weights in Select European Countries

(in tonnes)

Country	Weight per bearing axle	Weight per drive axle	Lorry 2 axles	Lorry 3 axles	Road train 4 axles	Road train 5 axles and more	Articulated vehicle 5 axles and more
Austria	10	11.5	18	25(1)	36	38(2)	38(2)
Belgium	10	12	18	26	39	44	44
Bulgaria	10	10/11.5(3)	16	26	36	40	40
Czech Republic	10	11.5	18	25/26	36	42	42
Denmark(4)	10	10/11.5	18/19	24/26	38	44/40	40/48
Finland(5)	10	11.5	18	26	36	40	40
France	13	13	18	26	38	40	40
Germany	10	11.5	18	26	36	40	40
Greece	10	11.5	18	26	36	40	40
Hungary	10	11	20	24	36	40	40
Ireland	10	10.5	17	26	35	40	40(6)
Italy	12	12	18	26	40	44	44
Netherlands	10	11.5	21.5	33	40	50	50
Norway (8)	10	11.5		26	-	50	47
Spain(10)	10	11.5	18	26	36	40	40
Sweden(11)	10	11.5	18	26	-	50	60
Switzerland	10	11.5	18	25(12)	34	34	34
United Kingdom(13)	10	11.5	18	26	36	40	40

(1) 26 tonnes is only allowed if the drive axle is equipped with air suspension; otherwise the weight limit is 25 tonnes.
(2) 38 tonnes generally for transport of goods by road; this weight limit is increased by 5% for vehicles registered within the EU (i.e. 40t for transport of goods by road in general). The limit value indicated for vehicles registered in a EU state is also valid for vehicles registered in countries which have a transport agreement with the EU and where full reciprocity is granted.
(3) 11.5 tonnes for certain road sections described in Annex 5 of the Transit agreement between EU and Bulgaria.
(4) National/international
(5) Road train: 5 axles = 44 tonnes; 6 axles = 53 tonnes; 7 axles = 60 tonnes; articulated vehicle: 5 axles = 42 tonnes; 6 axles = 44 tonnes.
(6) Articulated vehicle: weight depends on rear axle spacing (>8m:48 tonnes)
(7) Lorry 4 axles: 321
(8) Axle load for the main network (BK 10); weight depends on total wheelbase.
(9) Road train 5 axles and articulated vehicles 5 axles carrying ISO container 40 ft = 44 tonnes.
(10) 3 axles with ISO container 40 ft = 44 tonnes.
(11) Weight of road trains: depends on total wheel base, 60 tonnes on primary roads (BK1), 51.4 tonnes on secondary roads (BK2).
(12) 26 tonnes when drive axle is equipped with double tyres and pneumatic suspension or equivalent, or when each drive axle is equipped with double tyres and maximum weight of each drive axle does not exceed 9.5 tonnes.
(13) For 6 axles (3+3) or > 44 tonnes road trains and articulated vehicles with an engine conforming to EURO2 standards.

Annexure 1.3

Equivalence Factors and Damaging Power of Different Axle Loads

Gross axle weight kg.	Load equivalency factors	
	Single axle	Tandem axle
900	0.0002	0.0000
1810	0.002	0.0002
2720	0.009	0.001
3630	0.031	0.003
4540	0.08	0.006
5440	0.176	0.013
6350	0.35	0.024
7260	0.61	0.043
8160	1.00	0.070
9070	1.55	0.110
9980	2.30	0.166
10890	3.27	0.242
11790	4.48	0.342
12700	5.98	0.470
13610	7.80	0.633
14520	10.00	0.834
15420	12.50	1.08
16320	15.50	1.38
17230	19.00	1.73
18140	23.00	2.14
19051	27.70	2.61
19958	33.00	3.16
20865	39.30	3.79
21772	46.50	4.49
22680	55.00	5.28
23587	-	6.17
24494	-	7.15
25401	-	8.20
26308	-	9.40
27216	-	10.70
28123	-	12.10
29030	-	13.70
29937	-	15.40
30844	-	17.20
31752	-	19.20
32660	-	21.30
33566	-	23.60
34473	-	26.10
35380	-	28.80
36288	-	31.70

In case the class mark of the axle load survey does not match with above axle loads, 4^{th} power law may be used for converting axle loads into equivalent standard axle loads using the following formula:

Single axle load	*Tandem axle load*
Equivalency factor = $(\text{axle load in kg}/8160)^4$	Equivalency factor = $(\text{axle load in kg}/14968)^4$

The above equations also give reasonably correct results for practical values of axle loads.

Annexure 1.4

Formula for Calculating Damage to Pavement

The damage caused to the pavement is calculated as shown below:

$$F_j = \frac{N_{f18}}{N_{fj}} = \left[\frac{(L_1 + L_2)^a}{(18 + \frac{1}{\ell})^a}\right] - \left[\frac{10^{G/\beta}}{10^{G/\beta} L_2^b}\right]$$

$$G = \beta(\mathrm{Log}W_t - \mathrm{Log}\ell)$$

$$\beta = 0.40 + \frac{0.081(L_1 + L_2)^{3.23}}{(\overline{SN}+1)^{5.19} L_2^{3.23}}$$

$$\mathrm{Log}\ell = 5.93 + 9.36\ \mathrm{Log}(\overline{SN}+1) - 4.79\ \mathrm{Log}(L_1 + L_2) + 4.33\mathrm{Log}\ L_2$$

N_{f18} = Number of repetitions to failure of the 18 kip (8.16 tonnes) standard single axle load

N_{fj} = Number of repetitions to failure of the j^{th} vehicle

a = 4.79

b = 4.33

L_1 = 18

L_2 = 1 if single axle

= 2 if tandem axle

G = a function of the ratio of loss in serviceability at time *t* to the potential loss taken to a point where $p_t = 1.5$

β = a function of design and load variables that influence the shape of the *p* versus *w* serviceability curve.

ℓ = a function of design and load variables that denotes the expected number of axle load applications to a point where $P_t = 1.5$

W_t = Axle load applications at the end of time *t*

P_t = Serviceability at end of time *t*

$\overline{SN}$ = Structural number of pavement

For design of strengthening overlay on existing roads, the design traffic is considered in terms of the cumulative number of standard axles to be carried during the design life of the road. Its computation involves estimates of the initial volume of commercial vehicles per day, lateral distribution of traffic, the growth rate, the design life in years and the vehicle damage factor (number of standard axle per commercial vehicle) to convert commercial vehicles to standard axles.

The following equation may be used to make the required calculation.

$$N_s = \frac{365 x A [(1+r)^x - 1]}{r} x F$$

where,

N_s = The cumulative number of standard axles to be catered for in the design.

A = Initial traffic, in the year of completion of construction, in terms of the number of commercial vehicles per day duly modified to account for lane distribution.

r = Annual growth rate of commercial vehicles

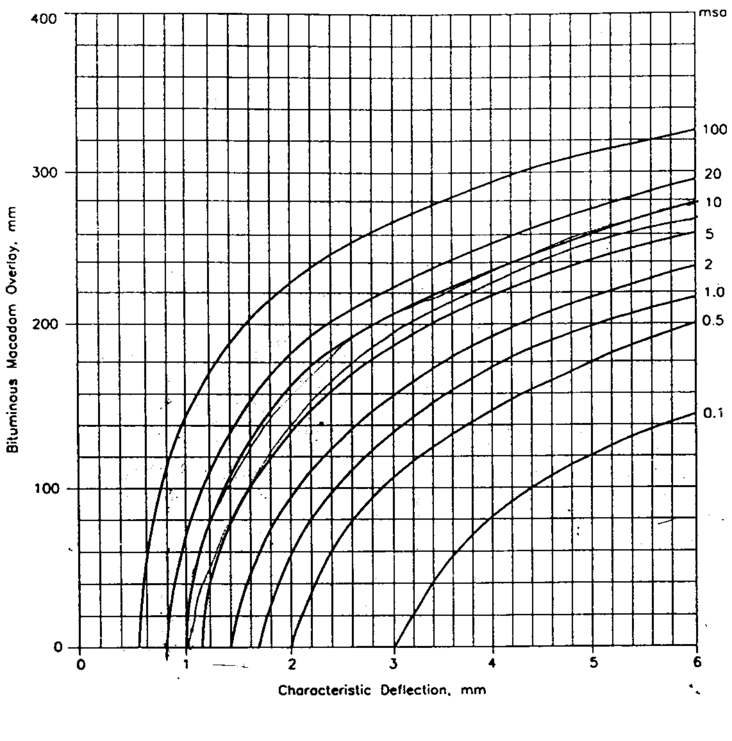
x = Design life in years

F = Vehicle damage factor (number of standard axles per commercial vehicle)

The vehicle damage factor (VDF) is a multiplier for converting the number of commercial vehicles of different axle loads to the number of standard axle-load repetitions. The vehicle damage factor is arrived at from axle-load surveys on typical road sections so as to cover various influencing factors such as traffic mix, type of transportation, type of commodities carries, time of the year, terrain, road condition and degree of enforcement.

The design curves relating characteristic pavement deflection to the cumulative number of standard axles to be carried over the design life is given in the figure below.

Overlay Thickness Design Curves



Chapter 2

Total Transport Costs – Optimum Axle Load

1. In this chapter, we examine the life-cycle costing of pavement performance under varying axle loads based on total costs (road user costs plus the road agency costs of maintenance and rehabilitation) in a net present value analysis over a 15-year period. The purpose of the study is to obtain the optimal axle weight at which the total costs are minimised. The analysis has been carried out for two sample road sections under prevailing operational conditions with regard to road surface, traffic levels and their composition. The Highway Development and Management (HDM-4) software has been used for this purpose.

2. The road agency costs relate to maintenance and rehabilitation requirements of pavement under varying time horizons. The types of maintenance interventions include semi-dense bituminous concrete, bituminous concrete and different combinations with bituminous macadam and dense bituminous macadam of varying thicknesses. The strengthening of pavement overlays has been considered for different widths of carriageway, characteristic deflection of the flexible pavement, levels of traffic per day in terms of commercial vehicles and vehicle damage factors for the related axle load spectrum. The maintenance strategy is based on the premise that funds are not a constraint.

3. The basic unit of analysis is a homogeneous road section classified on the basis of characteristic deflection of the pavement reflecting structural strength. In order to calibrate the HDM-4 model, field data on the effect of traffic and environment on pavement deterioration depicted by surface distress and pavement strength has been taken from the completed projects. The calibration factors relate to deterioration pattern available from models developed for Indian conditions. The sample road sections are the Sirhind-Morinda-Ropar section (46 km) and Agra-Bharatpur-Jaipur section (21.5 km). The former is a part of state highway and the latter a part of national highway.

4. To carry out the analysis, data was obtained for the sample road sections on such parameters as formation and carriageway width; details of cross-sections; composition, history of development, roughness, distresses and deflection of pavement; traffic composition; axle load spectrum of commercial vehicles (used for determining vehicle damage factors [VDF]); trend in growth of traffic; and the present

unit costs of various types of specifications used for maintenance and rehabilitation related interventions. The traffic growth rates for the chosen time horizon have been derived from secondary sources and observed past trends.

4. The road user costs relate to vehicle operating costs of commercial vehicles (trucks of two axles or more) and include all the fixed and variable costs. Fixed costs cover overheads, administration charges, interest on borrowed capital, etc. The variable component covers costs of fuel, tyres, lubricant, spares, maintenance, depreciation, and crew. The cost data is based on road user cost study (RUCS) 2001 and technical note developed for Indian conditions by Rodrigo Archandocallao (2003). The traffic composition for commercial vehicles has been considered at different axle loadings for the chosen time horizon using the growth rate and the capping principle. The variation of traffic flows during different periods of twenty-four hours has also been considered. The speed-flow relations have been taken into account by considering free flow, normal, and congested traffic conditions appropriately, as required in HDM-4.

5. A flow chart giving the various sequential steps involved in the analysis is placed at the end of the chapter. This is followed by a detailed technical note. The life-cycle cost analysis brings out the following broad conclusions.

(i) The total transport costs are minimised at an axle load of 11 tonnes, as against the prescribed limit of 10.2 tonnes in the case of sample road sections both from the national and state highways.

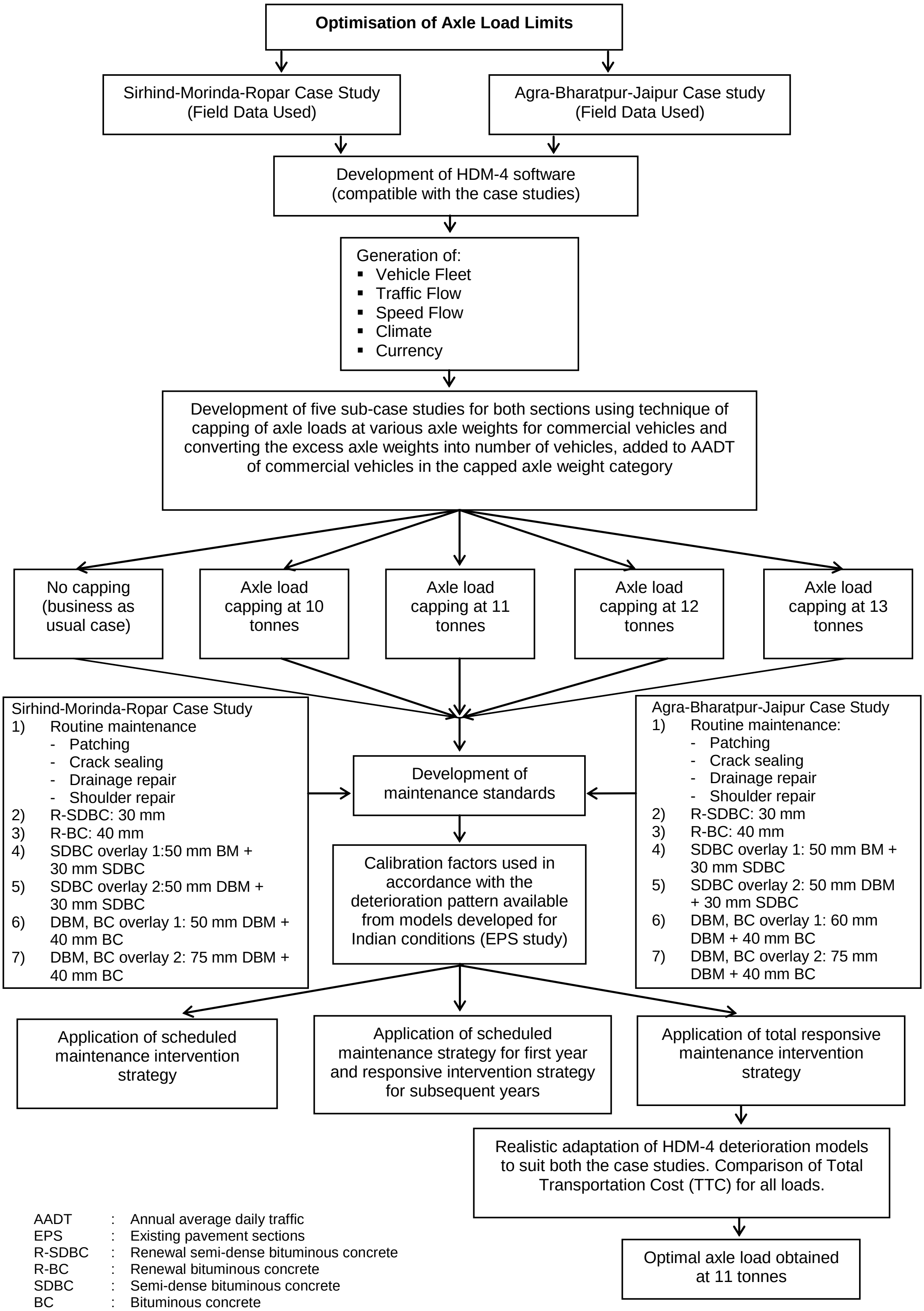
(ii) Higher dynamic loads cause higher rates of pavement deterioration. For example, increase in axle load from 10 to 13 tonnes for a two-axle truck plying on Sirhind-Morinda-Ropar stretch results in a two-fold increase in the vehicle damage factor (VDF). In the case of a multi-axle truck, the increase in VDF is much less for the same volume of traffic.

(iii) Reduced rates of pavement deterioration lead to significant reductions in total costs, arising mainly from vehicle operating costs, while increased rates of deterioration lead to significantly increased costs, arising from the same source.

(iv) There is no benefit in total costs in allowing the network to deteriorate beyond 6 international roughness index (IRI) or an overall pavement distress level of 25 percent of damaged area.

(v) The BAU scenario, meaning rampant overloading of commercial vehicles, results in the maximum increase in total costs in the considered axle load spectrum.

(vi) The pavement performance life is shortened by as much as 40 percent in case of BAU (business as usual) scenario in comparison with the operational life available at an axle load of 10 tonnes.



AADT	:	Annual average daily traffic
EPS	:	Existing pavement sections
R-SDBC	:	Renewal semi-dense bituminous concrete
R-BC	:	Renewal bituminous concrete
SDBC	:	Semi-dense bituminous concrete
BC	:	Bituminous concrete
DBM	:	Dense bituminous macadam
BM	:	Bituminous macadam

Chapter 3

Strengthening of Pavement – Investment Priorities

1. India has an extensive network of roads, ranging from pathways to national highways. This network is an enormous national asset, facilitating commerce, communication, economic growth and social development. Its growth has largely been under scarcity of funds and with an initial thrust on improving connectivity, sometimes even at the cost of productivity. It is, therefore, no wonder that the road network suffers from a host of deficiencies in terms of capacity, pavement thickness, distressed bridges, etc.

2. Most of the national highways are single or two-lane except for those being upgraded under the NHDP (national highway development project). About 28 percent of state highways are two-lane while the rest are single or intermediate lane. Approximately 80-90 percent of the national and state highways are suitable for a standard axle load of 8.16 tonnes and are not structurally adequate for the permissible axle loads of 10.2 tonnes. Over 50 percent of the national and state highways and a still higher percentage of other roads are in bad condition.

3. The road network is already under stress due to heavy incidence of overloading of commercial vehicles. This is borne out by conspicuously high vehicle damage factors (VDF) observed on the highways. The various studies covering *inter alia* axle-load spectrum survey during the years 1991-2000 conducted by the Central Road Research Institute and preparation of road projects on various stretches of highways revealed VDF ranging for the most part between 4 and 8. The details are given in Annexure 3.1.

4. The above vehicle damage factors are based on the AASHTO equivalency factors known as the "fourth power law". However, as mentioned in Chapter 1, the fourth power law may not apply universally since it is likely to be significantly modified by local conditions. In road sections with structural numbers matching those of the sampled roads (Agra-Bharatpur-Jaipur and Sirhind-Morinda-Ropar), the power for calculating the VDF in the standard AASHTO formula actually varies from 4.1 to 4.2, instead of taking a value of 4. These values of the power have been determined for different axle loads by back calculation, given a terminal serviceability value of 2.

To see how derived numbers of equivalent standard axles (ESAL) under actual values of the power are significantly more as compared with the calculation based on the fourth power law, we take the example of a truck with a front axle load of 5.5

tonnes and a rear axle load of 11 tonnes. As the power in the equivalency formula varies from 4.0 to 4.2, the VDF of the vehicle changes from 3.8 to 4.0. On a road with 2500 such trucks increasing at an annual rate of 7.5 percent over a 15-year period, the variation in the power from 4.0 to 4.2 leads to growth in the number of million standard axles (msa) from 90.21 to 94.62. This represents as much as a 5 percent increase and has a modifying influence on the optimum axle load derived.

5. The above shows that road damage is likely to be worse than what is indicated by the derived numbers based on the standard equivalency formula. Notwithstanding this drawback, removal of deficiencies in the road network even under existing norms requires massive investments. An attempt has been made to broadly assess the magnitude of these investments for strengthening the pavement of national and state highways. The total length of national highways is 65,600 km, out of which 24,000 km is being upgraded under various programmes. For the remaining 41,600 km, the matrix of width and traffic in terms of commercial vehicles is broadly as under.

Road width	Length with number of commercial vehicles/day				Total length
	500	1500	3000	5000	
Single-lane	10600 km	10000 km	-	-	20600 km
Two-lane	-	11000 km	6000 km	4000 km	21000 km
Total	10600 km	21000 km	6000 km	4000 km	41600 km

6. Based on the unit costs of overlays per kilometre for different axle loads and lower/upper levels of Benkelman Beam Deflection (BBD) measurements given in the Annexure 3.2, the total investments for a spectrum of axle loads ranging from 10 tonnes to 13 tonnes and business-as-usual work out as under, separately for single-lane pavement and two-lane pavement.

Single-lane Pavement

Rs. crore

Traffic Group	Length	BBD	10^t	11^t	12^t	13^t	BAU
500 CVs/day	10600 km	Lower	-	-	816	816	927
		Upper	927	927	1131	1131	1502
1500 CVs/day	10000 km	Lower	770	770	875	875	1068
		Upper	1417	1472	1627	1627	1627
Total	20600 km	Lower	770	770	1691	1691	1995
		Upper	2344	2399	2758	2758	3129

Two-lane Pavement

Rs. crore

Traffic Group	Length	BBD	10^t	11^t	12^t	13^t	BAU
1500 CVs/day	11000 km	Lower	1694	1694	1925	1925	2348
		Upper	3118	3234	3580	3580	3580
3000 CVs/day	6000 km	Lower	924	924	1050	1281	1428
		Upper	1953	1953	1953	2142	2268
5000 CVs/day	4000 km	Lower	616	854	854	952	1036
		Upper	1302	1428	1512	1512	1540
Total	21000 km	Lower	3234	3472	3829	4158	4812
		Upper	6373	6615	7045	7234	7388

Estimated Total Investment for National Highways

Rs. crore

Road width	Pavement condition (BBD)	10^t	11^t	12^t	13^t	BAU
Single-lane	Lower	770	770	1691	1691	1995
	Upper	2344	2399	2758	2758	3129
Two-lane	Lower	3234	3472	3829	4158	4812
	Upper	6373	6615	7045	7234	7388
Total	Lower	4004	4242	5520	5849	6807
	Upper	8717	9014	9803	9992	10517

7. It will be seen from the above that an investment of Rs.8,717 crore is required for strengthening the national highways for an axle load of 10 tonnes for an upper level of deflection measurement. The amount goes up to Rs.10,517 crore in case of business-as-usual scenario. These estimates are in addition to the funds required for strengthening 24,000 km under various ongoing programmes.

8. The state highways have a total length of 120,000 km, out of which 76,000 km are single-lane, 34,000 km two-lane, and the remaining 10,000 km are covered by various programmes of improvement. For the network, the matrix of width and traffic in terms of commercial vehicles works out broadly as under.

Road width	Length with number of commercial vehicles/day				Total length
	500	1500	3000	5000	
Single-lane	66000 km	10000 km	-	-	76000 km
Two-lane	2000 km	24000 km	6000 km	2000 km	34000 km
Total	68000 km	34000 km	6000 km	2000 km	110000 km

9. On the basis of the unit costs of overlay per km as given in the Annexure 3.3, the investments required for state highways are estimated as under.

(i) *Single-lane Pavement*

Rs. crore

Traffic Group	Length	BBD	10^t	11^t	12^t	13^t	BAU
500 CVs/day	66000 km	Lower	-	-	5082	5082	5775
		Upper	5775	5775	7045	7045	9355
1500 CVs/day	10000 km	Lower	770	770	875	875	1065
		Upper	1415	1470	1625	1625	1625
Total	76000 km	Lower	770	770	5957	5957	6840
		Upper	7190	7245	8670	8670	10980

(ii) *Two-lane Pavement*

Rs. crore

Traffic Group	Length	BBD	10^t	11^t	12^t	13^t	BAU
500 CVs/day	2000 km	Lower	-	-	308	308	350
		Upper	350	350	427	427	567
1500 CVs/day	24000 km	Lower	3696	3696	4200	4200	5124
		Upper	6804	7056	7812	7812	7812
3000 CVs/day	6000 km	Lower	924	924	1050	1281	1428
		Upper	1953	1953	1953	2142	2268
5000 CVs/day	2000 km	Lower	308	427	427	476	518
		Upper	651	714	756	756	777
Total	34000 km	Lower	4928	5047	5985	6265	7420
		Upper	9758	10073	10948	11137	11424

(iii) *Estimated Total Investments Needed for State Highways*

Rs. crore

Road Width	Pavement condition (BBD)	10^t	11^t	12^t	13^t	BAU
Single-lane	Lower	770	770	5957	5957	6840
	Upper	7190	7245	8670	8670	10980
Two-lane	Lower	4928	5047	5985	6265	7420
	Upper	9758	10073	10948	11137	11424
Total	Lower	5698	5817	11942	12222	14260
	Upper	16948	17318	19618	19807	22404

10. It will be seen from the above that an investment of Rs.16,948 crore is required for strengthening the state highways for an axle load of 10 tonnes, given an upper level of deflection measurement. The amount goes up to Rs.22,404 crore under

the business-as-usual scenario. These estimates are in addition to the funds required for strengthening 10,000 km under ongoing programmes.

11. Following conclusions can be drawn from the above analysis.

(i) Heavy investments are required to strengthen the existing NH and SH network for the currently prescribed axle load limits. It is therefore premature to revise upwards the axle load for the commercial vehicles. A view can be taken in the matter at the end of the Tenth Plan, which envisages adequate Plan outlays for upgrading the network.

(ii) Once the pavements are strengthened, the additional investments required for an axle load of 11 tonnes would be only marginal. Meanwhile, effort should be made to legislate for road-friendly vehicles which can carry higher loads with minimum distress to road pavement.

12. As mentioned in Chapter 1, the design of road pavements was all along based on an axle load of 18,000 lbs. (8.164 tonnes). In 1983, the allowable axle load of vehicles was increased to 10.2 tonnes. It was therefore stipulated that the road design parameters should take into account the enhanced axle load. In view of the excessive overloading of vehicles, the Indian Roads Congress latest guidelines provide for designing of roads on the basis of axle-load spectrum observed on the road section in question. This is leading to non-uniformity in road design because different road sections would naturally reveal different axle-load spectrums resulting in different vehicle damage factors. This is not a satisfactory situation and underlines the need to bring in uniformity in design of pavements across the road network.

Annexure 3.1

Vehicle Damage Factors for Different Roads in India

Name of the state	Name of road section/road	Road No.	Location (km)	VDF
A. National Highways				
Haryana	Delhi-Ambala	NH-01	48	4.05
Haryana	Delhi-Amritsar	NH-01	146	4.89
Haryana	Delhi-Palwal	NH-02	52	6.11
Haryana	Delhi-Palwal	NH-02	54	4.56
Uttar Pradesh	Kanpur-Allahabad	NH-02	164	8.30
Uttar Pradesh	Allahabad-Varanasi	NH-02	240	11.90
West Bengal	Burdwan-Durgapur	NH-02	527	6.06
West Bengal	Near Calcutta	NH-02	657	3.95
Uttar Pradesh	Agra-Gwalior	NH-03	14	7.10
Madhya Pradesh	Gwalior-Shivpuri	NH-03	190	11.88
Madhya Pradesh	Indore-Dewas	NH-03	590	3.42
Maharashtra	Nasik-Igatpuri	NH-03	41	4.48
Maharashtra	Dhule-Nasik	NH-03	356	5.16
Maharashtra	Mumbai-Pune	NH-04	38	1.57
Karnataka	Pune-Bangalore (Chattradurga)	NH-04	188	7.08
Karnataka	Bangalore-Chennai (Hoskote)	NH-04	307	2.52
Orissa	Near Baripara	NH-05	257	4.26
Orissa	Near Tangi	NH-05	371	4.57
West Bengal	Near Kharagpur	NH-06	125	4.90
Tamil Nadu	Madurai-Kanyakumari	NH-07	48	3.85
Madhya Pradesh	Varanasi-Mangwan	NH-07	204	6.79
Rajasthan	Delhi-Jaipur	NH-08	156	7.41
Rajasthan	Delhi-Jaipur	NH-08	203	8.13
Rajasthan	Jaipur-Ajmer	NH-08	280	12.53
Rajasthan	Jaipur-Ajmer	NH-08	376	9.25
Gujarat	Ahemdabad-Mumbai	NH-08	48	6.40
Gujarat	Ahemdabad-Mumbai	NH-08	284	3.99
Gujarat	Ahemdabad-Mumbai	NH-08	346	4.35
Gujarat	Ahemdabad-Mumbai	NH-08	223	5.14
Gujarat	Bharuch-Mumbai	NH-08	198	4.90

Gujarat	Vapi-Mumbai	NH-08	369	4.56
Haryana	Delhi-Hissar	NH-10	40	4.09
Haryana	Delhi-Hissar	NH-10	57	5.07
Haryana	Delhi-Hissar	NH-10	173	4.90
Haryana	Delhi-Hissar	NH-10	268	7.54
Uttar Pradesh	Agra-Jaipur	NH-11	14	6.50
Rajasthan	Agra-Jaipur	NH-11	168	5.11
Rajasthan	Jaipur-Bikaner	NH-11	357	5.12
Rajasthan	Bikaner-Jaisalmer	NH-15	28	5.83
Himachal Pradesh	Chakki Khad-Mandi	NH-20	13	3.05
Himachal Pradesh	Chakki Khad-Mandi	NH-20	111	0.90
Uttar Pradesh	Delhi-Lucknow	NH-24	118	8.92
Uttar Pradesh	Delhi-Lucknow	NH-24	238	10.84
Uttar Pradesh	Delhi-Lucknow	NH-24	267	11.24
Uttar Pradesh	Lucknow-Kanpur	NH-25	67	6.78
Best Bengal	Koochbihar-Baxirhat	NH-31	789	5.31
Tamil Nadu	Chennai-Trichy	NH-45	197	3.64
B. State Highways				
Karnataka	Corridor No. 3 at Mudhol			5.61
Karnataka	Corridor No. 5 at Gangavathi			7.35
Karnataka	Corridor No. 6 at Challakere			11.81
Karnataka	Corridor No. 6 at Pandavapura			4.27
Karnataka	Corridor No. 11 at Chickamagalur			4.32
Karnataka	Corridor No. 12 at Nargund			10.10
Punjab	Sirhind-Morinda-Ropar			6.55
Uttar Pradesh	Bhognipur-Ghatampur			8.04
Uttar Pradesh	Gonda-Bahraich			6.65
Uttar Pradesh	Sultanpur-Pratapgarh			6.78
Uttar Pradesh	Jaunpur-Azamgarh			4.90
Uttar Pradesh	Katra-Allahganj			10.35

Annexure 3.2

Cost per km, 4-lane road (7 m wide pavement)
Overlay design: 15 years
Jaipur – Agra Road NH11

Daily Traffic	Deflection	10^t	11^t	12^t	13^t	BAU
3000 CVs	Lower 0.75 mm	No overlay needed now	50 mm BM+25 mm SDBC Rs.220/m^2 Rs.15.40 lakh	50 mm BM+25 mm SDBC Rs.220/m^2 Rs.15.40 lakh	50 mm DBM+25 mm SDBC Rs.220/m^2 Rs.15.40 lakh	50 mm DBM+25 mm SDBC Rs.250/m^2 Rs.17.50 lakh
	Upper 1.50 mm	75 mm DBM+40 mm BC Rs.370/m^2 Rs.25.90 lakh	75 mm DBM+50 mm BC Rs.405/m^2 Rs.28.35 lakh	100 mm DBM+40 mm BC Rs.465/m^2 Rs.32.55 lakh	100 mm DBM+50 mm BC Rs.510/m^2 Rs.35.70 lakh	115 mm DBM+50 mm BC Rs.550/m^2 Rs.38.50 lakh
7000 CVs	Lower 0.75 mm	50 mm BM+25 mm SDBC Rs.220/m^2 Rs.15.40 lakh	50 mm DBM+25 mm SDBC Rs.220/m^2 Rs.15.40 lakh	50 mm BM+25 mm SDBC Rs.220/m^2 Rs.15.40 lakh	50 mm DBM+25 mm SDBC Rs.250/m^2 Rs. 17.50 lakh	75 mm DBM+40 mm BC Rs.370/m^2 Rs.25.90 lakh
	Upper 1.50 mm	75 mm DBM+50 mm BC Rs.405/m^2 Rs.28.35 lakh	100 mm DBM+40 mm BC Rs.465/m^2 Rs.32.55 lakh	100 mm DBM+40 mm BC Rs.465/m^2 Rs.32.55 lakh	100 mm DBM+50 mm BC Rs.510/m^2 Rs.35.70 lakh	75 mm BM+75 mm DBM+ 50 mm BC Rs.585/m^2 Rs.40.95 lakh
11000 CVs	Lower 0.75 mm	50 mm BM+25 mm SDBC Rs.220/m^2 Rs.15.40 lakh	50 mm BM+25 mm SDBC Rs.220/m^2 Rs.15.40 lakh	75 mm DBM+40 mm BC Rs.370/m^2 Rs.25.90 lakh	75 mm DBM+50 mm BC Rs.405/m^2 Rs.28.35 lakh	75 mm BM+50 mm DBM+ 50 mm BC Rs.520/m^2 Rs.36.40 lakh
	Upper 1.50 mm	75 mm DBM+50 mm BC Rs. 405/m^2 Rs.28.35 lakh	100 mm DBM+50 mm BC Rs.510/m^2 Rs.35.70 lakh	100 mm DBM+50 mm BC Rs.510/m^2 Rs.35.70 lakh	115 mm DBM+50 mm BC Rs.550/m^2 Rs.38.50 lakh	115 mm BM+75 mm DBM+ 50 mm BC Rs.640/m^2 Rs.44.80 lakh

Annexure 3.3

Cost per km, 2-lane road (7 m wide pavement)
Overlay design: 15 year
Sirhind – Ropar State Highway

Daily Traffic	Deflection	10^{t}	11^{t}	12^{t}	13^{t}	BAU
500 CVs	Lower 1.00 mm	-	-	50 mm BM+25 mm SDBC Rs.220/m^2 Rs.15.40 lakh	50 mm BM+25 mm SDBC Rs.220/m^2 Rs.15.40 lakh	50 mm DBM+25 mm SDBC Rs.250/m^2 Rs.17.50 lakh
	Upper 2.00 mm	50 mm DBM+25 mm SDBC Rs.250/m^2 Rs.17.50 lakh	50 mm DBM+25 mm SDBC Rs.250/m^2 Rs.17.50 lakh	50 mm DBM+40 mm BC Rs.305/m^2 Rs.21.35 lakh	50 mm DBM+40 mm BC Rs.305/m^2 Rs.21.35 lakh	75 mm DBM+50 mm BC Rs.405/m^2 Rs.28.35 lakh
1500 CVs	Lower 1.00 mm	50 mm BM+25 mm SDBC Rs.220/m^2 Rs.15.40 lakh	50 mm BM+25 mm SDBC Rs.220/m^2 Rs.15.40 lakh	50 mm DBM+25 mm SDBC Rs.250/m^2 Rs.17.50 lakh	50 mm DBM+25 mm SDBC Rs.250/m^2 Rs.17.50 lakh	50 mm DBM+40 mm BC Rs.305/m^2 Rs.21.35 lakh
	Upper 2.00 mm	75 mm DBM+50 mm BC Rs.405/m^2 Rs.28.35 lakh	80 mm DBM+50 mm BC Rs.420/m^2 Rs.29.40 lakh	100 mm DBM+40 mm BC Rs.465/m^2 Rs.32.55 lakh	100 mm DBM+40 mm BC Rs.465/m^2 Rs.32.55 lakh	100 mm DBM+40 mm BC Rs.465/m^2 Rs.32.55 lakh
3000 CVs	Lower 1.00 mm	50 mm BM+25 mm SDBC Rs.220/m^2 Rs.15.40 lakh	50 mm BM+25 mm SDBC Rs.220/m^2 Rs.15.40 lakh	50 mm DBM+25 mm SDBC Rs.250/m^2 Rs.17.50 lakh	50 mm DBM+40 mm BC Rs.305/m^2 Rs.21.35 lakh	50 mm DBM+50 mm BC Rs.340/m^2 Rs.23.80 lakh
	Upper 2.00 mm	100 mm DBM+40 mm BC Rs.465/m^2 Rs.32.55 lakh	100 mm DBM+40 mm BC Rs.465/m^2 Rs.32.55 lakh	100 mm DBM+40 mm BC Rs.465/m^2 Rs.32.55 lakh	100 mm DBM+50 mm BC Rs.510/m^2 Rs.35.70 lakh	110 mm DBM+50 mm BC Rs.540/m^2 Rs.37.80 lakh
5000 CVs	Lower 1.00 mm	50 mm BM+25 mm BC Rs.220/m^2 Rs.15.40 lakh	50 mm DBM+40 mm BC Rs.305/m^2 Rs.21.35 lakh	50 mm DBM+40 mm BC Rs.305/m^2 Rs.21.35 lakh	50 mm DBM+50 mm BC Rs.340/m^2 Rs.23.80 lakh	75 mm DBM+40 mm BC Rs.370/m^2 Rs.25.90 lakh
	Upper 2.00 mm	100 mm DBM+40 mm BC Rs.465/m^2 Rs.32.55 lakh	100 mm DBM+50 mm BC Rs.510/m^2 Rs.35.70 lakh	110 mm DBM+50 mm BC Rs.540/m^2 Rs.37.80 lakh	110 mm DBM+50 mm BC Rs.540/m^2 Rs.37.80 lakh	75 mm BM+75 mm DBM+40 mm BC Rs.550/m^2 Rs.38.50 lakh

Chapter 4

Overloading of Vehicles – Legal Provisions

1. Overloading of vehicles is an offence under the Motor Vehicles Act 1988, punishable with fine. The law also provides for compounding the offence by imposing compounding fees. The statutory provisions dealing with the offence of overloading are set out in Sections 113, 114, 194 and 200 of the Act. These are briefly described below; the full text may be seen in Annexure 4.1.

- Section 113 limits the driving of any transport vehicle in any public place (a) the unladen weight of which exceeds the unladen weight specified in the certificate of registration of the vehicle, or (b) the laden weight of which exceeds the gross vehicle weight (GVW) specified in the certificate of registration. The unladen weight and the gross vehicle weight of different types of vehicles are notified by the central government under Section 58 of the MV Act.
- Section 114 provides that authorised officers of the Motor Vehicle department have powers to get weighed the goods vehicle or trailer, which is believed to be operating in violation of Section 113, and require the driver of the vehicle to off-load the excess weight at his own risk and not to remove the vehicle till the laden weight of the vehicle has been reduced to satisfy the requirement of Section 113.
- Section 194 punishes the violation of Section 114 (i.e. overloading of vehicles) with a minimum fine of Rs.2,000 and an additional amount of Rs.1,000 per tonne of excess load together with the liability to pay charges for off-loading. Further, it provides that any driver who refuses to stop for weighment or removes part of the load prior to weighing shall be punishable with fine which may extend to Rs.3,000.
- Section 200 deals with the compounding of offences. The offence of overloading under Section 194 may be compounded by the prescribed authority for such amount as may be specified by the state government. After compounding, the offender is discharged and no further action is taken against him in respect of such offence.

Review of Legal Provisions

2. The rationale of overloading is based on the phenomenon known as ‘non-contribution’ in economics. A variant of this is the ‘free-rider’ problem at the

interface of public and private policy. Basically, what happens is that each individual player assumes that if he alone cheats, the cheating will go undiscovered and that the social cost will be negligible. Thus, each trucker operates under two perfectly rational assumptions; one, that he alone cheats and, as such, overall road damage is negligible; and, two, that if everyone else is cheating, he would be worse off if he did not cheat. Together, these add up to a powerful combination leading to overloading by everyone. The only measure that works when 'non-contribution' is in play is deterrent punishment for those who are caught cheating. It is in failing to provide such deterrence and indeed, as we shall see, providing positive incentives to cheat that the existing regulatory framework is found wanting.

3. Thus, firstly, the Act does not provide for any punishment for abetment of the offence. It is well known that transport companies and consignors freely abet in the loading of goods vehicles in excess of the prescribed limits. Secondly, crucially, language of some of the existing provisions is vague and prone to varying interpretations. As a result, various states have taken advantage of this to interpret these provisions in ways that do not maximise social utility. Particularly, Sections 194 and 200 have been liable to multiple interpretations. For example, some states are charging compounding fees as per Section 200 while simultaneously levying the fines prescribed in Section 194. Others view these provisions as mutually exclusive; they either levy a fine or impose a compounding fee. Third, while the central government is responsible for enacting Motor Vehicles Act and framing the Central Motor Vehicles Rules, it has no power to enforce its writ on the states that are responsible for implementing the provisions of the Act. Lastly, the Motor Vehicle Rules of different states vary. As a result, trucks plying on inter-state routes on national permits, or counter-signature permits are exposed to varying degrees of load restrictions by the enforcement agencies on their way from origin to destination. The overall consequence is that there is no uniformity in the approach of the states while dealing with the offence of overloading and its compounding. Legal provisions should stand the test of enforceability in a manner that is uniform and non-discriminatory. Examples of provisions failing to meet this test abound.

4. Thus, for example, Section 114(1) stipulates that "any officer of the Motor Vehicles Department" authorised by the state government shall have the power to subject a vehicle to weighment. This has severely restricted the scope of the persons who can be authorised by the state government to conduct checks for overloading because now only officers of the Motor Vehicles Department can do so. In this context, a point to remember is that police officers are not authorised to book cases of

overloading. Considering the widespread malaise of overloading in the country, the scope of checks by persons who can be authorised by the State Government needs to be widened, particularly in the remote areas. It is therefore, suggested that the words "of the Motor Vehicle Department" should be deleted from Section 114(1).

5. Similarly, Section 114(2), requiring the discovery of overloading to be recorded on the goods carriage permit and intimation of such an endorsement to be sent to the permit-issuing authority, is followed only in its breach. Our surveys did not show such recordings being made or such intimation being sent at all. This provision, therefore, needs to be deleted as it does not seem to serve any purpose.

6. Schemes like issues of special tokens followed in some states whereby overloading is permitted on payment of compounding fees under Section 200 of Motor Vehicles Act, also help in avoiding the maximization of social utility as it permits an illegal action on payment of a premium. Indeed, overloading also constitutes a safety hazard and the compounding of the offence does nothing to improve safety on the roads. Pay and offend cannot be the guiding spirit of state policy.

7. Studies have revealed that vehicle weight shows the strongest association with fatal accident rates. It has been estimated that overloaded trucks on the country's highways involved in accidents cause a loss of Rs.5000 crore. This has been worked out by taking into account the volume of freight traffic moving on highways, the percentage of highway fatalities in which trucks are implicated, costs of fatality, injury and vehicle damage, and the observed share of overloaded trucks in total trucks.

8. The existing legal provisions do not provide a margin for minor errors in weighment. Even with the best of maintenance practices, weighbridges can show some minor variations in weight. As such, it is felt that inconsequential differences in weight recorded by different weighbridges should not straightaway lead to maximum penalty stipulated. It is, therefore, recommended that a provision may be inserted in the Act under which a nominal fine of Rs.500/- may be imposed if, on weighment, the difference in GVW is found upto 5 per cent. However, a driver, who refuses to stop and submit his vehicle for weighment on being directed to do so by an authorised officer, deserves to be meted out severe punishment.

9. In order to ensure the smooth and socially consistent application of the law, it is necessary that not only the law should be simple and enforceable, it should also adopt the principle of third-party regulation and adjudication. It is, therefore, recommended that a Road Transport Regulatory Authority be set up. On the government's decision to set up such an authority, suitable provisions shall also have to be included in the Motor Vehicles Act.

10. In the light of the above, the specific amendments proposed in the statutory provisions relating to the offence of overloading are given below:

Present Provision	Proposed Amendment
Section 114(1) Any officer of the Motor Vehicles Department authorised in this behalf by the State Government shall, if he has reason to believe that a goods vehicle or trailer is being used in contravention of Section 113 requires the driver to convey the vehicle to a weighing device, if any, within a distance of ten kilometres from any point on the forward route or within a distance of twenty kilometres from the destination of the vehicle for weighment; and if on such weighment the vehicle is found to contravene in any respect the provisions of Section 113 regarding weight, he may, by order in writing, direct the driver to off-load the excess weight at his own risk and not to remove the vehicle or trailer from that place until the laden weight has been reduced or the vehicle or trailer has otherwise been dealt with so that it complies with Section 113 and on receipt of such notice, the driver shall comply with such directions.	***Section 114(1)*** Any officer authorised in this behalf by the State Government shall, if he has reason to believe that a goods vehicle or trailer is being used in contravention of Section 113, may require the driver to produce a certificate or other proof from a government authorised weighing device and in case of failure to produce such a certificate, require the driver to convey the vehicle to a weighing device, if any, within a distance of ten kilometres from any point on the forward route or within a distance of twenty kilometres from the destination of the vehicle for weighment; (2) (a) If the laden weight is found to be within the gross vehicle weight specified in the certificate of registration of the vehicle, the vehicle shall be allowed to proceed. (b) In case the laden weight exceeds the gross vehicle weight specified in the certificate of registration of the vehicle by upto 5%, a fine of Rs. 500/- shall be imposed by the authorised officer and the vehicle allowed to proceed to destination. (c) In case the laden weight exceeds 5% of the gross vehicle weight specified in the certificate of registration of the vehicle, the authorised officer may, by order in writing, direct the driver to off-load the excess weight at his own cost and risk and not to remove the vehicle or the trailer from that place until the laden weight has been reduced or the vehicle or trailer has otherwise been dealt with so that it complies with Section 113.

(3) Whoever drives a motor vehicle or causes or allows a motor vehicle to be driven in contravention of Section 113 or Sub-Clauses (b) and (c) of this Section shall be punishable with a minimum fine of two thousand rupees and an additional amount of one thousand rupees per tonne of excess load or part thereof.

Section 114(2)
Where the person authorised under sub-section (1) makes the said order in writing, he shall also endorse the relevant details of the overloading on the goods carriage permit and also intimate the fact of such endorsement to the authority which issued that permit.

Section 114(2)
The existing provision may be dropped.

Section 188
Whoever abets the commission of an offence under Section 184 or Section 185 or Section 186 shall be punishable with punishment provided for the offence.

Section 188
The existing provision may be enlarged to include overloading. The amended provision will be as follows:
"Whoever abets the commission of an offence under Section 113, Section 114, Section 184, Section 185 or Section 186 shall be punishable with a fine and a term in jail as provided for the offence".

Section 194(1)
Whoever drives a motor vehicle or causes or allows a motor vehicle to be driven in contravention of the provisions of Section 113 or Section 114 or Section 115 shall be punishable with minimum fine of two thousand rupees and an additional amount of one thousand rupees per tonne of excess load, together with the liability to pay charges for off-loading of the excess load.

Section 194(1)
Reference to Sections 113 and 114 may be deleted in view of amendment to Section 114 suggested above. Section 194(1) shall read as under:
Whoever drives a motor vehicle or causes or allows a motor vehicle to be driven in contravention of Section 115 shall be punishable with minimum fine of two thousand rupees and an additional amount of one thousand rupees per tonne of excess load or part thereof, together with the liability to pay charges for off-loading of the excess load.

Section 194(2)
Any driver of a vehicle who refuses to stop and submit his vehicle to weighing after being directed to do by an officer authorised in this behalf under Section 114 or removes or causes the removal of the load or part of it prior to weighing shall be punishable with fine which may extend to three thousand rupees.

Section 194(2)
Add "or imprisonment upto one month" at the end of the Section. The Section shall thus read as follows:
"Any driver of a vehicle who refuses to stop and submit his vehicle to weighing on being directed to do by an officer authorised in this behalf under Section 114 or removes or causes the removal of the load or part of it prior to weighing shall be

	punishable with fine which may extend to three thousand rupees or imprisonment upto one month".
Section 200(1) Any offence whether committed before or after the commencement of this Act punishable under Sections 177, 178, 179, 180, 181, 182, Sub-section (1) or (2) of Section 183, Sections 184, 186, (Section 189, Sub-section (2) or Section 190), Sections 191, 192, 194, 196 or Section 198, may either before or after the institution of the prosecution, be compounded by such officers or authorities and for such amount as the State Government may, by notification in the Official Gazette, specify in this behalf.	***Section 200(1)*** Delete Section 194 from sub-section (1) of Section 200.

Compounding the Offence of Overloading

11. Section 200 of the Motor Vehicles Act empowers the state governments to prescribe and levy compounding fees for the offence of overloading. Some state governments made use of this provision to introduce special token schemes which permit overloading within their respective states. This was done with a view to mobilise additional resources, minimise corruption at operational levels and facilitate smooth flow of traffic on the roads. The fees for these schemes varied from state to state. Some differentiated between the vehicles registered in the state and vehicles registered outside the state.

12. The position in respect of special token fees and compounding fees of various states for which information is available, is given below.

(i) ***Gujarat***

Charge for carrying excess load upto two tonnes is Rs. 3000/- and for each additional one tonne of excess load, it is Rs. 250/-. This is on per trip basis.

(ii) ***Haryana***

A flat levy of Rs. 150/- per tonne of excess load is charged regardless of whether the vehicle is registered in Haryana or elsewhere. Further, this charge is payable by the vehicle on each of its trips, wherever it is overloaded.

(iii) ***Karnataka***

For excess load of upto 1000 kg, the fee is Rs. 500/- and for each additional 100 kg, the extra fee is Rs. 60/-.

(iv) ***Madhya Pradesh***

If declared voluntarily, the fee is Rs. 600/- upto excess load of 3 tonnes. For each tonne in excess of 3 tonnes, additional Rs. 200/- per tonne is charged. Where the vehicle is detected moving without declaration, charges are Rs.2000/- upto 3 tonnes and Rs.500/- for each additional tonne.

(v) ***Maharashtra***

A penalty of Rs. 100/- per metric tonne for overloading upto 2 metric tonnes is charged from the person driving the vehicle. Penalty of Rs. 150/- per metric tonne or part thereof for overloading above 2 metric tonnes is charged from the person who abets driving.

(vi) ***Orissa***

There is a flat rate of Rs.5000/- p.m. whatever the make or size of vehicle and whatever the excess load.

(vii) ***Punjab***

The vehicles registered in the state and opting to take the token, are charged Rs. 150/- per tonne per day. The vehicles registered outside the state are charged Rs. 300/- per tonne per day.

(viii) ***Rajasthan***

Fee structure is given under the relevant case study.

(ix) ***Uttar Pradesh***

Fee structure is given under the relevant case study.

Revenue Receipts

13. There is no reliable data available at the all India level on the earnings from the special token schemes. However, based on the data furnished by the Transport Commissioners of Rajasthan and Uttar Pradesh, a broad estimate has been worked out. For instance, in the year 2001-02, Rajasthan earned Rs.120.50 crore from special tokens. In 2002-03, this figure increased to Rs. 172.60 crore. Uttar Pradesh earned Rs.89.94 crore in 2001-02, calculated after annualizing the figures for the whole year. In 2002-03, the revenue increased to Rs.149.72 crore. In addition, revenue from penalties imposed for overloading in the course of checks amounted to Rs. 21 crore.

14. Considering that the scheme started maturing after initial hiccups, we may adopt the data for the year 2002-03 while estimating the revenue at all India level. This has been done based on the number of goods vehicles on road for plying in the country during the relevant year. This figure has been estimated at 2.4 million. Using the revenue figures of Uttar Pradesh, this works out to an earning potential of over Rs.4100 crore during the year at the all India level.

15. Further assuming that only 20 percent of the trucks came under the ambit of special token schemes or were brought to book during the course of checks in the year 2002-03, this works out to an earning potential of Rs.20,500 crore at all India level. This colossal amount indicates the level of earning or leakage (whichever way one looks at it) from the incidence of overloading of vehicles. It is well recognised that the private benefit is invariably higher than the outgo on account of compounding fees, penalties, etc. by a minimum factor of two. Thus, private gain works out to Rs. 41,000 crore on a conservative estimate.

Case Study of Rajasthan

16. The special token (also called golden token) scheme was introduced in Rajasthan in the late 1990s to allow overloaded vehicles to ply within the state on payment of the prescribed fees. The token was available both on a monthly or annual basis. The annual token was issued in March at the normal rate. Late applications were charged higher fees. Annual tokens were issued only to vehicles registered in Rajasthan. Vehicles registered outside the state were eligible for the monthly token scheme. The fees were generally linked to the gross vehicle weight of the vehicle. The details are given in the following table:

Fee Structure of Special Tokens

(notified in 2000)

<table>
<tr><th rowspan="2">Gross Vehicle Weight</th><th colspan="2">Per calendar month or part thereof</th><th colspan="2">For the complete financial year or part thereof</th></tr>
<tr><th>Vehicles registered in Rajasthan</th><th>Vehicles registered outside the state</th><th>If paid in March</th><th>If paid in April or later</th></tr>
<tr><td>Upto 7500 kg</td><td>1000</td><td>2000</td><td>5000</td><td>6000</td></tr>
<tr><td>Above 7500 kg and upto 16200 kg</td><td>1500</td><td>3000</td><td>7500</td><td>9500</td></tr>
<tr><td>Above 16200 kg and upto 25000 kg</td><td>2000</td><td>3500</td><td>11000</td><td>13000</td></tr>
<tr><td>Above 25000 kg and upto 35200 kg</td><td>2500</td><td>4000</td><td>19000</td><td>21000</td></tr>
<tr><td>Above 35200 kg and upto 40200 kg</td><td>3000</td><td>4500</td><td rowspan="2">31000</td><td rowspan="2">31000</td></tr>
<tr><td>Above 40200 kg</td><td>3500</td><td>5000</td></tr>
</table>

16.1 The scheme was withdrawn in December 2003, apparently because the Central Government threatened to stop disbursements from the Central Road Fund. However, the regime of levying the compounding fees on per trip basis was again introduced. A fee of Rs.1000/- is being charged for the excess load upto 4 tonnes and if the load exceeds the limit, an additional sum of Rs. 500/- per tonne or part thereof is charged.

16.2. The transport department collected Rs. 650 crore from the goods transport segment in 2002-03. Special tokens accounted for a share of 26.5 percent. The share of penalties, which includes fines realised from overloaded vehicles, contributed an equal share. The realisation from special tokens in terms of monetary value for 2001-02 and 2002-03 was as under:

Year	Annual Tokens		Monthly Tokens		Total amount (Rs. crore) (3+5)
	Number	Amount (Rs. crore)	Number	Amount (Rs. crore)	
1	2	3	4	5	6
2001-2002	31600	45.27	297256	75.23	120.50
2002-2003	38773	59.70	364533	112.90	172.60

16.3 The punitive measures require an extensive infrastructure of weighbridges to weigh the loaded vehicles and availability of godown space for storage of unloaded excess cargo. The number of weighbridges in the state is not adequate and there is no availability of godown space for storage of off-loaded excess cargo. The truckers take advantage of this situation, so also the enforcement agencies. Thus a self-serving nexus has come into existence between the operators and the state agencies.

Case Study of Uttar Pradesh

17. The special token scheme was introduced in Uttar Pradesh in March 2001 but it was made operational only in August 2001. Initially, the tokens were issued on a quarterly and half-yearly basis but were later issued on a monthly basis as well. Subsequently, tokens were also issued for plying the trucks in a limited area of the state at a lower tariff. As in the case of Rajasthan, the fee for special token was higher for vehicles registered outside the state. The fees prescribed from time to time are set out in the following tables.

(Vehicles Registered in Uttar Pradesh)

Gross Vehicle Weight	Fees (Rs.) (w.e.f. 19th March 2001)		Fees (Rs.) (w.e.f. 26th November 2001)		
	Quarterly	Half-yearly	Monthly	Quarterly	Half-yearly
Upto 7500 kg	3000	6000	1000	3000	6000
Above 7500 kg and upto 16200 kg	4500	9000	1500	4500	9000
Above 16200 kg and upto 25000 kg	6000	12000	2000	6000	12000
Above 25000 kg and upto 35200 kg	7500	15000	2500	7500	15000
Above 35200 kg and upto 40200 kg	9000	18000	3000	9000	18000
Above 40200 kg	10500	21000	3500	10500	21000

(Vehicles Registered outside Uttar Pradesh)

Gross Vehicle Weight	Fees (Rs.) (w.e.f. 19th March 2001)		Fees (Rs.) (w.e.f. 26th November 2001)		
	Quarterly	Half-yearly	Monthly	Quarterly	Half-yearly
Upto 7500 kg	4500	9000	1500	4500	9000
Above 7500 kg and upto 16200 kg	6000	12000	2000	6000	12000
Above 16200 kg and upto 25000 kg	7500	15000	2500	7500	15000
Above 25000 kg and upto 35200 kg	9000	18000	3000	9000	18000
Above 35200 kg and upto 40200 kg	10500	21000	3500	10500	21000
Above 40200 kg	12000	24000	4000	12000	24000

17.1 In July 2002, the fees were steeply increased. The hike was however, stayed by the court. The special token scheme was withdrawn in December 2003, apparently, after the Central Government threatened to stop disbursement from Central Road Fund. Presently, the compounding fee for the offence of overloading is the same as envisaged in Section 194 of the Motor Vehicles Act, 1988. A minimum fee of Rs.2000/- is charged with an additional amount of Rs.1000/- per tonne of excess load.

17.2 The revenue collection from special token scheme during the years 2001-02, 2002-03 and 2003-04, was as under. The annualized figures are also shown in juxtaposition.

Year	Special Tokens		
	Number*	Amount (Rs. crore)	Annualised amount (Rs. crore)
2001-02 (August 01-March 02)	169706	59.96	89.94
2002-03	598443	149.72	149.72
2003-04 (April-November 03)	551332	103.87	155.80

** Category-wise breakup of tokens is not available*

17.3 The support infrastructure of weighbridges and godown space is woefully lacking in the state. The weighbridges are fewer in number and are generally run by the private sector. As in the case of Rajasthan, there are no godown facilities available for storage of off-loaded goods.

Facilitating Enforcement

18. Fining and offloading are, however, punitive solutions. The prevailing technological impasse has to be overcome and punitive measures have to be supplemented with incentives for technological upgradation. Effort should be made to

find solutions that eliminate profits from overloading. The easy way of doing this is to impose heavy fines. The more long term and permanent solution would, however, require a restructuring of the trucking business.

19. The structure of the trucking industry is highly skewed. For example, about 77 percent of the truck owners own a fleet size of about 5 vehicles, 10 percent between 6 to 10 vehicles, 4 percent between 11 to 15 vehicles, 3 percent between 16 to 20 vehicles and the remaining 6 percent more than 20 vehicles. The ownership pattern clearly confirms the fact that small operators dominate this industry. However, their margins are extremely low, estimated in a recent study at 4 percent.

20. The industry is also characterised by a host of intermediaries – transporters, brokers, sub-brokers, etc. Transporters are trucking companies which have the primary contact with customers. They solicit freight and are responsible for cargo loss and damage claims. They rely primarily on small truck operators for their linehaul transport. Brokers and agents have links with the truck operators and they connect these operators to the transporters. Each of these actors has a legitimate role to play and each is subject to intense competition from one source or the other. Each set of agents has a different level of access to information and ability to influence price and risk factors. Most of the profit is appropriated by the brokers. Operators are encouraged to overload on every trip, given the lack of adequate policing and proper regulation.

21. The starting point of reform therefore has to be the recognition of the fact that over half of the trucking firms are single-truck firms. For them, a 20 per cent overload is a pure bonus. In this scenario, overloading could be greatly reduced if there is a movement away from single-truck firms to larger ones owning at least 10-12 trucks because in that case there would be a strong incentive at the firm level to keep all the assets in use rather than overload just a few. To achieve this, would require a comprehensive overhauling of the financing and regulatory regimes.

22. The specific elements to be reformed would, among others, include:

- (i) The provisions of the Motor Vehicles Act.
- (ii) The laws governing the truck manufacturers and ancillary industry.
- (iii) Road infrastructure and its governance and regulation.
- (iv) The financial services industry, including banks, NBFCs and insurance firms.
- (v) Contradictory, or excessively complex policies arising from the intersection of Central and State laws.

23. To facilitate enforcement, a number of weigh-in-motion (WIM) and static weighing stations need to be set up on the highways. A beginning should be made on the national highways where the NHAI/BOT entrepreneurs should set up WIM and the static weighing stations together with providing suitable space for removal of excess cargo at the risk and cost of the transport operators. BOT operators should also be vested with powers to enforce the provisions of the Motor Vehicles Act and authorised to offload the cargo in excess of the axle load limits prescribed by the government. If enforcement of the provisions against overloading is lax, the very basis of private sector participation in this area will fall flat.

Annexure 4.1

Extracts from the Motor Vehicles Act, 1988

Section 113. Limits of weight and limitations on use.

(1) The State Government may prescribe the conditions for the issue of permits for transport vehicles by the State or Regional Transport Authorities and may prohibit or restrict the use of such vehicles in any area or route.

(2) Except as may be otherwise prescribed, no person shall drive or cause or allow to be driven in any public place any motor vehicle which is not fitted with pneumatic tyres.

(3) No person shall drive or cause or allow to be driven in any public place any motor vehicle or trailer:

(a) the unladen weight of which exceeds the unladen weight specified in the certificate of registration of the vehicle, or

(b) the laden weight of which exceeds the gross vehicle weight specified in the certificate of registration.

(4) Where the driver or person in charge of a motor vehicle or trailer driven in contravention of Sub-section (2) or clause (a) of Sub-section (3) is not the owner, a Court may presume that the offence was committed with the knowledge of or under the orders of the owner of the motor vehicle or trailer.

Section 114. Power to have vehicle weighed.

(1) Any officer of the Motor Vehicles Department authorised in this behalf by the State Government shall, if he has reason to believe that a goods vehicle or trailer is being used in contravention of Section 113, require the driver to convey the vehicle to a weighing device, if any, within a distance of ten kilometres from any point on the forward route or within a distance of twenty kilometres from the destination of the vehicle for weighment; and if on such weighment the vehicle is found to contravene in any respect the provisions of Section 113 regarding weight, he may, by order in writing, direct the driver to off-load the excess weight at his own risk and not to remove the vehicle or trailer from that place until the laden weight has been reduced or the vehicle or trailer has otherwise been dealt with so

that it complies with Section 113 and on receipt of such notice, the driver shall comply with such directions.

(2) Where the person authorised under Sub-section (1) makes the said order in writing, he shall also endorse the relevant details of the overloading on the goods carriage permit and also intimate the fact of such endorsement to the authority which issued that permit.

Section 194. Driving vehicle exceeding permissible weight.

(1) Whoever drives a motor vehicle or causes or allows a motor vehicle to be driven in contravention of the provisions of Section 113 or Section 114 or Section 115 shall be punishable with minimum fine of two thousand rupees and an additional amount of one thousand rupees per tonne of excess load, together with the liability to pay charges for off-loading of the excess load.

(2) Any driver of a vehicle who refuses to stop and submit his vehicle to weighing after being directed to do so by an officer authorised in this behalf under Section 114 or removes or causes the removal of the load or part of it prior to weighing shall be punishable with fine which may extend to three thousand rupees.

Section 200. Composition of certain offences.

(1) Any offence whether committed before or after the commencement of this Act punishable under Section 177, Section 178, Section 179, Section 180, Section 181, Section 182, Sub-section (1) or Sub-section (2) of Section 183, Section 184, Section 186, (Section 189, Sub-section (2) of Section 190); Section 191, Section 192, Section 194, Section 196, or Section 198, may either before or after the institution of the prosecution, be compounded by such officers or authorities and for such amount as the State Government may, by notification in the Official Gazette, specify in this behalf.

(2) Where an offence has been compounded under Sub-section (1) the offender, if in custody, shall be discharged and no further proceedings shall be taken against him in respect of such offence.

BIBLIOGRAPHY

1. Asian Institute of Transport Development, 2002. *Environmental and Social Sustainability of Transport: Comparative Study of Rail and Road*, Report prepared for the Ministry of Railways.
2. Montana Department of Transportation, 2001. *State Truck Activity Reporting System*, presentation by Dennis Hult.
3. Nebraska Department of Roads, 1999. *Legal Sizes and Weights for Vehicles in Nebraska.*
4. OECD,1998. *Dynamic Interaction between Vehicles and Infrastructure Experiment (DIVINE): Technical Report*.
5. OECD, 1998. *Dynamic Interaction between Vehicles and Infrastructure Experiment (DIVINE Project): Policy Implications.*
6. Rufolo, A M, L Bronfman and E Kuhner, 1999. *Effect of Weight-Mile Tax on Road Damage in Oregon,* Final Report, Oregon Department of Transportation and Federal Highway Administration.
7. Russell, E R, M W Babcock and C Mauler, 1996. *A Methodology for Determining Road Damage due to Railroad Branchline Abandonment*, Paper from the 1996 Semisesquicentennial Transportation Conference
8. US Federal Highway Administration, 1995 – *Comprehensive Truck Size and Weight Study,* Summary Report.
9. US Federal Highway Administration, 1995. *Pavements and Truck Size and Weight Regulations*, Working Paper 3 of Truck Size and Weight Study.
10. US Federal Highway Administration, 1995. *Vehicle Characteristics Affecting Safety*, Working Papers 1 and 2 combined of Truck Size and Weight Study.
11. Vermont Local Roads Program, 2000. *How Vehicle Loads Affect Roads*.
12. World Bank, 2000. *India – Transport Sector, Long Term Issues*.

Technical Note on Optimum Axle Load of Commercial Vehicle for Indian Roads

The World Bank

Technical Note on Optimum Axle Load of Commercial Vehicle for Indian Roads

Prepared by

Pavement Engineering & Materials
Central Road Research Institute
New Delhi-110 020

June 2004

Contents

Tables

Figures

1. INTRODUCTION

1.1 Project Background

The legal axle load limit in India is 10.2 tonnes, but there is rampant violation of this legal limit. The damage to the road pavement due to overloading of the trucks and consequent higher axle loads has serious implications in the progression of the deterioration in a faster pace than normal. It is well known that the damaging power of such overloaded axles is governed by the fourth-power law. In addition to the central Government budget, Central Road Fund (CRF) and state budgets, the road infrastructures in India are now getting refurbished through Technical Assistance loans from the World Bank, ADB and other multi-lateral arrangements. Therefore, unless the legal axle load is enforced, the new roads are likely to be crumbling much before their design life. In this context, the World Bank has shown concern and desired that a preliminary study be conducted to ascertain the strategic requirement of policy in this regard by a quick study. Accordingly, Asian Institute of Transport Development (AITD) and Central Road Research Institute (CRRI), New Delhi were contacted for taking up the study. The aim of this study is to find an optimum axle load representing the minimum total transportation cost by assuming that the legal limit of 10.2 tonnes or any higher limit chosen for analysis can be enforced. Further, this optimality of axle load limit is required to be analysed and derived using the Highway Development and Management (HDM-4) software.

Accordingly, the Institute accepted the request and worked out for three real cases which are as follows:

- Agra-Bharatpur (NH-11)
- Bharatpur-Jaipur (NH-11)
- Morinda-Ropar (SH)

The detailed field data for Agra-Bharatpur-Jaipur case study was available from a consultancy project duly completed by CRRI in the month of July 2003, sponsored by Rajasthan PWD and the field data of Morinda-Ropar case study was provided by AITD.

1.2 Need for Optimization of Axle Loads

In the present Indian scenario, the standard axle loads as applicable in the analysis of vehicle damage factor (VDF) are as follows:

- 6.60 tonne single wheel, single axle
- 8.16 tonne dual wheel, single axle
- 15.1 tonne dual wheel, tandem axle group

The overloading as described above is going on unabated for very long and there are several types of effects for the road users as well as the road agencies. While the road agencies are not able to plan the maintenance in any scheduled manner, the road users are paying the price of overloading in terms of higher vehicle operating cost (VOC) due to bad roads as well as higher tractive effort required by the trucks to overcome all resistance to move at a desired speed on a bad road. Thus, HDM-4 software is used for capping the normally overloaded trucks to the chosen maximum limits alternately at 10, 11, 12 and 13 tonnes. Therefore, the total transportation cost (TTC) at different possible legal limits are likely to show a definite pattern for locating the optimum in terms of TTC. The effect of overloading, which is reflected in the faster deterioration of the road, damage to vehicle parts and increase in power consumption leading to higher vehicle operating cost (VOC), will make the TTC higher. Thus, a major part of the TTC is being borned by the road users without any choice for avoiding it. While the truck operators think that overloading saves additional trips, the wear and tear of the vehicle and the vehicle operating costs in terms of fuel and lubricants are never recognized. Further, the deterioration impinged to the road in turn affected the VOC of all the vehicles including the trucks adversely. It is, therefore, important that an appropriate analysis should reveal the economics of operating the trucks with most optimum legal axle loads so as to minimize the TTC.

1.3 Objectives and Scope of the Project

AITD and CRRI through discussion with the World Bank have came to an agreement that three specific case studies of Agra-Bharatpur, Bharatpur-Jaipur and Morinda-Ropar shall be taken as the specific cases where the axle load spectrum and classified traffic counts were carried out in recent times. They have the maximum data that will be required for operating with HDM-4. Accordingly the following three road stretches have been identified from the three case studies for the preliminary study of the axle load policy. These are as follows:

- Agra – Bharatpur section
- Bharatpur – Jaipur section
- Morinda-Ropar section

Thus the study has utilized the data already collected from the two specific cases as described above for experimenting with the axle load optimization. The latest version of HDM-4 package as available in CRRI is used for analysis to meet the objectives of the project. The main objectives are:

- To examine the available data for its completeness and also the possible effective utilization in the HDM-4 software
- Development of specific database in relation to each site for axle load optimization analysis
- Formulation of maintenance strategy options based on technologies available in the country for routine, periodic, and renewal maintenance operations
- Economic evaluation of alternate technology options of maintenance strategies through a programme analysis in HDM-4
- Optimization of axle load in terms of TTC for a period of 15 years

1.4 Structure of the Report

This report describes the methodology used and results obtained for optimization of axle loads, taking the actual field data from case studies viz. Agra-Bharatpur, Bharatpur-Jaipur and Morinda-Ropar, the first two national highway sections, and and third one from a State Highway, applying it in the widely used maintenance management tool HDM-4. Therefore, the report broadly covers:

- Details of database development
- An overview of features and applicability of HDM-4
- Details of data input and analysis
- The maintenance alternatives
- Economic analysis in terms of Total Transportation Cost
- Discussion of output
- Recommendations

Also, the discussion on the output and recommendations shall be useful in formulating suitable policy in reference to legalizing the axle load limits of commercial vehicles at an optimum level (in reference to the present legal axle load limit) which shall be beneficial in terms of TTC.

2. PROPOSED METHODOLOGY

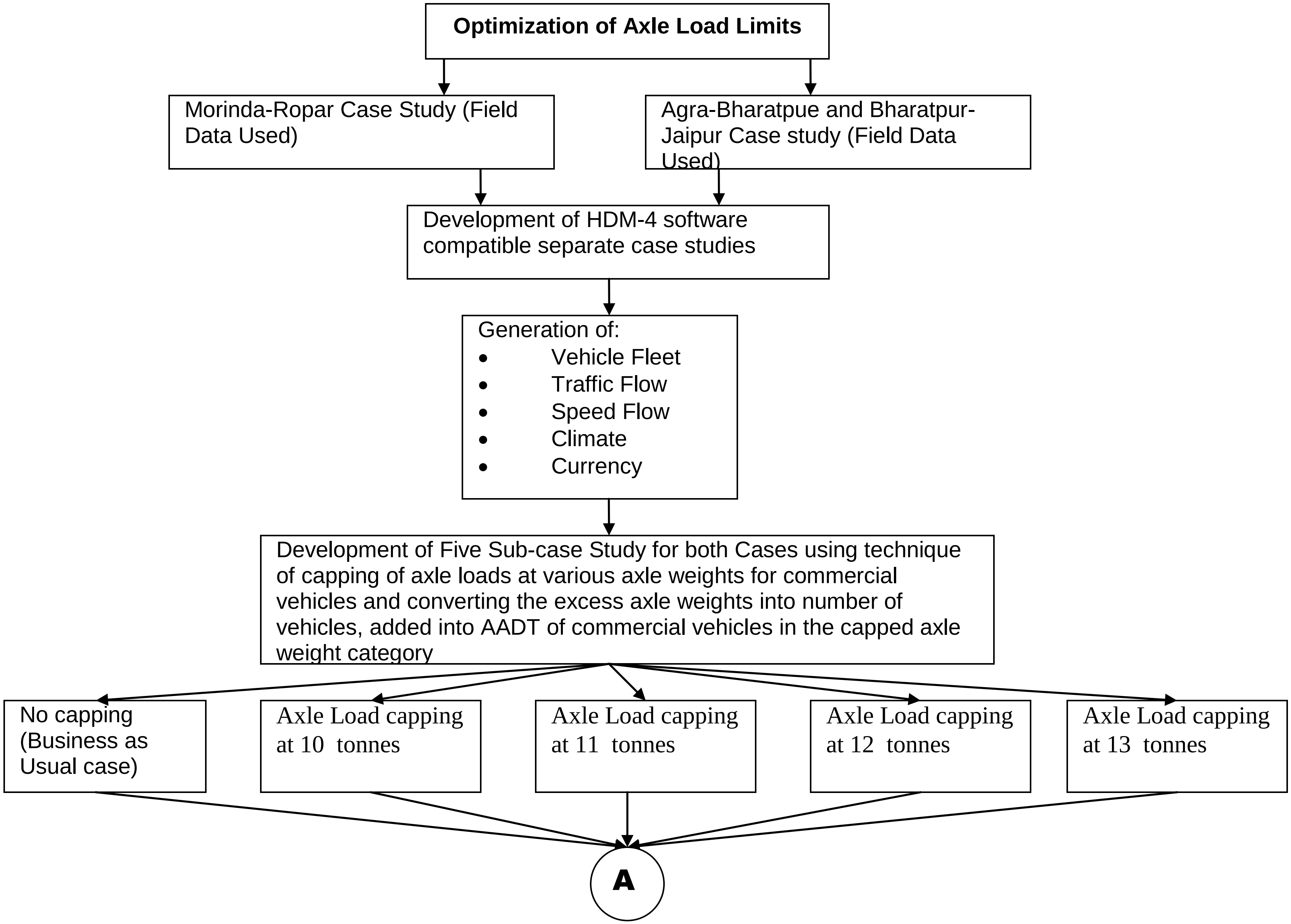
2.1 General

The main purpose of axle load policy study is to determine the cost associated with providing various levels of serviceability for any given pavement. This is an important feed back in planning, design and construction. The type and degree of maintenance can also influence the rate of deterioration or serviceability loss for a pavement. This, of course, has a link to the VOC as well through additional road user costs. It is well known that axle load policy study using HDM-4 shall require careful planning, availability of correct and detailed data, incorporating the specifications used in maintenance practices and their associated deterioration patterns. Since most of the detailed data collected for each case study shall be the input for HDM-4 software, the adaptation/calibration of HDM-4 for the case studies has to be realistic. Once it is achieved by doing sensitivity analysis, the process of optimization of axle load starts. The axle weight spectrum obtained after capping the axle weights at various levels viz. 10 tonnes, 11 tonnes, 12 tonnes and 13 tonnes, is converted into number of vehicles of capped axle weights for using in the computation of VDF (vehicle damage factor). The flow diagram of the various steps involved in the complete analysis is presented in **Figure 1**.

2.2 Data Matrix

A full study of axle load policy evaluation in a country context would require an extensive analysis with a much greater inquiry into the ranges of each variable, in reference to the vast road network with varying conditions, which goes into HDM-4 as an input. Such a framework was initially developed jointly by AITD and CRRI. This complete data matrix, as a global analysis for the countrywide policy development, is given below.

1) Data required to be compiled on sample stretches of:
    - National Highways
    - State Highways
    - Major District Roads


Optimization of Axle Load Limits
Morinda-Ropar Case Study (Field Data Used)
Agra-Bharatpue and Bharatpur-Jaipur Case study (Field Data Used)
Development of HDM-4 software compatible separate case studies
Generation of:
Vehicle Fleet
Traffic Flow
Speed Flow
Climate
Currency
Development of Five Sub-case Study for both Cases using technique of capping of axle loads at various axle weights for commercial vehicles and converting the excess axle weights into number of vehicles, added into AADT of commercial vehicles in the capped axle weight category
No capping (Business as Usual case)
Axle Load capping at 10 tonnes
Axle Load capping at 11 tonnes
Axle Load capping at 12 tonnes
Axle Load capping at 13 tonnes
A

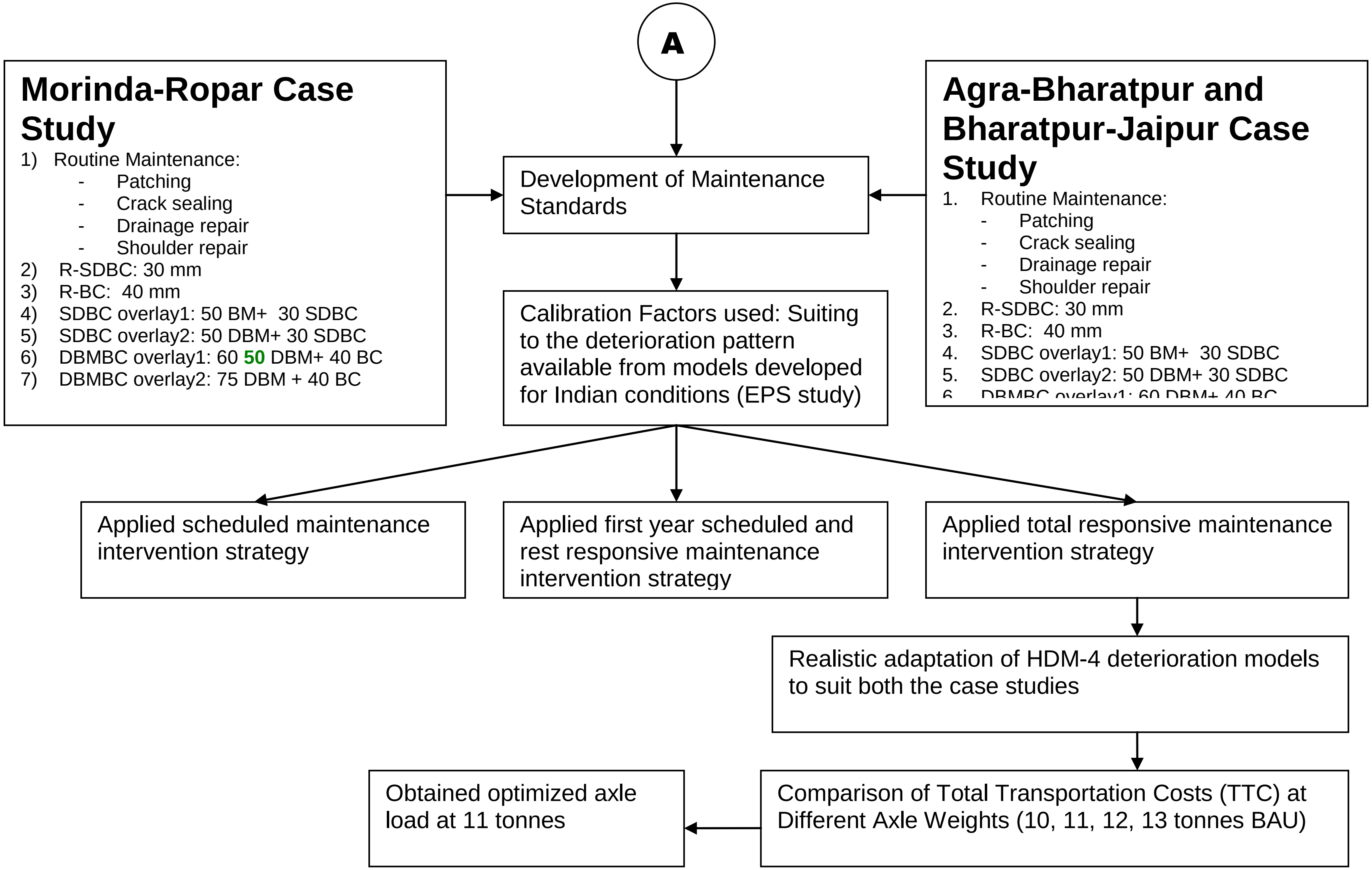


Figure 1: Schematic Diagram of Methodology Adopted for Optimisation of Axle Load

2) Broad status of a major part of the network on a sample basis will be required, such as formation width, carriageway width, other cross section details, pavement composition (with pavement history) and details of wearing surface. The will be obtained correctly from the ground truth. In addition, the following data on the condition of the representative sample road sections will be required as follows:
   - Condition of road such as roughness, other types of distress and deflection
   - Traffic data, axle load spectrum of commercial vehicles, and past trend of traffic growth.
3) Data on VOC, vehicle travel characteristics (annual estimate of total travel) for all categories of vehicles (as estimated by latest RUCS study). Also, data to be used from World Bank note, prepared by Rodrigo Archondo Callao.
4) Data on unit costs of WBM, WMM, BM, DBM, SDBC and BC. Surface treatment are the items like MSS, PC + seal coat, two coat surface dressing, etc.
5) The frequency of periodic renewals as observed in India as well as from the performance of these specifications can be used to formulate alternative scenarios given in **Table 1**.

Table 1: Service Life Scenarios of Maintenance Interventions

Frequency of periodic renewal	**Scenario of service life(Years)**	**Optimal service life (years)**
Surface dressing (SD)	3, 4, 5, 6 and 7	4
Premix carpet (PMC)	4, 5, 6, 7 and 8	5
Mix seal surface (MSS)	4, 5, 6, 7 and 9	5
Semi-dence bituminous carpet (SDBC)	5, 6, 7, 8 and 9	7
Bituminous carpet (BC)	6, 7, 8, 9 and 10	7

6) Discount rate can be taken as 8%, 10% and 12%.
7) The strengthening and/or rehabilitation plan can form many combinations of pavement overlays for the following scenarios:
   - For single, intermediate, two and four lane carriageway width.
   - Deflection 1.0 mm, 1.5 mm and 2.0 mm
   - Commercial vehicles per day CVPD):
     Single lane: 300, 400, 500, 600 and 700
     Intermediate lane: 700, 1000, 1500, 2000
     Two lanes: 700, 1000, 1500, 2000, 3000, 4000, 5000
     Four lanes: 3000, 5000, 7000, 9000, 1100
   - Vehicle Damage Factor (VDF)
     - To be computed from data on axle load spectrum obtained for actual case studies.
     - Recalculate the VDF from the axle load spectrum obtained by capping the maximum permitted single axle load alternately as 13, 12.5, 12.0, 11.5, 11.0, and 10.2 tonnes.
   - Design period for overlay be taken as 10 years and 15 years, including the routine maintenance in between.
   - VOC to be worked out (as per RUCS) in respect of commercial vehicles viz. trucks of two axles or more with capping of axle loads at 13, 12.5, 12.0, 11.5, 11.0, and 10.2 tonnes.
   - The cost of strengthening of pavement and annual maintenance (which is the road agency cost) during the design life is to be determined using the HDM-4 with axle load limit scenarios of 13, 12.5, 12.0, 11.5, 11.0, and 10.2 tonnes for different road geometry and pavement conditions.

The above data matrix, when used with HDM-4 analysis, can provide the complete exposure of the road management requirements of the country with most cost effective axle load limit. It has very large number of permutation and combinations of the data, and therefore, the results to be obtained using HDM-4 shall be extremely time consuming and complicated. No doubt, a complete study of the axle load policy should look at the problem in this manner covering all the situations of the road network that exist in the country. However, for the present study, AITD and CRRI in consultation with the World Bank decided to narrow down the scope for a quick estimate of the viable cost effective axle load limit considering the total transportation cost.

2.3 Applicability of HDM-4

Highway Development and Management (HDM-4) is user-friendly software which provides a harmonized systems approach to road management with adaptability to varying situations. It provides a powerful system for the analysis of road management and investment alternatives, and therefore, the HDM-4 has been used to investigate the economic viability of road projects in over 100 countries, and to optimize economic benefits to road users under different levels of expenditures. HDM-4 allows it to be used for different stages of highway development and management as follows:

- Planning – It involves the analysis of the road system as a whole, typically requiring the preparation of medium to long term or strategic estimates of expenditures for road development and preservation under various budget and economic scenarios.

- Programming – It involves the preparation of multi-year roadwork expenditure programmes under budget constraints indicating the road sections of the network which are likely to require maintenance, improvement or new construction. Cost-benefit analysis is undertaken to determine the economic feasibility of each set of works. The physical road network is considered at the programming stage on a link-by-link basis, with each link characterized by homogeneous pavement sections defined in terms of physical attributes.

- Preparation – It is a short term planning stage where road schemes are packaged for implementation. In this stage designs are refined and prepared in more details.

- Operation – It covers the activity of on-going operation of an organization for the network it handles. In such case decisions about managing the operations on daily or weekly basis, including the scheduling of work is carried out.

The present study is a long term programming issue where the economics of adopting different axle load options are to be evaluated. HDM-4 simulates total life cycle conditions and costs for an analysis period under a user-defined scenario of deterioration for the maintenance specifications. The primary costs for the life cycle analysis includes the costs of capital investment, maintenance and vehicle operation, to which travel time costs can be added as an option. The costs of accidents and environmental pollution can also be included in the analysis. However, the present study has excluded the costs of travel time as well as accidents and environmental pollution due to the absence of authentic data for them.

The life cycle cost analysis used in HDM-4 is about a set of interacting costs, related to those incurred by the road agency and those incurred by the road user which is added together over time in discounted present values. Costs are determined by first predicting the physical quantities of resource consumption (maintenance interventions that will be required) and then multiplying these quantities by their unit costs. Economic benefits are then determined by comparing the total cost streams for various maintenance and construction alternatives with a base case **(do nothing** or **do minimum** alternative), usually representing minimal routine maintenance. The present study has followed this method of analysis.

To perform the programme analysis for life cycle costs a set of realistic and accurate data for the road sections are required. The data obtained from the field and used to run HDM-4 software generally depend on sophisticated methods of collecting and processing. The data used for the present study are obtained from both primary and secondary sources, and the overall data can be categorised at Information Quality Level 3 (IQL-3) as defined by HDM-4. Further, the details of the homogenous sections etc are discussed in the subsequent section.

3. APPLICATION OF HDM-4 FOR THE CASE STUDIES

3.1 Location of Case Studies

a) The Agra-Bharatpur-Jaipur road is located in the state of Rajasthan, the westernmost state of India and having a semi-arid climate. The total length of the study road is 21.5 km. and is divided into two stretches viz. km 42.5 to km 54 (Agra-Bharatpur) and km. 196 to km. 206 (Bharatpur-Jaipur). The relative location of the road is shown on a map as given in **Figure 2**. It consists of seven homogenous sections of different lengths. The homogenous sections have been classified on the basis of deflection and the details of these road sections are shown in **Table 2**.

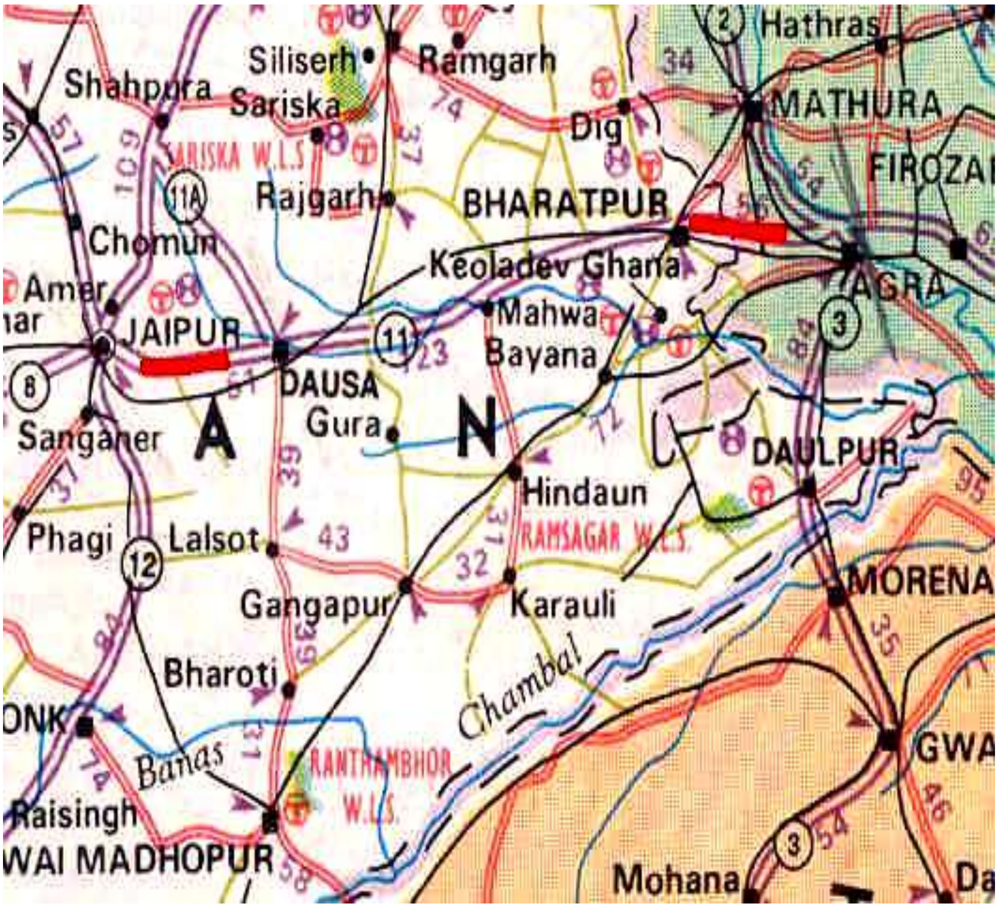


Figure 2: Location of Agra-Bharatpur-Jaipur Road Section

Table: 2 Homogenous Sections (Agra-Bharatpur-Jaipur)				
Agra-Bharatpur				
S. No.	**Pavement Width (meter)**	**Chainage (Km)**	**Length (Km)**	**Average Ch. Deflection (mm)**
1	7.00	42.00-43.00	1.00	1.08
2	7.00	43.00-44.00	1.00	1.08
3	7.00	44.00-45.00	1.00	0.92
4	7.00	45.00-46.00	1.00	1.27
5	7.00	46.00-47.00	1.00	1.35
6	7.00	47.00-48.00	1.00	0.64
7	7.00	48.00-49.00	1.00	0.99
8	7.00	49.00-50.00	1.00	0.90
9	7.00	50.00-51.00	1.00	1.13
10	7.00	51.00-52.00	1.00	1.17
11	7.00	52.00-53.00	1.00	0.66
12	7.00	53.00-54.00	1.00	0.75
Bharatpur-Jaipur				
S. No.	**Pavement Width (meter)**	**Chainage (Km)**	**Length (Km)**	**Average Ch. Deflection (mm)**
1	7.00	196.00-197.00	1.00	1.82
2	7.00	197.00-198.00	1.00	1.50
3	7.00	198.00-199.00	1.00	1.60
4	7.00	199.00-200.00	1.00	1.34
5	7.00	200.00-201.00	1.00	1.52
6	7.00	201.00-202.00	1.00	1.52
7	7.00	202.00-203.00	1.00	1.04
8	7.00	203.00-204.00	1.00	0.98
9	7.00	204.00-205.00	1.00	1.13
10	7.00	205.00-206.00	1.00	1.24

(b) Morinda - Ropar

The road is located in the state of Punjab located in north-west of India having a hot-humid climate. The total road length of the case study is 46 km. The relative location of the road is shown on a map as given in **Figure 3**. It has been divided into two separate road portions viz. Sirhind - Morinda and Morinda - Ropar. It consists of 16 (sixteen) homogenous sections of different lengths. The homogenous sections have been classified on the basis of deflection and the details of these road sections of the case study have been given in **Table 3**.

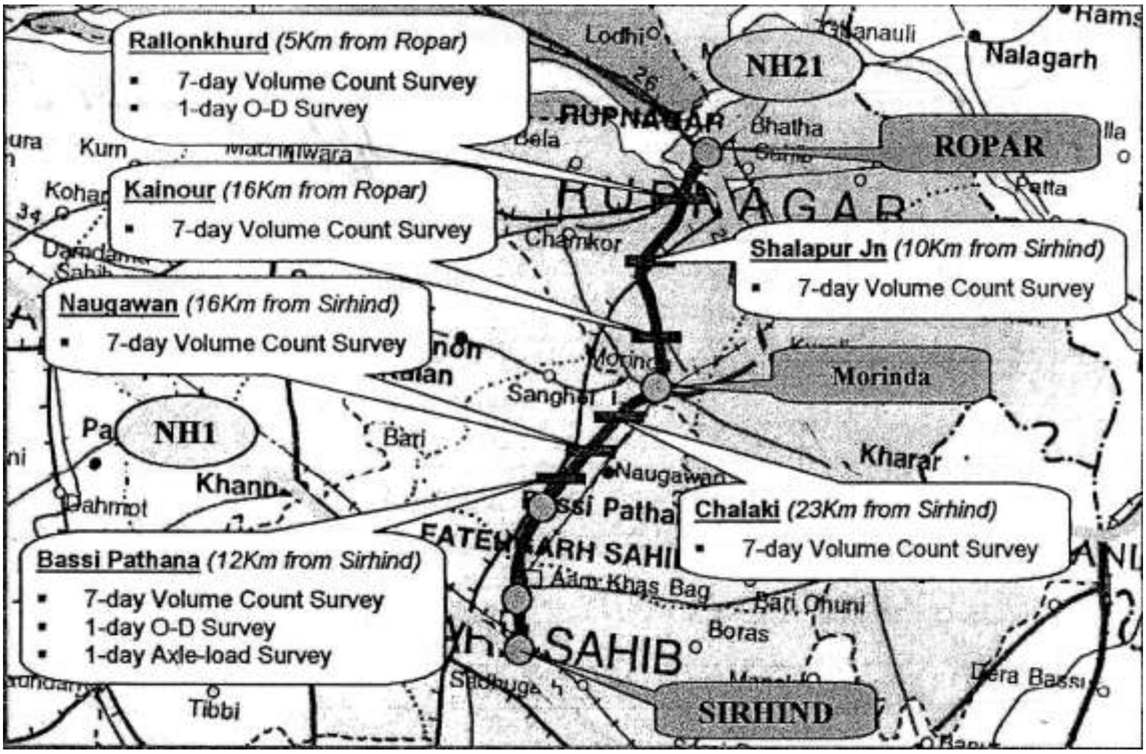


Figure 3: Location of Sirhind-Morinda-Ropar Road Section

3.2 Pavement Condition Data for Case Studies

In order to model road deterioration properly the homogeneous road sections were identified in terms of physical attributes and pavement condition so that a particular set of road deterioration relationships can be applied. Therefore, the basic unit of analysis is **homogeneous** road section with the present condition of pavement to which several investment options viz. maintenance interventions/alternatives can be assigned for analysis. The pavement conditions for Agra-Bharatpur, Bharatpur-Jaipur and Morinda-Ropar case studies are presented in **Table 4 and 5.**

Table 3: Homogenous Sections (Sirhind-Morinda-Ropar)

Sirhind-Morinda				
S. No.	**Pavement Width (meter)**	**Chainage (Km)**	**Length (Km)**	**Average Ch Deflection (mm)**
1	5.5	0.0 - 3.0	3.00	1.4600
2	5.5	3.0 - 6.0	3.00	1.6600
3	5.5	6.0 - 9.0	3.00	1.8700
4	5.5	9.0 - 11.5	2.50	2.4400
5	5.5	11.5 - 15.0	3.50	1.5800
6	5.5	15.0 - 17.0	2.00	1.0900
7	5.5	17.0 - 19.0	2.00	1.0700
8	5.5	19.0 - 24.0	5.00	2.1900
9	5.5	24.0 - 26.0	2.00	1.0000
Morinda-Roper				
S. No.	**Pavement Width (meter)**	**Chainage (Km)**	**Length (Km)**	**Average Ch Deflection (mm)**
1	5.5	0.0 - 2.2	2.20	1.8500
2	5.5	2.2 - 6.0	3.80	1.3900
3	5.5	6.0 - 8.5	2.50	1.3100
4	5.5	8.5 - 11.5	3.00	0.9800
5	5.5	11.5 - 15.0	3.50	1.5300
6	5.5	15.0 - 17.0	2.00	1.5800
7	5.5	17.0 - 20.0	3.00	1.6600

3.3 Calibration Factors for HDM-4 Models for Case Studies

Pavement deterioration manifests itself in various kinds of distresses, each of which are modeled separately viz. roughness, cracking, potholing, raveling, edge breaks, rutting, surface texture and skid resistance, in HDM-4. Each mode of distress develops and progresses at different rates in different environments; therefore it is important that the road deterioration relationships should be calibrated for the case studies before using them for road investment analyses.

Table 4: Pavement Condition Details and Roughness (Agra-Bharatpur-Jaipur)										
Agra-Bharatpur										
S. No.	**Pavement Width (meter)**	**Chainage (Km)**	**Roughness (IRI)**	**Area Cracking (%)**	**Area Ravelling (%)**	**No. of Potholes**	**Mean Rut Depth (mm)**	**Edge Break Area (m^2/km)**	**Texture Depth**	**SCRIM No.**
1	7.00	42.00-43.00	4.35	23.00	4.00	0	0.00	0.00	0.50	0.40
2	7.00	43.00-44.00	4.20	20.00	2.50	53	0.00	0.00	0.50	0.40
3	7.00	44.00-45.00	4.80	26.00	2.50	70	0.00	0.00	0.50	0.40
4	7.00	45.00-46.00	4.78	27.00	5.50	149	0.00	0.00	0.50	0.40
5	7.00	46.00-47.00	4.31	43.50	9.00	105	0.00	0.00	0.50	0.40
6	7.00	47.00-48.00	4.23	27.00	5.25	70	0.00	0.00	0.50	0.40
7	7.00	48.00-49.00	3.78	16.50	2.75	18	0.00	0.00	0.50	0.40
8	7.00	49.00-50.00	3.90	13.00	3.00	18	0.00	0.00	0.50	0.40
9	7.00	50.00-51.00	4.14	8.00	2.00	35	0.00	0.00	0.50	0.40
10	7.00	51.00-52.00	3.83	3.50	0.70	18	0.00	0.00	0.50	0.40
11	7.00	52.00-53.00	4.03	3.50	0.85	18	0.00	0.00	0.50	0.40
12	7.00	53.00-54.00	3.78	2.00	0.25	18	0.00	0.00	0.50	0.40
Bharatpur-Jaipur										
1	7.00	196.00-197.00	3.61	15.50	2.50	35	0.00	0.00	0.50	0.40
2	7.00	197.00-198.00	3.69	14.00	1.75	35	0.00	0.00	0.50	0.40
3	7.00	198.00-199.00	3.69	16.50	1.50	53	0.00	0.00	0.50	0.40
4	7.00	199.00-200.00	3.64	11.50	2.50	35	0.00	0.00	0.50	0.40
5	7.00	200.00-201.00	4.32	15.00	3.75	88	0.00	0.00	0.50	0.40
6	7.00	201.00-202.00	3.98	16.00	3.75	35	0.00	0.00	0.50	0.40
7	7.00	202.00-203.00	4.39	16.00	7.00	61	0.00	0.00	0.50	0.40
8	7.00	203.00-204.00	3.81	8.00	6.00	35	0.00	0.00	0.50	0.40
9	7.00	204.00-205.00	3.52	15.50	4.75	35	0.00	0.00	0.50	0.40
10	7.00	205.00-206.00	3.79	18.50	5.75	35	0.00	0.00	0.50	0.40

Table 5: Pavement Condition Details and Roughness (Sirhind-Morinda-Ropar)

S. No.	Pavement Width (meter)	Chainage (Km)	Roughness (IRI)	Area Cracking (%)	Area Ravelling (%)	No. of Potholes	Edge Break Area (m^2/km)	Mean Rut Depth (mm)	Texture Depth	SCRIM No.
Sirhind-Morinda										
1	5.5	0.0 - 3.0	2.70	0.00	0.00	0.00	0.00	0.00	0.70	0.50
2	5.5	3.0 - 6.0	3.10	0.00	0.00	0.00	0.00	0.00	0.70	0.50
3	5.5	6.0 - 9.0	2.90	0.00	0.00	0.00	0.00	0.00	0.70	0.50
4	5.5	9.0 - 11.5	2.60	0.00	0.00	0.00	0.00	0.00	0.70	0.50
5	5.5	11.5 - 15.0	3.20	0.00	0.00	0.00	0.00	0.00	0.70	0.50
6	5.5	15.0 - 17.0	2.70	0.00	0.00	0.00	0.00	0.00	0.70	0.50
7	5.5	17.0 - 19.0	2.80	0.00	0.00	0.00	0.00	0.00	0.70	0.50
8	5.5	19.0 - 24.0	2.50	0.00	0.00	0.00	0.00	0.00	0.70	0.50
9	5.5	24.0 - 26.0	2.30	4.50	2.00	0.00	0.00	0.00	0.70	0.50
Morinda- Roper										
S. No.	**Pavement Width (meter)**	**Chainage (Km)**	**Roughness (IRI)**	**Area Cracking (%)**	**Area Ravelling (%)**	**No. of Potholes**	**Edge Break Area (m^2/km)**	**Mean Rut Depth (mm)**	**Texture Depth**	**SCRIM No.**
1	5.5	0.0 - 2.2	4.20	9.80	4.90	0.05	137.00	6.36	0.70	0.50
2	5.5	2.2 - 6.0	2.70	1.40	0.00	0.00	15.00	3.60	0.70	0.50
3	5.5	6.0 - 8.5	2.84	0.00	0.00	0.00	0.00	0.00	0.70	0.50
4	5.5	8.5 - 11.5	2.86	3.60	0.00	0.00	13.33	1.66	0.70	0.50
5	5.5	11.5 - 15.0	2.73	8.60	0.00	0.00	181.42	7.50	0.70	0.50
6	5.5	15.0 - 17.0	2.72	2.70	0.20	0.05	20.00	0.90	0.70	0.50
7	5.5	17.0 - 20.0	2.79	14.33	0.20	0.05	20.00	4.70	0.70	0.50

To facilitate this, the relationships include a number of user-definable deterioration factors to change the scale of a particular distress. Since the models simulate future changes to the road system from current conditions through rate of deterioration, the reliability of the results is dependent upon two primary considerations:

- How well the data provided to the model represent the reality of current conditions and influencing factors, and
- How well the predictions of the model fit to the true deterioration behaviour and the interactions between various factors for the variety of conditions (the matrix).

Therefore, application of the model thus involves two important steps:

- Correct input data for the existing conditions
- Calibration of HDM-4 – Adjusting the model parameters to match with the actual changes represented by the knowledge and experience, or observed data on quantitative measures of influences over time for various interventions.

Calibration of the HDM-4 model, therefore, focuses on the two primary components that determine the physical quantities, costs and benefits predicted for the analysis, which are:

- **Road User Effects (RUE) –** It consists of vehicle operating costs (VOC), travel time, safety and emissions, and
- **Road Deterioration and Work Effects (RDWE) –** It consists of the deterioration of the pavement and the impact of maintenance activities on pavement condition, and the future rate of pavement deterioration.

The rational values of various components of road user costs with respect to VOC and value of time etc as given by Archondo Callao (2003) and gross vehicle weight (GVW) influence on speed as given by TRRL Report 1057 (1982) are appropriately used to account for road user effect (RUE), while the influence of road deterioration (roughness) on VOC is a in-built relationship of HDM-4.

For calibrating the HDM-4 models on road deterioration and work effects, the following data items were collected appropriate to the two case studies:

- The effect of traffic on pavement deterioration
- The effect of the environment on pavement deterioration
- Deterioration rates by pavement type
- Surface distresses, and
- Pavement strength parameters

Some of the important inputs related to construction quality, structural defects, drainage condition and calibration factors for roughness, cracking, potholing, raveling, etc were established by repeated running of the models for homogenous sections to have the deterioration pattern simulated in a realistic manner as it occurs. Since the performance history of both the case studies with its maintenance history was not available, iterative trial runs were taken to produce the present insitu conditions. The calibration factors so obtained were matched with the factors obtained using the data of Pavement Performance Study: Study on Existing Pavements (PPS-EPS). It was found that the quality of pavement construction specially in the case study sections were generally inferior. In HDM-4, the inputs for construction defects are given through two factors:

CDS – Construction defects indicator for bituminous surfacing (range from 0.5 to 1.5). When bituminous surfacing is dry (brittle), with binder content nominally 10 % below optimal then CDS is 0.5. If it is normal surfacing, with binder content at optimal value then CDS is 1.0 and if bituminous surfacing is rich (soft), with binder content nominally 10 % above optimal then CDS is 1.5. The value of CDS used in this analysis is 0.9.

CDB – Construction defects indicator for the base ranges between 0 (no construction defects) and 1.5 (severe defects). Defects considered are only moderate for the case studies and it can be less than 0.5

representing, fair gradation of base material, fair aggregate shape and fair compaction.

The values given to these control parameters are chosen on the basis of extensive data collected during construction of several road projects under PPS-NPS study. Based on the quality of pavement construction and the material properties revealed from the data collected at sites of the two case study roads, the values are decided for trial runs of HDM-4 for calibration.

As per the detailed traffic survey data available for Agra-Bharatpur and Bharatpur-Jaipur sections the commercial vehicle traffic were considerably high in comparison to Morinda-Ropar section. Therefore, the calibration factors for initiation and progression of structural cracking, raveling and potholing were varied for individual distress as well as with a combination of distresses. It was found that the deterioration of road due to traffic loads was matching with the time taken for deterioration in actual conditions (based on historical data of other roads in the same area), and the period was ranging from 4-6 years for different maintenance interventions. Thus the most logical and acceptable calibration factors were given as input for running the HDM-4 which is presented in **Table 6**.

Table 6: Calibration Factors Adopted in Analysis

Parameter	Range Explored		Values Adopted		Limits
	Initiation	Progression	Initiation	Progression	
All Structural Cracking	0.5-0.75	1.5-1.75	0.5	1.5	0-20
Wide Structural Cracking	1-1.15	1-1.25	1	1	0-20
Ravelling	0.8-1	1-1.2	0.8	1.2	0-20
Pothole	0.7-1	1-1.5	0.7	1.5	0-20
Edge Break	1-1.5		1		0-20
Environment Coefficient	1-1.5		1.5		0-20
Roughness Progression	1-3		2-2.5		0-20
Construction Defect -Surface	0.9-1		0.9		0.5-1.5
Construction Defect -Base	0.4-0.6		0.4		0-1.5

3.4 Database for HDM-4 Inputs for Case Studies

3.4.1 Capping of Axle Loads

The vehicle damage factor (VDF) is a measure of the damage caused to the pavement by heavy vehicles. It is a function of the axle configuration and it's mass. The VDF is calculated using the equation given below (HDM-4):

$$VDFVEH_K = \sum_{L_1}^{n} \left(\frac{AX_i}{SX_j} \right)^4 \quad \text{Eq. (1)}$$

and

$$VDF_z = \frac{\sum_{k=1}^{z} VDFVEH_K}{z} \quad \text{Eq. (2)}$$

where:

$VDFVEH_k$ is the vehicle damage factor for vehicle k (ESA/vehicle)

VDF_z is the vehicle damage factor for a class of vehicles (ESA/vehicle)

AX_i is the load on axle i (tonnes)

SX_j is the standard axle load for the axle group j (tonnes)

n is the number of axles on the vehicle

z is the number of vehicles in the given class of vehicles.

It is common to divide the stream into similar vehicle class, for example, medium, heavy and articulated trucks, and calculate a VDF_z for each class. The standard axle loads SX_j for different configurations adopted in HDM-4 are:

6.60 tonne single wheel, single axle

8.16 tonne dual wheel, single axle

9.00 tonne dual wheel, per tandem axle

15.1 tonne dual wheel, per tandem axle group

10.0 tonne dual wheel, per triple axle

22.9 tonne dual wheel, per triple axle group

There are several steps in computation of the VDF which are:

a) Divide the actual axle load of the rear and front axle of a vehicle by the standard axle load of respective type of axle (with specific wheel configuration) to obtain the equivalent standard axles, which is then converted to VDF of the particular vehicle using the 4^{th} power law as shown in equation (1).

b) The sum of all VDFs of a given class of vehicles when divided by total number of vehicles of that class, say 'z', as shown in equation (2), gives average VDF for that category of vehicle.

c) The VDF for the total traffic stream is computed from the weighted sum of average VDFs of all categories of vehicles present in the traffic stream which includes empty, partially-loaded as well as fully and over-loaded vehicles.

Since the calculations use the 4^{th} power rule, some vehicles operating with very high axle loads will have very high values for their $VDFVEH_k$. The 'business as usual' (BAU) scenario describes the actual situation on the road with respect to the actual spectrum of axles operating in each of the case studies of the two roads. The computation of $VDFVEH_k$ and VDF of Agra-Bharatpur-Jaipur and Morinda-Ropar, the two road sections, from the observed data (BAU) are presented in **Table 7 and 8**.

The aim of this study is to examine the effect on the road system through the possible other alternative scenarios when the axle loads are strictly enforced as 10, 11, 12 and 13 tonnes separately. Therefore, two different approaches were proposed in each of these scenarios which amount to capping the axle load at the chosen level (and to derive the resultant composition of traffic). Of course, this assumes that the enforcement regime will be able to control the legal axle load considered in each of the scenarios. The explanations of these methods are detailed below:

Table 7: Vehicle Damage Factor (VDF) at Different Loadings (Agra-Bharatpur-Jaipur)

Vehicle Type	10 Tonnes		11 Tonnes		12 Tonnes		13 Tonnes		Business As Usual	
	No. of Vehicles	VDF	No. of Vehicles	VDF	No. of Vehicles	VDF	No. of Vehicles	VDF	No. of Vehicles	VDF
LCV	198	0.21	198	0.21	198	0.21	198	0.21	198	0.21
Buses	380	0.95	380	0.95	380	0.95	380	0.95	380	0.95
Truck-2Axles	987	2.13	919	2.98	862	4.07	814	5.42	754	13.19
Truck-Multi Axles	776	2.94	725	4.11	682	5.57	648	7.03	618	12.86
Total Vehicles Weighed /Average VDF	2341	2.04	2222	2.75	2122	3.63	2040	4.59	1950	9.38

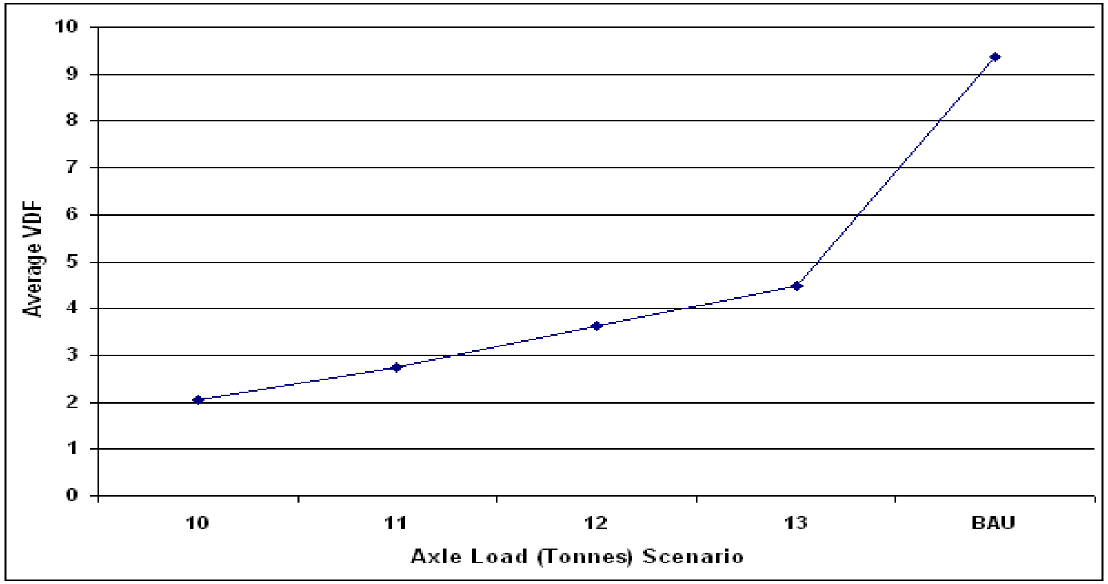


FIGURE 4 AXLE LOADS vs. AVERAGE VDF (AGRA-BHARATPUR-JAIPUR)

Table 8: Vehicle Damage Factor (VDF) at Different Loadings (Morinda-Ropar)

Vehicle Type	10 Tonnes		11 Tonnes		12 Tonnes		13 Tonnes		Business As Usual	
	No. of Vehicles	VDF	No. of Vehicles	VDF	No. of Vehicles	VDF	No. of Vehicles	VDF	No. of Vehicles	VDF
LCV	29	0.18	29	0.18	29	0.18	29	0.18	29	0.18
Buses	14	0.63	14	0.63	14	0.63	14	0.63	14	0.63
Truck-2Axles	180	1.76	174	2.32	170	2.90	166	3.67	121	6.55
Truck-Multi Axles	6	2.00	6	2.50	6	3.10	6	3.60	7	4.19
Truck-Tandam Axles	30	0.50	29	0.60	28	0.70	28	0.80	19	2.94
Total Vehicles Weighed & Average VDF	259	1.38	252	1.79	247	2.21	243	2.75	190	4.69

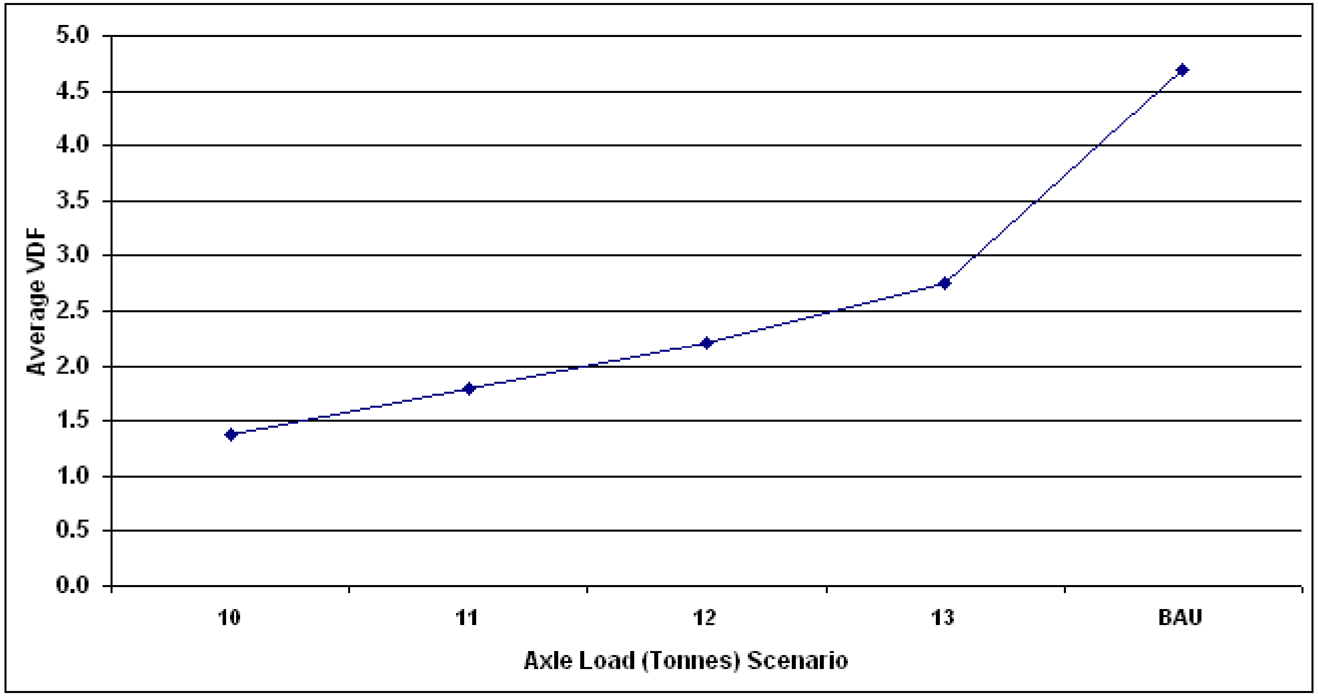


FIGURE 5 Axle Loads vs. Average VDF (Morinda-Ropar)

a) In the first method, when the axle legal load limit is at 10 tonnes, all trucks carrying extra loads making axle load more than 10 tonnes are converted to additional trucks of 10 tonnes axle category using the total extra load carried by such trucks, and additional trucks of 10 tonnes axle limit only are added to the traffic to make up for the extra load that were carried by the overloaded trucks. All the trucks and other vehicles carrying less than 10 tonnes axle load are considered as it is with their respective axle loads for calculation of VDF. Thus, in other scenarios of 11, 12 and 13 tonnes also the axle loads below the capping level were considered in the traffic composition as they were observed in the case of BAU for calculation of VDFs separately for each scenario.

b) In the second method, all the trucks carrying 10 tonnes axle and more (i.e. above the present legal axle load limit) are totaled in terms of total load that is carried along the route (road section) by the truck fleet. This total load is separately divided by 10, 11, 12, and 13 tonnes to create the fleet of capped axle load trucks in the traffic for each scenario. All the trucks and other vehicles carrying less than 10 tonnes axle load are considered as it is with their respective axle loads and added to the capped fleet to obtain the total composition of traffic for calculation of the VDF in each scenario.

The second approach was considered more realistic (through discussion with the World Bank), and therefore, has been used for further analysis. The details of VDFs after capping for the two case studies are already presented in **Tables 7 & 8** as well as **Figures 4 and 5**. The vehicle fleet formed by capping of axle load adds to the specific axle weight category, and modifies the AADT as well as changes the composition of the traffic. These scenarios with capping of axle loads were used in HDM-4 to determine the optimal TTC for suggesting the best axle load policy.

3.4.2 Generation of Alternative Specifications of Maintenance Options

After the identification of homogenous sections, a design matrix of maintenance actions applicable for these sections has been evolved. The overlay specifications developed for the sections based on structural adequacies of the pavement are presented in **Table 9 and 10** for Bharatpur-Jaipur and Morinda-Ropar, respectively. The required overlay can be provided with different alternative combinations of maintenance specifications. Moreover, the maintenance strategies, of course, can be developed considering the minimum investment maintenance strategy or up to a rich maintenance strategy. In the present study, the maintenance action matrix is developed considering different axle load scenarios before and after capping the axle loads and the analysis period of 15 years.

Table 9: Rebound Deflection and Corresponding Overlay Requirements (Bharatpur-Jaipur)

Chainage(Km.)	Deflection	15 Years		
		BM Thickness (mm)	DBM (mm)	BC (mm)
Actual Loading				
196-197	1.82	260	130	50
197-198	1.50	240	120	50
198-199	1.60	245	120	50
199-200	1.34	230	110	50
200-201	1.52	240	120	50
201-202	1.52	240	120	50
202-203	1.04	205	100	50
203-204	0.98	200	90	50
204-205	1.13	215	100	50
205-206	1.24	225	110	50
10 Tonnes				
196-197	1.82	190	85	50
197-198	1.50	165	70	50
198-199	1.60	170	70	50
199-200	1.34	145	50	50
200-201	1.52	165	70	50
201-202	1.52	165	70	50
202-203	1.04	120	50	40
203-204	0.98	120	50	40
204-205	1.13	130	50	40
205-206	1.24	140	50	50
11 Tonnes				
196-197	1.82	200	90	50
197-198	1.50	175	75	50
198-199	1.60	180	75	50
199-200	1.34	150	55	50
200-201	1.52	175	75	50
201-202	1.52	175	75	50
202-203	1.04	125	50	40
203-204	0.98	125	50	40
204-205	1.13	140	50	50
205-206	1.24	150	55	50

Chainage(Km.)	Deflection	15 Years	DBM (mm)	BC (mm)
		BM Thickness (mm)		
12 Tonnes				
196-197	1.82	210	100	50
197-198	1.50	185	80	50
198-199	1.60	190	85	50
199-200	1.34	160	65	50
200-201	1.52	185	80	50
201-202	1.52	185	80	50
202-203	1.04	130	50	40
203-204	0.98	130	50	40
204-205	1.13	145	50	50
205-206	1.24	160	65	50
13 Tonnes				
196-197	1.82	220	105	50
197-198	1.50	190	85	50
198-199	1.60	195	90	50
199-200	1.34	180	75	50
200-201	1.52	190	85	50
201-202	1.52	190	85	50
202-203	1.04	150	55	50
203-204	0.98	145	50	50
204-205	1.13	155	60	50
205-206	1.24	175	75	50

3.4.3 Climate

Each case study location has a very different type of climate, and therefore, specific climatic factors for both the cases have been configured for HDM-4. Agra-Bharatpur and Bharatpur-Jaipur case studies are located at semi-arid climate. The details of input provided in these cases have been presented in **Tables 11 and 12.**

Table 10: Rebound Deflection and Corresponding Overlay Requirements (Sirhind-Morinda-Ropar)

Chainage (Km.)	Deflection		10 Years			15 Years		
	Left	Right	Gr. Th,ness (mm)	BM (mm)	SDBC (mm)	Gr. Th,ness (mm)	DBM (mm)	BC (mm)
Actual Loading								
20	1.4180	1.6600	170	75	40	175	75	40
17	1.5620	1.5780	170	75	40	175	75	40
14	1.4940	1.5320	170	75	40	175	75	40
11.2	0.9280	0.9800	75	50	40	80	50	40
8	1.3100	1.2200	125	50	40	130	50	40
5	1.3010	1.3870	135	50	40	140	60	40
2	1.8520	1.8450	175	75	40	180	75	40
10 Tonnes								
20	1.4180	1.6600	105	75	25	95	60	25
17	1.5620	1.5780	90	60	25	105	75	25
14	1.4940	1.5320	90	60	25	105	75	25
11.2	0.9280	0.9800						
8	1.3100	1.2200	80	50	25	80	50	25
5	1.3010	1.3870	80	50	25	95	65	25
2	1.8520	1.8450	120	75	40	140	75	25
11 Tonnes								
20	1.4180	1.6600	120	75	40	150	75	50
17	1.5620	1.5780	105	75	25	120	75	40
14	1.4940	1.5320	100	75	25	115	75	40
11.2	0.9280	0.9800						
8	1.3100	1.2200	90	60	25	90	60	25
5	1.3010	1.3870	95	60	25	105	75	25
2	1.8520	1.8450	140	75	50	155	75	50
12 Tonnes								
20	1.4180	1.6600	125	75	40	145	60	40
17	1.5620	1.5780	120	75	40	125	60	40
14	1.4940	1.5320	115	75	40	120	50	40
11.2	0.9280	0.9800						
8	1.3100	1.2200	80	50	25	100	50	40
5	1.3010	1.3870	80	50	25	110	50	40
2	1.8520	1.8450	155	75	50	160	75	40
13 Tonnes								
20	1.4180	1.6600	145	60	40	150	60	40
17	1.5620	1.5780	125	50	40	140	60	40
14	1.4940	1.5320	120	50	40	130	50	40
11.2	0.9280	0.9800				60		40
8	1.3100	1.2200	95	50	40	110	50	40
5	1.3010	1.3870	105	50	40	120	50	40
2	1.8520	1.8450	160	75	40	170	75	40

Table 11: Input parameters of Agra-Bharatpur-Jaipur Section

Name	Rajasthan
Moisture Classification	Semi-Arid
Moisture Index	- 40
Duration of Dry Season	0.75
Mean Monthly Precipitation	50
Temperature Classification	Sub Tropical Hot
Mean Temperature	23
Average Temperature Range	15
Days T>32^{o}C	180 Days
Freeze Index	21 days
Percentage of Time Driven On Snow Covered Roads On Water Covered Roads	 0 (0<=PCTDS<=100) 10 (0<=PCTDW<=100)

Table 12: Input parameters of Sirind-Morinda-Ropar

Name	Punjab
Moisture Classification	Sub Humid
Moisture Index	0
Duration of Dry Season	0.5
Mean Monthly Precipitation	100
Temperature Classification	Sub Tropical Hot
Mean Temperature	21
Average Temperature Range	17
Days T>32^{o}C	150 Days
Freeze Index	0^{0} C - 0 days
Percentage of Time Driven On Snow Covered Roads On Water Covered Roads	 0 (0<=PCTDS<=100) 10 (0<=PCTDW<=100)

3.4.4 Traffic Volume

Annual Average Daily Traffic (AADT) is required as an input in HDM-4, with the composition of vehicle categories in percentage. In the present analysis, the traffic volume changes due to capping of axle weights at different axle load limits considered in the study and excess weight is converted into number of extra vehicles of same category. These extra vehicles modify the respective AADT of the weight categories. Thus, the traffic composition also changes with respect to the capped weight category. The traffic compositions arrived at after capping for both the cases have been presented in **Tables 13 and 14.**

Table 13 : Traffic Composition at Different Loadings (Agra-Bharatpur-Jaipur)

(Agra-Bharatpur) July-2003

Name of Vehicle	Actual Traffic		10 Tonnes		11 Tonnes		12 Tonnes		13 Tonnes		Traffic Growth
	Nos.	Percent	Nos.	Percent	Nos.	Percent	Nos.	Percent	Nos.	Percent	
Two Wheelers	2501	31.03	2501	28.54	2501	29.26	2501	29.88	2501	30.42	3%
Cars	1844	22.88	1844	21.04	1844	21.57	1844	22.03	1844	22.43	6%
Tra. Tro	597	7.41	597	6.81	597	6.98	597	7.13	597	7.26	6%
Buses	406	5.04	406	4.63	406	4.75	406	4.85	406	4.94	3%
LCV	240	2.98	240	2.74	240	2.81	240	2.87	240	2.92	2%
Tr.2-Axle	1332	16.53	1744	19.90	1623	18.99	1523	18.20	1438	17.49	6%
Tr.M-Axle	1140	14.14	1431	16.34	1337	15.64	1258	15.03	1195	14.54	2%
Total	8060	100.00	8763.07	100.00	8548.86	100.00	8368.85	100.00	8221.33	100.00	3%

(Bharatpur-Jaipur) July-2003

Name of Vehicle	Actual Traffic		10 Tonnes		11 Tonnes		12 Tonnes		13 Tonnes		Traffic Growth
	Nos.	Percent	Nos.	Percent	Nos.	Percent	Nos.	Percent	Nos.	Percent	
Two Wheelers	1052	14.65	1052	13.29	1052	13.68	1052	14.02	1052	14.32	3%
Cars	2246	31.27	2246	28.38	2246	29.20	2246	29.94	2246	30.57	6%
Tra. Tro	137	1.91	137	1.73	137	1.78	137	1.83	137	1.86	6%
Buses	699	9.73	699	8.83	699	9.09	699	9.32	699	9.51	3%
LCV	450	6.26	450	5.69	450	5.85	450	6.00	450	6.12	2%
Tr.2-Axle	1258	17.51	1647	20.81	1533	19.94	1438	19.17	1358	18.48	6%
Tr.M-Axle	1341	18.67	1684	21.28	1573	20.46	1480	19.726	1406	19.14	2%
Total	7183	100.00	7914.59	100.00	7690.471	100.00	7502.065	100.00	7348.203	100.00	3%

Table 14 : Traffic Composition at Different Loadings (Morinda-Ropar)

(Morinda-Ropar) December-2003											
Name of Vehicle	**Actual Traffic**		**10 Tonnes**		**11 Tonnes**		**12 Tonnes**		**13 Tonnes**		**Traffic Growth**
	Nos.	**Percent**	**Nos.**	**Percent**	**Nos.**	**Percent**	**Nos.**	**Percent**	**Nos.**	**Percent**	
Two Wheelers	1354	32.33	1354	31.00	1354	31.60	1354	32.05	1354	32.46	3%
Cars Old	68	1.62	68	1.56	68	1.59	68	1.61	68	1.63	6%
Cars New	1110	26.50	1110	25.41	1110	25.90	1110	26.28	1110	26.61	6%
Tra. Tro	232	5.54	232	5.31	232	5.41	232	5.49	232	5.56	3%
Buses	97	2.32	97	2.22	97	2.26	97	2.30	97	2.33	2%
LCV	253	6.04	253	5.79	253	5.90	253	5.99	253	6.07	6%
Tr.2-Axle	951	22.71	1101	25.21	1030	24.04	975	23.08	928	22.25	2%
Tr.M-Axle	7	0.17	6	0.14	6	0.14	6	0.14	6	0.14	3%
Tr.Ta-Axle	116	2.77	147	3.37	135	3.15	129	3.05	123	2.95	3%
Total	4188	100.00	4368	100.00	4285	100.00	4224	100.00	4171	100.00	

3.4.5 Speed

Normally the vehicle fleet is to be generated as per the actual traffic composition present at the site, and thereafter, the basic desired speed of the stream in kilometers per hour is required. The basic desired speed is defined as the speed at which drivers would desire to travel on an ideal two lane bi-directional rural highway when there are no interruptions due to traffic, and the speed is not constrained by geometrics of highway. The desired speeds for different vehicles are taken from the study on 'Updation of Road User Cost Data', carried out in the year 2001. The desired speeds for light vehicles are considered same with or without capping for axle loads, as under Vehicle Damage Factor (VDF) analysis only the commercial vehicles are considered. Also the commercial vehicle coming under the capped axle weights categories are only two axle trucks, multi-axle trucks and tandem axle trucks (excluding the buses). The decrease in speed for these commercial vehicles due the increased operating weights has also been considered. The method adopted for arriving at the commercial vehicle speed at a given operating weight (GVW) has been as shown in Equation 3 (TRRL, 1982). The combined equation developed for bus and truck for estimation of speed is as follows:

$$V = 49.0 + (1.429-0.02860\ S_T)\ RS + (-0.867 + 0.01318S_T)\ F + (0.177 - 0.00346\ S_T)\ C + (-1.900 + 0.04346\ S_T)\ PW - 0.00106\ R \qquad \text{Eq.. (3)}$$

Where:

S_T = Observed 'free speed' of buses and trucks in kmph.

RS = Rise in m/km

F = Fall in m/km

C = Curvature in degrees/km

R = Roughness in mm/km

PW = Power to weight ratio in brake horse power/tonne

A partial differentiation of the equation has been used to arrive at operating speed based on only power weight ratio and free speed of the vehicle category. The speed reduction due to different operating weights in a truck is presented in **Figure 6**. Similar, plots can be derived for different categories of trucks. However, for the simplicity and brevity of analysis a BHP of 200 has been adopted uniformly for all the three categories of trucks.

The modified speeds at different levels of capped axle weight are derived from the graph shown in **Figure 6** and desired inputs to HDM-4 are presented in **Table 15**. The operating speeds for all other vehicles are taken from RUCS and remain unaffected due to capping of axle loads.

Table 15: Desired Speeds of Different Vehicles at Different Operating Weight

Vehicle Category	Speed (kmph) at Different Axle Loads				
	10 (Tonnes)	11 (Tonnes)	12 (Tonnes)	13 (Tonnes)	Normal case (BAU)
Car New	86.83	86.83	86.83	86.83	86.83
Car old	71.70	71.70	71.70	71.70	71.70
LCV	70.75	70.75	70.75	70.75	70.75
Bus	72.65	72.65	72.65	72.65	72.65
Two Wheelers	54.50	54.50	54.50	54.50	54.50
Tractor Trolley	30	30	30	30	30
Two- Axle Trucks	60.45	60.04	59.30	59.00	58.72
Multi Axle Trucks	57.62	57.31	56.90	56.70	56.60
Tandem Trucks	57.62	57.31	56.90	56.70	56.60/57.64*

* The operating speed of Tandem Trucks at Agra-Bharatpur-Jaipur section for normal case is high (57.64 kmph).

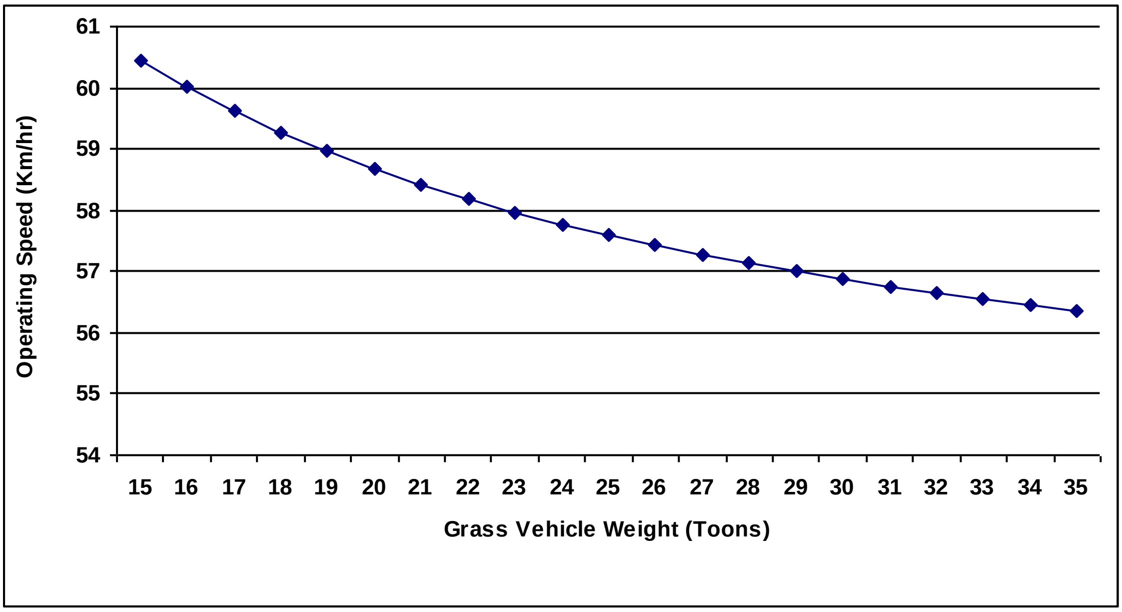


FIGURE 6 GROSS VEHICLE WEIGHT AND OPERATING SPEED FOR TRUCKS

3.4.6 Generation of Traffic Flow and Speed Flow Types

The variation of traffic flow during the 24 hrs is captured by accounting the percent of AADT operated during the relevant hours of the day. Further, the speed - flow relationship is characterized by three distinct volumes: ultimate capacity, free flow capacity and normal capacity. In addition, free flow speeds for the stream is required to effect the speed reduction due to increase in volume. The traffic and speed flow for Agra-Bharatpur-Jaipur and Morinda-Ropar case studies have been detailed in **Tables 16 and 17.**

Table 16: Traffic Flow and Speed-Flow for Agra-Bharatpur-Jaipur Case

Traffic Flow	Road use	Inter-Urban	
	Flow distribution of AADT over time	Hours Per Year	% of AADT during the period
	Period 1	2190	20
	Period 2	2190	25
	Period 3	2190	20
	Period 4	2190	35
Speed Flow			
	Road type	Two Lane (7.5. meter)	
	Ultimate capacity	1400	
	Free flow capacity	0.1 (0<XQ1<1)**	
	Nominal capacity	0.75 (0<XQ2<1)***	
	Jam speed capacity	25 km/hr	
	Accident rates (in numbers per 100 million veh.-km)	Data not available	

* PCSE — Passenger Car Space Equivalent

** $XQ1 = X_0 / X_{ult}$ — where X_0 = Flow level below which traffic interactions are negligible in PCSE /Hr, and X_{ult}= Ultimate capacity of road for stable flow (PCSE/Hr)

*** $XQ2 = X_{nom} / X_{ult}$ — where X_{nom} = Nominal capacity of the road in PCSE/Hr

Table 17: Traffic Flow and Speed-Flow for Morinda-Ropar Case

Traffic Flow	Road use	Inter-Urban	
	Flow distribution of AADT over time	Hours Per Year	% of AADT during the period
	Period 1	2190	20
	Period 2	2190	25
	Period 3	2190	20
	Period 4	2190	35
Speed Flow			
	Road type	Intermediate Lane (5.5. meter)	
	Ultimate capacity	1100	
	Free flow capacity	0.1 (0<XQ1<1)**	
	Nominal capacity	0.7 (0<XQ2<1)***	
	Jam speed capacity	20 km/hr	
	Accident rates (in numbers per 100 million veh.-km)	Data not available	

* PCSE Passenger Car Space Equivalent

** XQ1 = X_0 / X_{ult} where X_0 = Flow level below which traffic interactions are negligible in PCSE /Hr, and X_{ult}= Ultimate capacity of road for stable flow (PCSE/Hr)

*** XQ2 =X_{nom} / X_{ult} where X_{nom} = Nominal capacity of the road in PCSE/Hr

3.5 General Inputs for the Case Studies

The general inputs used for the run of HDM-4 software in either of the two case studies are presented in **Table 18.**

Table 18: General Inputs

Patching	Time lapse to patching	Two months
Shoulders	Number of shoulders Edge steps	2 10 mm
Drainage	Condition	Poor
Type of analysis		Life cycle
Start period		Year 2004
Analysis period		15 years
Currency		Indian rupees
Discount rate		8% and 12%

4. PROGRAMME ANALYSIS IN HDM-4

Programme analysis is concerned with preparation of a multi-year rolling programme or life cycle cost analysis for a road network in which the investment options are identified and selected, subject to resource constraint or without the constraint. Road networks are analysed section by section and estimates are produced for road works, and expenditure requirements for each section for each year of the analysis period is computed. The total transportation cost (TTC) consisting road agency cost (RAC) and vehicle-operating cost (VOC) is obtained as an output from the analysis (HDM-4 run). In the present case studies the programme analysis is applied and the life cycle cost analysis method has been used for a period of 15 years. Also, a comparison is made with a base case (minimum required maintenance). In the two case studies with six different alternatives of maintenance interventions and a “do nothing” alternative (with routing maintenance only) have been provided as possible interventions to all homogenous sections of both the case studies. In the base alternative three activities viz. pothole repairs, crack sealing and shoulder repair are included as a normal routine maintenance. However, it may be mentioned that all other interventions will invariably be accompanied with the normal routine maintenance requirements. The details of the base alternative and other alternatives provided with specific interventions are given in **Table 19**.

These maintenance interventions shown in **Table 19** are applicable for both Agra-Bharatpur and Bharatpur-Jaipur case studies. The maintenance for a given section of road can be applied in different ways; for example, on a fixed schedule of maintenance or a fully responsive one to the threshold level (i.e. minimum acceptable level of serviceability) defined as responsive maintenance. However, the routine maintenance as indicated in **Table 19** is applied as minimum required maintenance i.e. required for operating the road. Thus, three alternative maintenance strategies have been explored with the two case studies which are described in this section.

Table 19 : Maintenance Strategies, Strength Coefficient, Costs, Type of Maintenance and Intervention Criteria

Maintenance Strategy with Thickness (mm)	Strength Coefficient	Economic Cost (Rs./Sq mt)	Financial Cost (Rs./Sq mt)	Type of Maintenance	Intervention Criteria	Remarks
Patching	N.A.	30.00	35.00	Routine Maintenance	>=3 no. of Potholes	Base Alternative
Crack Sealing	N.A.	11.00	13.00	Routine Maintenance	Wide Structural Cracking>=5%, Thermal Cracking >= 5%	Base Alternative
Shoulder Repair	N.A.	10500 (Per/Km)	12000 (Per/Km)	Routine Maintenance	Yearly	Base Alternative
Drainage Repair	N.A.	280000 (Per/Km)	322000 (Per/Km)	Routine Maintenance	Yearly	Base Alternative
30 mm SDBC	0.300	102.00	120.00	Renewal	Total Damage>=25% & Roughness >=6 IRI	R-SDBC
40 mm BC	0.350	125.00	155.00	Renewal	Total Damage>=25% & Roughness >=6 IRI	R-BC
50 mm BM +30 mm SDBC	0.280	206.00	240.00	Overlay	Total Damage>=25% & Roughness >=6 IRI	STG1
50 mm DBM +30 mm SDBC	0.310	240.00	270.00	Overlay	Total Damage>=25% & Roughness >=6 IRI	STG2
50 mm DBM +40 mm BC	0.325	260.00	305.00	Overlay	Total Damage>=25% & Roughness >=6 IRI	STG3 +
60 mm DBM +40 mm BC	0.328	265.00	305.00	Overlay	Total Damage>=25% & Roughness >=6 IRI	STG3*
75 mm DBM +40 mm BC	0.330	320.00	370.00	Overlay	Total Damage>=25% & Roughness >=6 IRI	STG4

SDBC = Renewal by Semi Dense Bitumeniuos Concrete
BC = Renewal by Bitumeniuos Concrete
DBM = Dense Bitumeniuos Macadam
BM = Bitumeniuos Macadam
+STG3 = Maintenance Alternative used in Morinda-Ropar Sections
*STG3 = Maintenance Alternative used in Agra-Bharatpur-Jaipur Sections

4.1 Scheduled Maintenance Intervention Strategy

In HDM-4, scheduled maintenance intervention at a fixed year indicates the application of the particular maintenance intervention in the given year whether justified or not. The cost of work items of the maintenance strategy shall be added in the economic analysis for the chosen year. Whereas, in responsive maintenance the work items of interventions are used for maintenance depending on the intervention criteria viz. threshold level of roughness, cracking etc. Whenever the maintenance interventions are falling in any analysis year, the costing of work item shall be added in that year for economic analysis.

Initially it was felt appropriate to enforce maintenance interventions at fixed intervals for both the cases (as is happening in the case for many roads) as detailed in Section 2.2. It has been observed that the maintenance strategies applied as scheduled intervention on homogenous sections had negligible pavement deterioration in the analysis period. As the results of analysis were felt to be not realistic, this strategy was abandoned.

4.2 First Year Fixed and Remaining Responsive Maintenance Intervention Strategy

The normal process of pavement management includes the evaluation of existing pavement for determination of overlay thickness, based on the traffic and structural capability of the existing pavement. Thus, this strategy allows the appropriate overlay cost in the first year as the required intervention which goes into the economic analysis. Of course, once the road is brought to the required threshold level, the maintenance strategy for the rest of the period of life cycle is provided as responsive maintenance interventions. The pavement deterioration pattern after the application of first year scheduled maintenance intervention is found to be almost negligible for more than 7 to 9 years in both the study cases, which is not realistic as per the existing pavement deterioration behaviour observed in India. This is also, therefore, felt to be an unrealistic behaviour of pavement, and therefore, this strategy was also abandoned.

4.3 Total Responsive Maintenance Intervention Strategy

After experimenting with both the strategies mentioned above, it was decided that the maintenance intervention criteria should be totally responsive for both the case studies. Therefore, the work items in the maintenance strategies were made totally responsive to the intervention criteria as detailed in **Table 19,** and these were applied to the homogenous sections for both the case studies. The deterioration pattern was controlled by the calibration factors described in the earlier section 3.3 based on the construction history and structural details of pavement in each case study in reference to the traffic using these roads. The deterioration pattern was found quite satisfactory and matching to the normal case, as it happens in this region of the country. Once the HDM-4 output was validated as above using the BAU scenario, the different simulating runs were taken fo the alternate axle load limit scenarios for 10 tonnes, 11 tonnes, 12 tonnes and 13 tonnes, by capping the axle load at these levels, meaning thereby that a stricter enforcement regime will be able to achieve it in each scenario. Thus, the two specific homogenous sections for the case studies as already mentioned in Table 2 were identified for this experimentation. The details of the analysis outputs with road agency cost, vehicle operating cost and total transportation cost are shown in **Tables 20-25. Figures 7-12** show the variation of total transportation cost and road user costs (RUC) at different axle load scenarios with discount rate of 8% and 12% separately. **Tables 26-28** and **Figures 13-15** show the share of VOC per vehicle-km for all types of trucks and all other motorized vehicles separately.

Table 20 : Analysis of Total Transportation Cost for Different Axle Load Scenario (Agra-Bharatpur- Rupees in Millions, Discount Rate: 8 %)

Axle Load Scenario (Tonnes)	Maintenance Alternatives											
	Base			R-BC			R-SDBC			STG1		
	RAC	RUC	TTC	RAC	RUC	TTC	RAC	RUC	TTC	RAC	RUC	TTC
10	14.78	2604.72	2619.5	10.16	1694.29	1704.45	8.42	1703.18	1711.6	15.64	1699.58	1715.22
11	14.78	2037.98	2052.77	10.16	1350.41	1360.57	8.42	1358.17	1366.6	15.64	1354.58	1370.22
12	14.78	2064.87	2079.65	10.16	1366.07	1376.23	10.12	1369.35	1379.47	15.85	1363.16	1379.01
13	14.78	2078.14	2092.92	10.58	1368.41	1378.99	10.39	1373.24	1383.62	16.48	1362.65	1379.14
BAU	14.78	2486.55	2501.33	16.27	1624.51	1640.77	13.78	1638.71	1652.49	21.22	1627.53	1648.74

Axle Load Scenario (Tonnes)	Maintenance Alternatives								
	STG2			STG3			STG4		
	RAC	RUC	TTC	RAC	RUC	TTC	RAC	RUC	TTC
10	14.64	1699.42	1714.06	17.93	1687.25	1705.18	18.98	1688.06	1707.04
11	18.22	1350.89	1369.11	17.93	1344.05	1361.98	18.98	1344.73	1363.71
12	18.47	1359.04	1377.5	17.93	1356.44	1374.37	19.51	1350.27	1369.79
13	18.47	1367.97	1386.44	22.31	1359.69	1382.00	19.51	1356.75	1376.26
BAU	21.57	1617.15	1638.71	24.5	1617.3	1641.8	25.6	1616.77	1642.37

RAC	:	Road Agency Cost	
RUC	:	Road User Cost	
TTC	:	Total Transportation Cost	
Base	:	Routine Maintenance	Routine Maintenance
R-SDBC	:	30 mm SDBC	Renewal
R-BC	:	40 mm BC	Renewal
STG1	:	50 mm BM +30 mm SDBC	Overlay
STG2	:	50 mm DBM +30 mm SDBC	Overlay
STG3 +	:	50 mm DBM +40 mm BC	Overlay
STG3 *	:	60 mm DBM +40 mm BC	Overlay
STG4	:	75 mm DBM +40 mm BC	Overlay

Table 21 : Analysis of Total Transportation Cost for Different Axle Load Scenario (Agra-Bharatpur- Rupees in Millions, Discount Rate: 12%)

	Maintenance Alternatives											
Axle Load Scenario (Tonnes)	Base			R-BC			R-SDBC			STG1		
	RAC	RUC	TTC	RAC	RUC	TTC	RAC	RUC	TTC	RAC	RUC	TTC
10	12.20	2096.54	2108.74	8.93	1376.59	1385.52	7.42	1383.74	1391.16	13.58	1378.85	1392.43
11	12.20	1641.85	1654.04	8.93	1097.82	1106.75	7.42	1104.07	1111.49	13.58	1099.52	1113.09
12	12.20	1662.65	1674.85	8.93	1110.12	1119.05	8.65	1112.02	1120.67	13.77	1107.21	1120.98
13	12.20	1673.43	1685.63	9.42	1111.88	1121.30	8.91	1116.05	1124.96	14.47	1107.22	1121.69
BAU	12.20	1986.97	1999.16	14.11	1308.67	1322.77	12.01	1321.82	1333.83	18.41	1311.07	1329.47

	Maintenance Alternatives								
Axle Load Scenario (Tonnes)	STG2			STG3			STG4		
	RAC	RUC	TTC	RAC	RUC	TTC	RAC	RUC	TTC
10	13.42	1379.70	1393.12	16.44	1370.51	1386.95	17.30	1371.28	1388.58
11	15.82	1096.82	1112.64	16.44	1092.36	1108.80	17.30	1093.00	1110.30
12	16.04	1104.08	1120.12	16.44	1101.98	1118.43	17.90	1097.29	1115.18
13	16.04	1111.30	1127.37	19.37	1104.17	1123.55	17.90	1102.60	1120.50
BAU	19.55	1303.29	1322.84	21.77	1303.90	1325.67	22.48	1303.87	1326.35

RAC	:	Road Agency Cost	
RUC	:	Road User Cost	
TTC	:	Total Transportation Cost	
Base	:	Routine Maintenance	Routine Maintenance
R-SDBC	:	30 mm SDBC	Renewal
R-BC	:	40 mm BC	Renewal
STG1	:	50 mm BM +30 mm SDBC	Overlay
STG2	:	50 mm DBM +30 mm SDBC	Overlay
STG3 +	:	50 mm DBM +40 mm BC	Overlay
STG3 *	:	60 mm DBM +40 mm BC	Overlay
STG4	:	75 mm DBM +40 mm BC	Overlay

Table 22 : Analysis of Total Transportation Cost for Different Axle Load Scenario (Bharatpur-Jaipur- Rupees in Millions, Discount Rate: 8 %)

Maintenance Alternatives												
Axle Load Scenario (Tonnes)	**Base**			**R-BC**			**R-SDBC**			**STG1**		
	RAC	**RUC**	**TTC**	**RAC**	**RUC**	**TTC**	**RAC**	**RUC**	**TTC**	**RAC**	**RUC**	**TTC**
10	21.50	3112.35	3133.85	14.77	2116.85	2131.61	12.77	2121.26	2134.03	22.74	2120.43	2143.16
11	21.50	3047.81	3069.31	14.77	2071.20	2085.97	14.72	2077.25	2091.97	23.05	2064.62	2087.66
12	21.50	3091.27	3112.76	15.65	2074.15	2089.80	15.85	2076.41	2092.26	23.97	2070.89	2094.86
13	21.50	3100.18	3121.68	15.65	2079.05	2094.69	15.85	2082.30	2098.15	23.97	2074.10	2098.06
BAU	21.50	3205.36	3226.86	23.66	2139.99	2163.65	20.59	2153.51	2174.10	31.37	2133.36	2164.73

Maintenance Alternatives									
Axle Load Scenario (Tonnes)	**STG2**			**STG3**			**STG4**		
	RAC	**RUC**	**TTC**	**RAC**	**RUC**	**TTC**	**RAC**	**RUC**	**TTC**
10	21.29	2120.94	2142.23	25.36	2114.82	2140.18	27.61	2105.67	2133.28
11	26.49	2066.32	2092.80	26.07	2054.03	2080.10	27.61	2055.08	2082.68
12	27.93	2064.39	2092.31	26.84	2064.43	2091.27	28.38	2060.52	2088.89
13	27.93	2065.91	2093.84	32.45	2065.23	2097.68	28.38	2060.60	2089.00
BAU	27.93	2142.66	2169.59	35.63	2135.96	2171.59	38.21	2131.48	2169.68

RAC	:	Road Agency Cost	
RUC	:	Road User Cost	
TTC	:	Total Transportation Cost	
Base	:	Routine Maintenance	Routine Maintenance
R-SDBC	:	30 mm SDBC	Renewal
R-BC	:	40 mm BC	Renewal
STG1	:	50 mm BM +30 mm SDBC	Overlay
STG2	:	50 mm DBM +30 mm SDBC	Overlay
STG3 +	:	50 mm DBM +40 mm BC	Overlay
STG3 *	:	60 mm DBM +40 mm BC	Overlay
STG4	:	75 mm DBM +40 mm BC	Overlay

Table 23 : Analysis of Total Transportation Cost for Different Axle Load Scenario (Bharatpur-Jaipur- Rupees in Millions, Discount Rate: 12%

	Maintenance Alternatives											
Axle Load Scenario (Tonnes)	**Base**			**R-BC**			**R-SDBC**			**STG1**		
	RAC	**RUC**	**TTC**	**RAC**	**RUC**	**TTC**	**RAC**	**RUC**	**TTC**	**RAC**	**RUC**	**TTC**
10	17.74	2479.99	2497.73	13.00	1713.72	1726.71	11.41	1716.45	1727.85	19.75	1714.38	1734.12
11	17.74	2430.97	2448.71	13.00	1676.63	1689.62	12.57	1680.45	1693.03	20.03	1670.66	1690.69
12	17.74	2467.43	2485.16	13.98	1679.53	1693.51	13.83	1680.99	1694.82	21.05	1676.40	1697.44
13	17.74	2475.87	2493.61	13.98	1683.62	1697.59	13.83	1685.76	1699.58	21.05	1679.07	1700.11
BAU	17.74	2578.10	2595.83	20.51	1739.30	1759.81	18.12	1750.59	1768.71	28.44	1734.23	1762.66

	Maintenance Alternatives								
Axle Load Scenario (Tonnes)	**STG2**			**STG3**			**STG4**		
	RAC	**RUC**	**TTC**	**RAC**	**RUC**	**TTC**	**RAC**	**RUC**	**TTC**
10	19.52	1715.78	1735.30	23.12	1711.28	1734.39	25.16	1704.33	1729.49
11	23.00	1670.68	1693.68	23.91	1662.38	1686.29	25.16	1663.22	1688.38
12	24.52	1671.40	1695.92	24.81	1670.41	1695.21	26.03	1668.22	1694.25
13	24.52	1672.78	1697.30	28.18	1671.06	1699.23	26.03	1668.40	1694.41
BAU	24.52	1741.41	1765.81	31.66	1736.04	1767.70	33.91	1731.55	1765.46

RAC	:	Road Agency Cost	
RUC	:	Road User Cost	
TTC	:	Total Transportation Cost	
Base	:	Routine Maintenance	Routine Maintenance
R-SDBC	:	30 mm SDBC	Renewal
R-BC	:	40 mm BC	Renewal
STG1	:	50 mm BM +30 mm SDBC	Overlay
STG2	:	50 mm DBM +30 mm SDBC	Overlay
STG3 +	:	50 mm DBM +40 mm BC	Overlay
STG3 *	:	60 mm DBM +40 mm BC	Overlay
STG4	:	75 mm DBM +40 mm BC	Overlay

Table 24 : Analysis of Total Transportation Cost for Different Axle Load Scenario (Morinda-Roper) – (Rupees in Millions, Discount Rate: 8%)

Axle Load Scenario(Tonnes)	Maintenance Alternatives											
	Base			R-BC			R-SDBC			STG1		
	RAC	RUC	TTC	RAC	RUC	TTC	RAC	RUC	TTC	RAC	RUC	TTC
10	9.41	472.87	482.27	2.89	357.75	360.74	2.52	357.62	360.14	4.90	356.27	361.16
11	9.41	455.66	465.07	3.07	344.06	347.13	2.52	345.49	348.00	4.90	343.71	348.61
12	9.41	456.40	465.80	3.07	346.04	349.12	3.26	347.12	350.38	4.90	345.48	350.37
13	9.41	463.74	473.14	4.13	348.40	352.53	3.51	348.68	352.20	5.44	345.71	351.15
BAU	9.41	478.88	486.28	4.29	356.87	361.16	3.57	358.20	361.77	5.44	355.67	361.11

Axle Load Scenario(Tonnes)	STG2			STG3			STG4		
	RAC	RUC	TTC	RAC	RUC	TTC	RAC	RUC	TTC
10	5.54	357.51	363.05	6.12	356.86	362.98	7.19	357.61	364.86
11	5.70	343.39	349.08	6.12	344.29	350.40	7.38	343.09	350.47
12	5.70	345.04	350.73	6.29	344.29	350.57	7.38	344.52	351.89
13	6.15	346.54	352.70	6.79	345.55	352.34	7.97	345.59	353.56
BAU	6.33	354.93	361.26	7.00	353.74	360.73	8.19	353.26	361.45

RAC	:	Road Agency Cost	
RUC	:	Road User Cost	
TTC	:	Total Transportation Cost	
Base	:	Routine Maintenance	Routine Maintenance
R-SDBC	:	30 mm SDBC	Renewal
R-BC	:	40 mm BC	Renewal
STG1	:	50 mm BM +30 mm SDBC	Overlay
STG2	:	50 mm DBM +30 mm SDBC	Overlay
STG3 +	:	50 mm DBM +40 mm BC	Overlay
STG3 *	:	60 mm DBM +40 mm BC	Overlay
STG4	:	75 mm DBM +40 mm BC	Overlay

Table 25 : Analysis of Total Transportation Cost for Different Axle Load Scenario (Morinda-Roper) – (Rupees in Millions, Discount Rate:12%)

	Maintenance Alternatives											
Axle Load Scenario(Tonnes)	Base			R-BC			R-SDBC			STG1		
	RAC	RUC	TTC	RAC	RUC	TTC	RAC	RUC	TTC	RAC	RUC	TTC
10	7.76	373.26	381.01	2.46	289.33	291.78	2.09	289.22	291.30	4.03	288.26	292.29
11	7.76	360.14	367.90	2.55	278.68	281.23	2.09	279.69	281.78	4.03	278.44	282.46
12	7.76	360.53	368.29	2.55	279.94	282.49	2.57	280.58	283.14	4.03	279.53	283.56
13	7.76	366.46	374.22	3.34	281.58	284.92	2.87	281.78	284.68	4.68	279.65	284.32
BAU	7.76	377.23	384.99	3.51	288.65	292.15	2.93	289.78	292.70	4.68	287.77	292.45

Axle Load Scenario(Tonnes)	STG2			STG3			STG4		
	RAC	RUC	TTC	RAC	RUC	TTC	RAC	RUC	TTC
10	4.53	289.09	293.62	5.00	288.64	293.63	5.85	289.10	294.94
11	4.69	278.20	282.88	5.00	278.78	283.78	6.03	277.94	283.96
12	4.69	279.22	283.90	5.17	278.68	283.85	6.03	278.78	284.81
13	5.25	280.29	285.54	5.79	279.57	285.36	6.75	279.55	286.30
BAU	5.44	287.23	292.67	6.01	286.37	292.37	6.98	286.04	293.02

RAC	:	Road Agency Cost	
RUC	:	Road User Cost	
TTC	:	Total Transportation Cost	
Base	:	Routine Maintenance	Routine Maintenance
R-SDBC	:	30 mm SDBC	Renewal
R-BC	:	40 mm BC	Renewal
STG1	:	50 mm BM +30 mm SDBC	Overlay
STG2	:	50 mm DBM +30 mm SDBC	Overlay
STG3 +	:	50 mm DBM +40 mm BC	Overlay
STG3 *	:	60 mm DBM +40 mm BC	Overlay
STG4		75 mm DBM +40 mm BC	Overlay

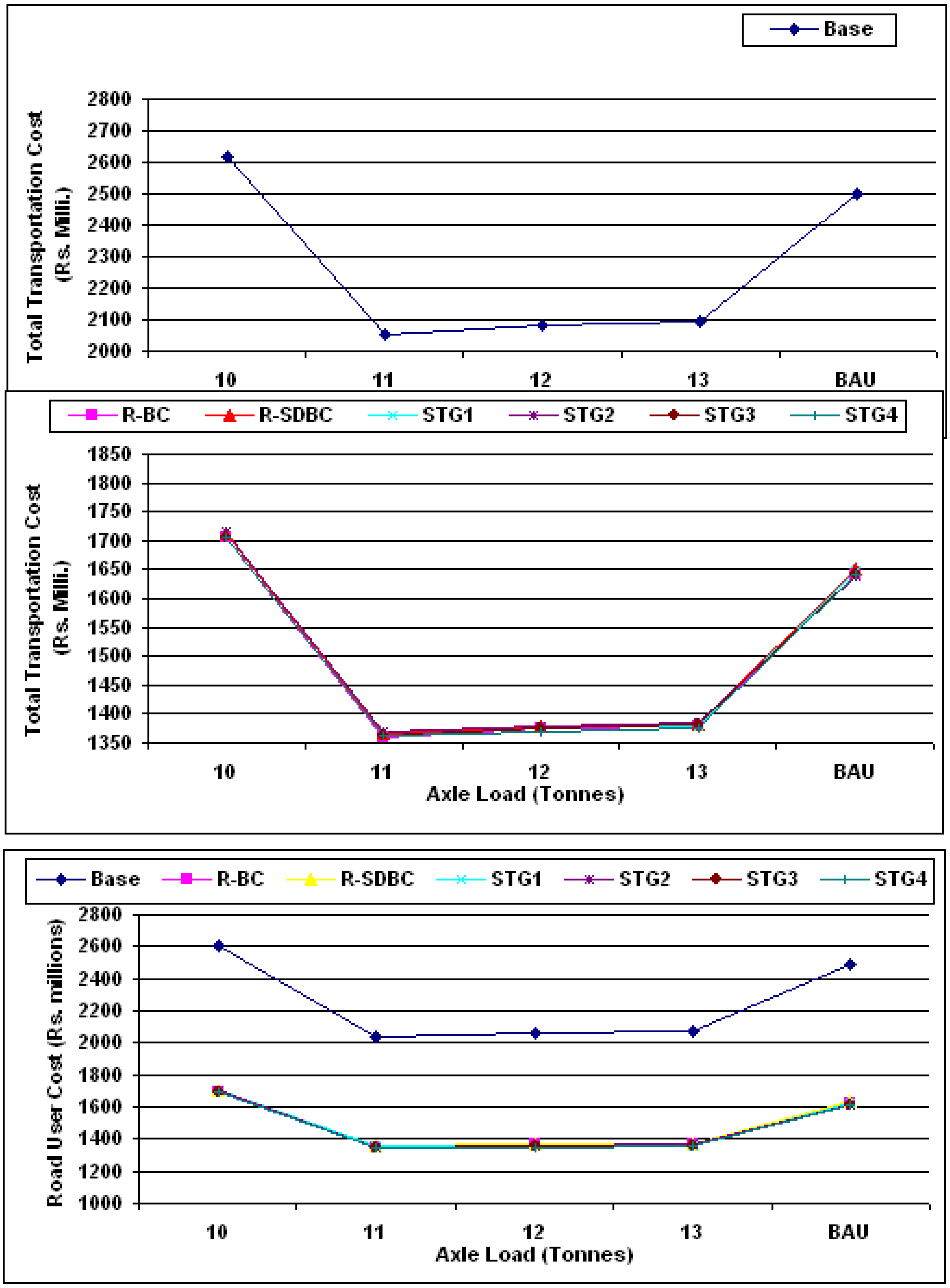


FIGURE 7 TOTAL TRANSPORTATION COST AND ROAD USER COST AT DIFFERENT AXLE LOADS (AGRA-BHARATPUR :8% DISCOUNT)

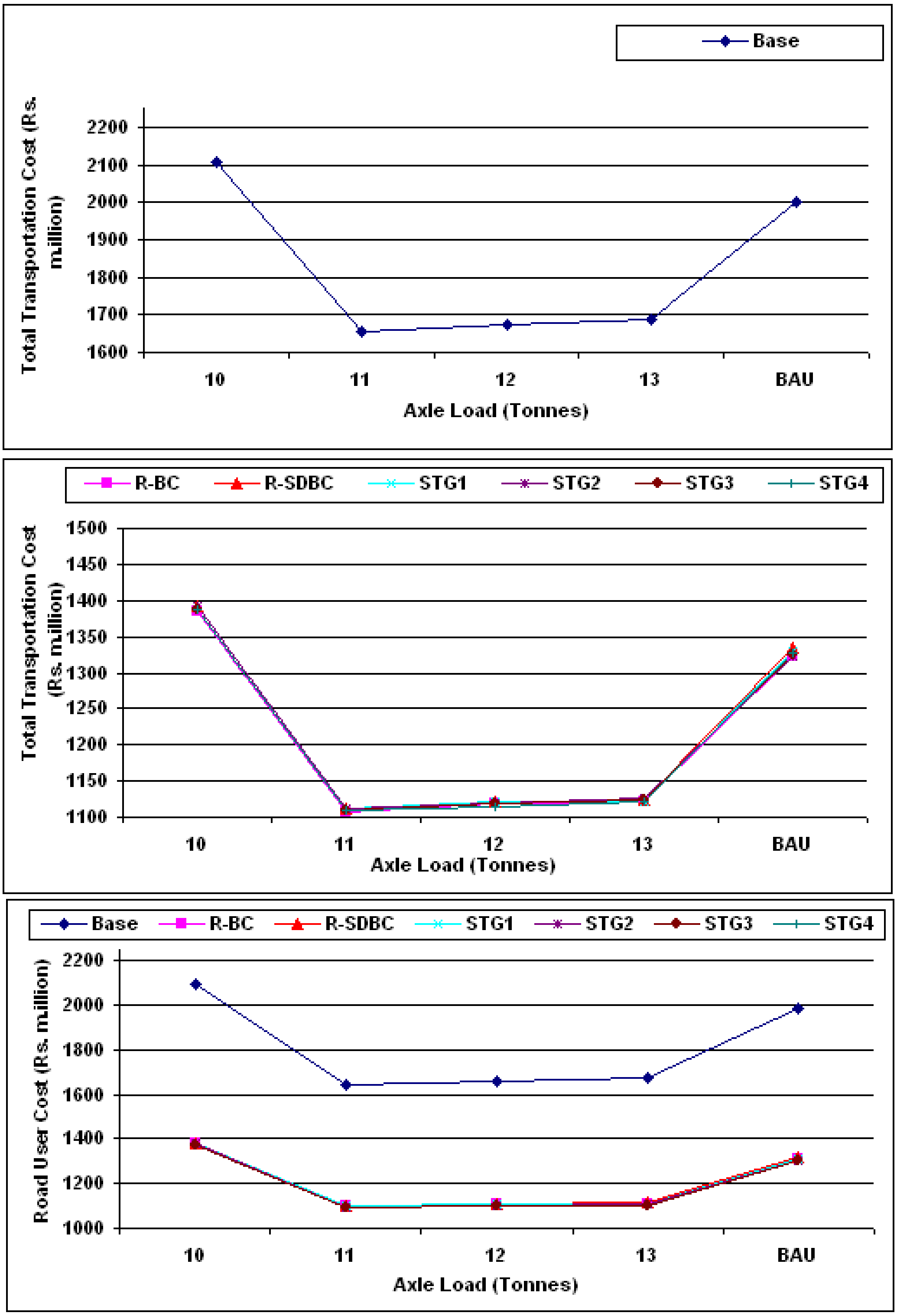


FIGURE 8 TOTAL TRANSPORTATION COST AND ROAD USER COST AT DIFFERENT AXLE LOADS (AGRA BHARATPUR: 12% DISCOUNT)

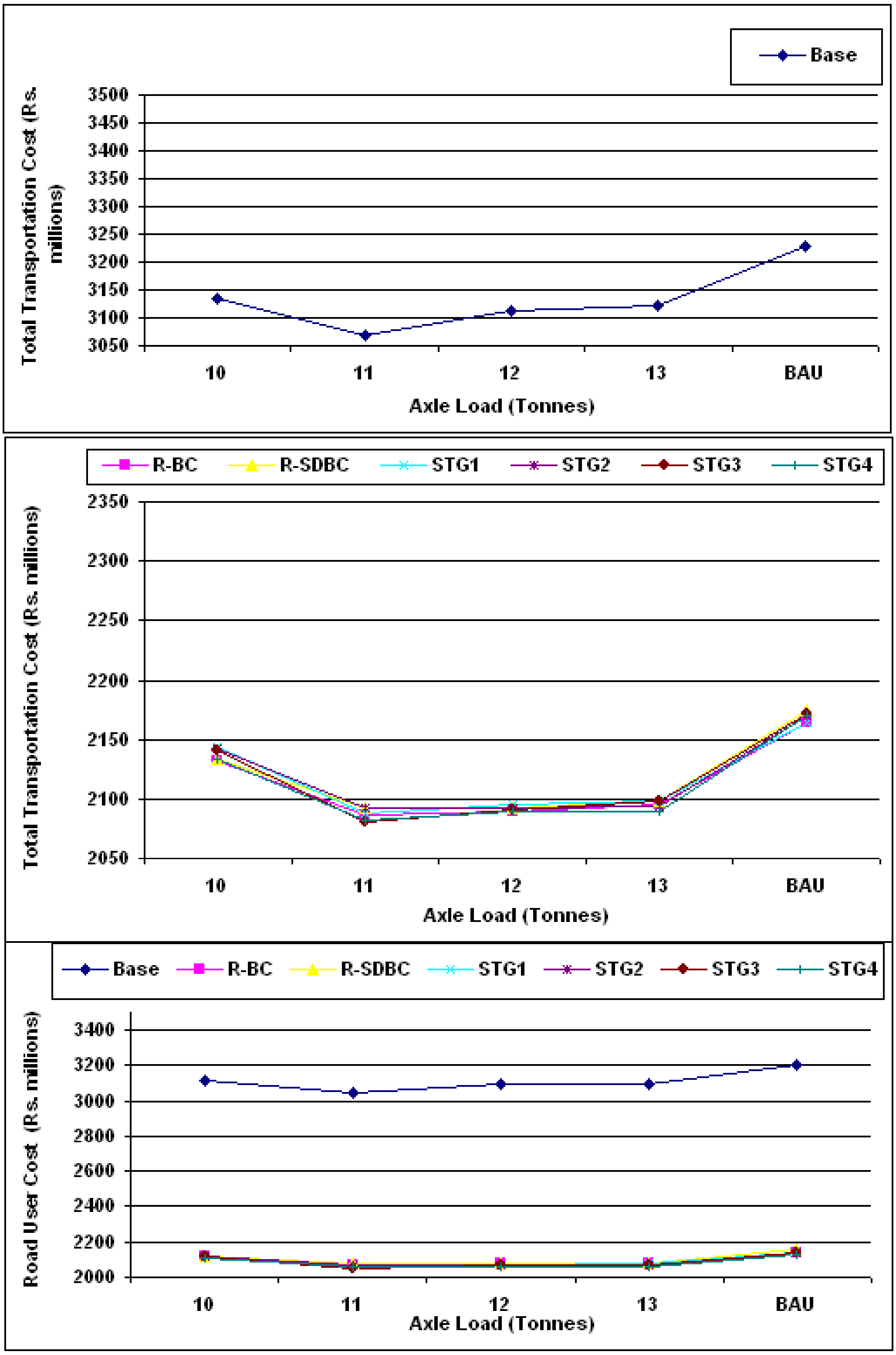


FIGURE 9 TOTAL TRANSPORTATION COST AND ROAD USER COST AT DIFFERENT AXLE LOADS (BHARATPUR - JAIPUR :8% DISCOUNT)

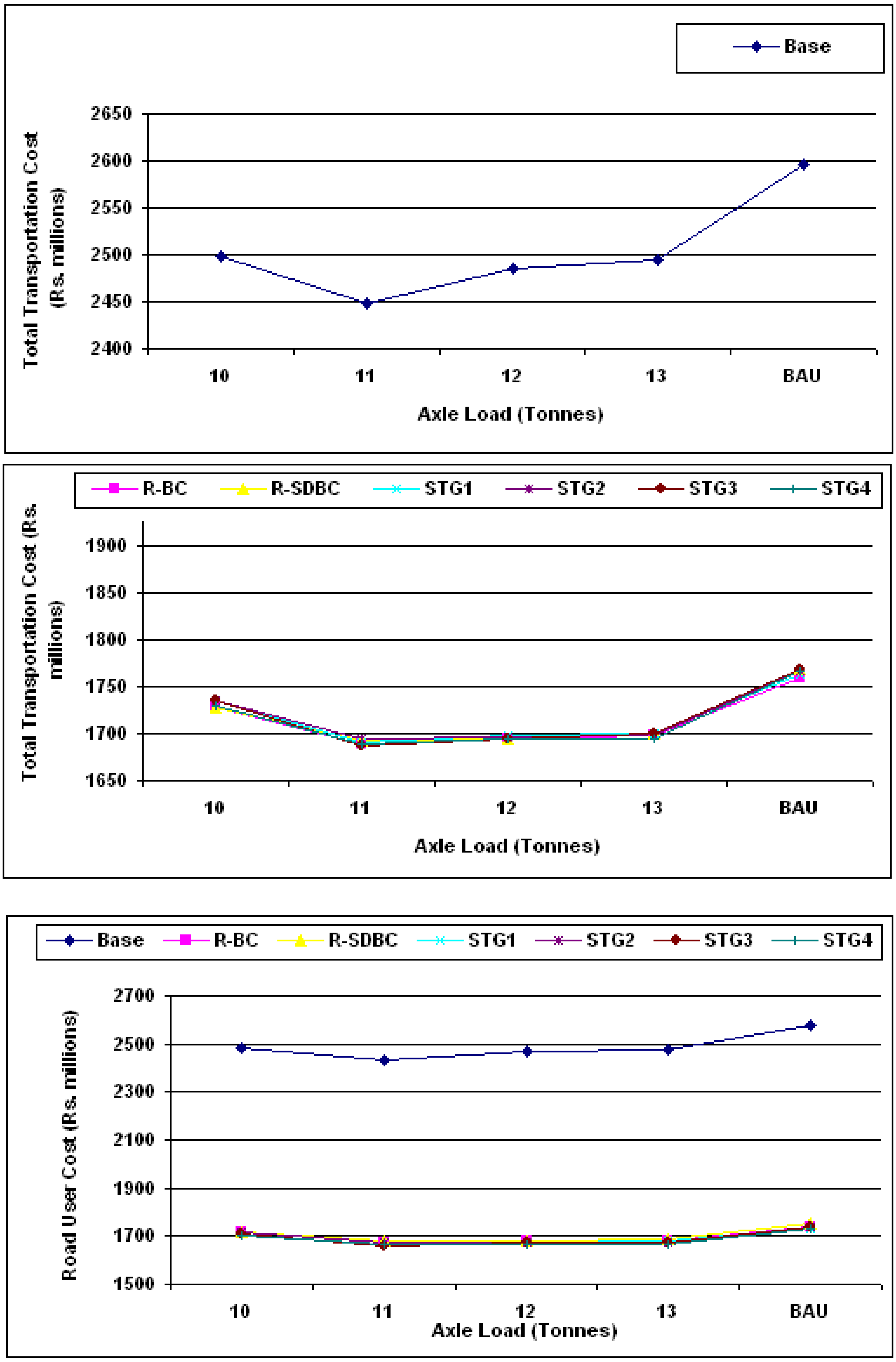


FIGURE 10 TOTAL TRANSPORTATION COST AND ROAD USER COST AT DIFFERENT AXLE LOADS (BHARATPUR - JAIPUR :12% DISCOUNT)

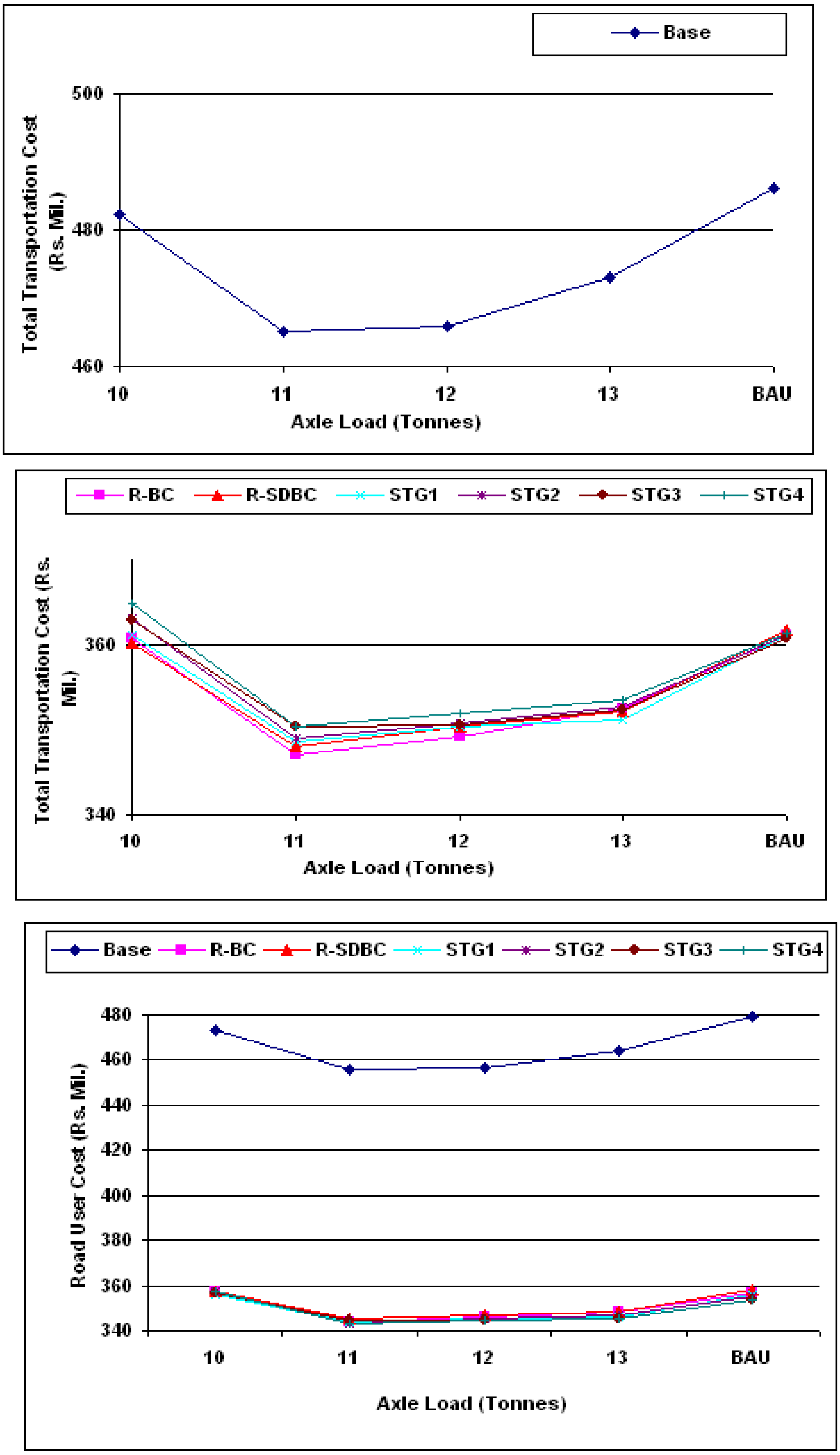


FIGURE 11 TOTAL TRANSPORTATION COST AND ROAD USER COST AT DIFFERENT AXLE LOADS (MORINDA-ROPAR: 8% DISCOUNT)

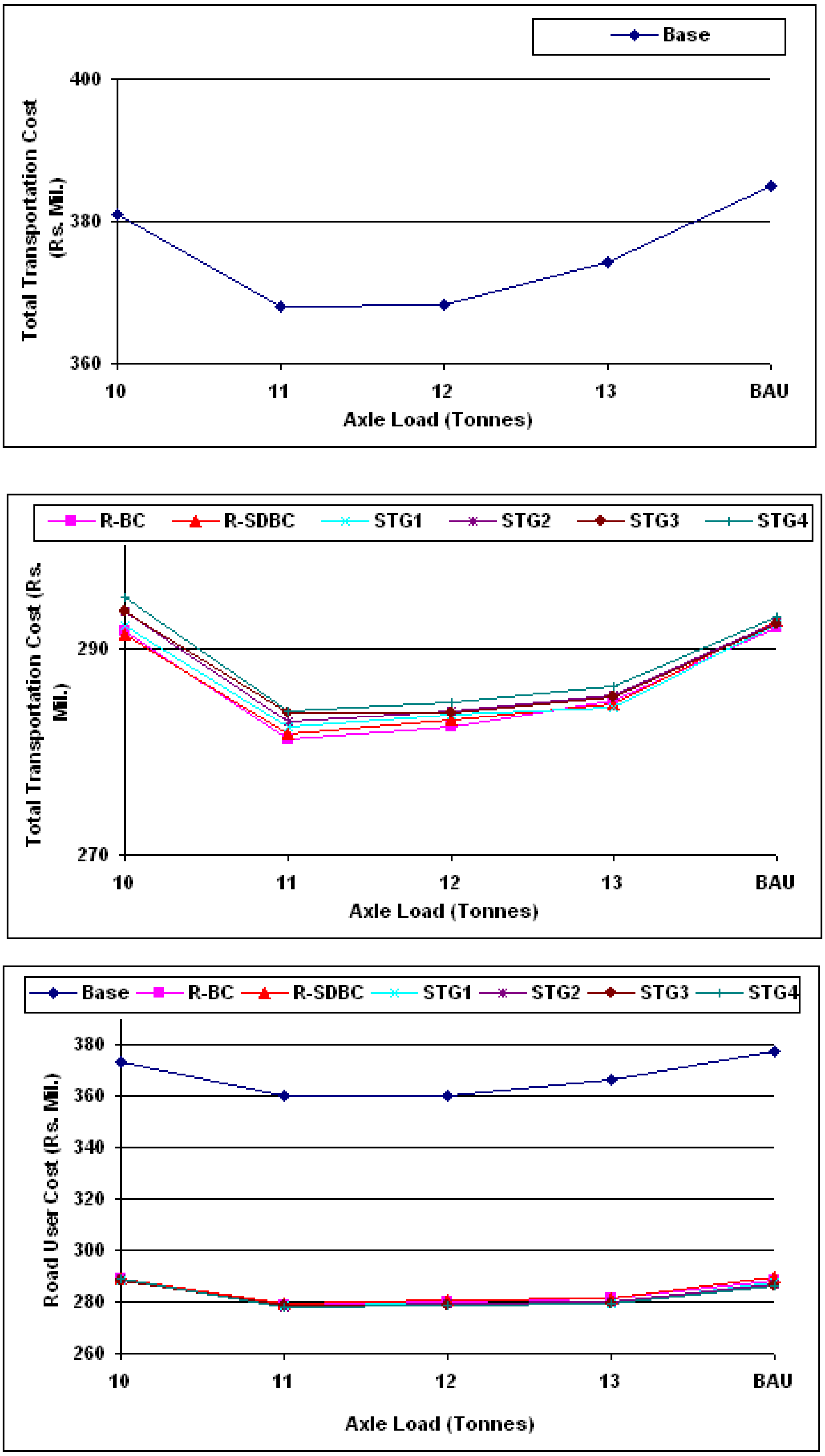


FIGURE 12 TOTAL TRANSPORTATION COST AND ROAD USER COST AT DIFFERENT AXLE LOADS (MORINDA-ROPAR: 12% DISCOUNT)

Table 26 Vehicle Operating Cost Per Vehicle Km. for Motorised Vehicles for Agra-Bharatpur Section (In Rupees: 12% Discount Rate)

Axle Load (Tonnes)	Two Wheelers				Cars				LCV				Bus			
	Base	R-BC	STG2	STG4	Base	R-BC	STG2	STG4	Base	R-BC	STG2	STG4	Base	R-BC	STG2	STG4
10.00	30.48	20.79	20.88	20.74	64.27	43.78	43.98	43.61	75.87	52.97	53.23	52.75	113.44	78.76	79.06	78.52
11.00	30.38	20.76	20.81	20.70	63.99	43.93	44.06	43.75	75.54	52.97	53.13	52.72	112.70	78.43	78.61	78.17
12.00	30.36	20.87	20.77	20.64	63.93	44.20	44.00	43.70	75.48	53.27	53.01	52.62	112.54	78.72	78.41	77.97
13.00	30.34	20.84	20.85	20.68	63.87	44.18	44.19	43.82	75.42	53.24	53.24	52.76	112.48	78.69	78.69	78.16
BAU	30.41	20.91	20.84	20.87	64.07	44.28	44.10	44.08	75.64	53.47	53.23	53.19	112.90	79.07	78.81	78.18

Axle Load (Tonnes)	Truck-2-Axle				Truck-Multi-Axle				Tractor			
	Base	R-BC	STG2	STG4	Base	R-BC	STG2	STG4	Base	R-BC	STG2	STG4
10.00	170.81	117.91	118.52	117.34	236.92	160.11	161.00	159.29	132.94	106.94	107.31	106.59
11.00	172.07	119.28	119.68	118.64	239.30	162.28	162.85	161.37	132.57	106.69	106.93	106.32
12.00	186.37	128.47	127.78	126.65	259.01	175.03	174.03	172.41	132.49	107.07	106.70	106.13
13.00	200.23	136.65	136.63	135.10	278.15	186.34	186.32	184.12	132.43	106.99	106.98	106.30
BAU	255.56	170.36	169.18	168.76	355.97	234.04	232.36	231.80	132.66	107.49	107.14	107.06

Table 27 Vehicle Operating Cost Per Vehicle Km. for Motorised Vehicles for Bharatpur-Jaipur Section (In Rupees:12% Discount Rate)

Axle Load (Tonnes)	Two Wheelers				Cars				LCV				Bus			
	Base	R-BC	STG2	STG4	Base	R-BC	STG2	STG4	Base	R-BC	STG2	STG4	Base	R-BC	STG2	STG4
10.00	29.44	20.48	20.54	20.39	61.98	43.45	43.59	43.20	73.33	52.42	52.61	52.09	109.18	77.70	77.91	77.34
11.00	29.53	20.62	20.60	20.46	62.18	43.80	43.80	43.44	73.53	52.80	52.79	52.32	109.45	78.06	78.03	77.52
12.00	29.58	20.50	20.43	20.40	62.28	43.67	43.47	43.39	73.64	52.59	52.32	52.21	109.57	77.73	77.43	77.31
13.00	29.62	20.62	20.51	20.46	62.33	43.92	43.66	43.54	73.70	52.90	52.54	52.40	109.69	78.10	77.70	77.54
BAU	29.99	20.71	20.75	20.62	63.12	44.17	44.21	43.89	74.57	53.15	53.20	52.77	110.96	78.24	78.32	77.83

Axle Load (Tonnes)	Truck-2-Axle				Truck-Multi-Axle				Tractor			
	Base	R-BC	STG2	STG4	Base	R-BC	STG2	STG4	Base	R-BC	STG2	STG4
10.00	164.79	116.66	117.11	115.85	228.24	158.00	158.66	156.84	130.09	106.07	106.34	105.58
11.00	167.26	119.02	119.03	117.84	232.29	161.79	161.78	160.08	130.31	106.54	106.53	105.83
12.00	183.68	128.10	127.25	126.91	254.87	174.19	172.98	172.50	130.42	106.20	105.78	105.62
13.00	195.30	135.88	134.68	134.19	271.05	185.11	183.39	182.69	130.49	106.58	106.05	105.84
BAU	230.15	161.25	161.44	160.78	322.15	221.88	222.88	221.14	131.45	106.83	106.91	106.26

Table 28: Vehicle Operating Cost Per Vehicle Km. for Motorised Vehicles for Morinda - Ropar Section (In Rupees: 12% Discount)

Axle Load (Tonnes)	Two Wheelers				Cars-New				Cars-Old				LCV			
	Base	R-BC	STG2	STG4	Base	R-BC	STG2	STG4	Base	R-BC	STG2	STG4	Base	R-BC	STG2	STG4
10.00	27.82	20.76	20.76	20.80	58.23	43.05	43.03	43.10	68.97	50.12	50.10	50.18	69.31	52.45	52.41	52.49
11.00	27.86	20.73	20.70	20.69	58.31	43.08	42.96	42.93	69.07	50.10	49.95	49.91	69.40	52.45	52.29	52.24
12.00	27.94	20.88	20.83	20.81	58.49	43.40	43.23	43.16	69.29	50.52	50.30	50.21	69.60	52.84	52.62	52.52
13.00	28.03	20.85	20.74	20.69	58.65	43.40	43.08	42.95	69.50	50.49	50.08	49.92	69.79	52.84	52.43	52.25
BAU	28.21	20.93	20.79	20.70	58.98	43.53	43.22	42.97	69.94	50.67	50.27	49.95	70.18	52.99	52.62	52.29

.

Axle Load (Tonnes)	Bus				Truck-2-Axle				Truck-Multi-Axle				Truck-Tandem-Axle			
	Base	R-BC	STG2	STG4	Base	R-BC	STG2	STG4	Base	R-BC	STG2	STG4	Base	R-BC	STG2	STG4
10.00	103.33	78.57	78.55	78.63	155.71	117.64	117.54	117.70	215.34	160.52	160.39	160.62	208.72	155.13	154.99	155.22
11.00	103.35	78.46	78.30	78.25	157.78	119.20	118.77	118.66	218.81	163.09	162.49	162.33	211.54	157.20	156.59	156.43
12.00	103.62	78.92	78.68	78.58	160.71	122.14	121.53	121.30	223.41	167.60	166.73	166.41	215.59	161.25	160.36	160.04
13.00	103.83	78.86	78.42	78.23	175.55	131.45	130.18	129.63	243.85	180.39	178.58	177.80	237.40	174.77	172.92	172.12
BAU	104.38	79.06	78.63	78.28	184.07	137.00	135.86	134.73	245.86	180.29	178.70	177.16	247.82	180.72	179.06	177.42

Axle Load (Tonnes)	Tractor-Trolly			
	Base	R-BC	STG2	STG4
10.00	130.56	112.05	111.99	112.09
11.00	128.58	110.04	109.80	109.74
12.00	128.83	110.60	110.25	110.12
13.00	129.05	110.58	109.99	109.73
BAU	131.59	112.77	112.23	111.74

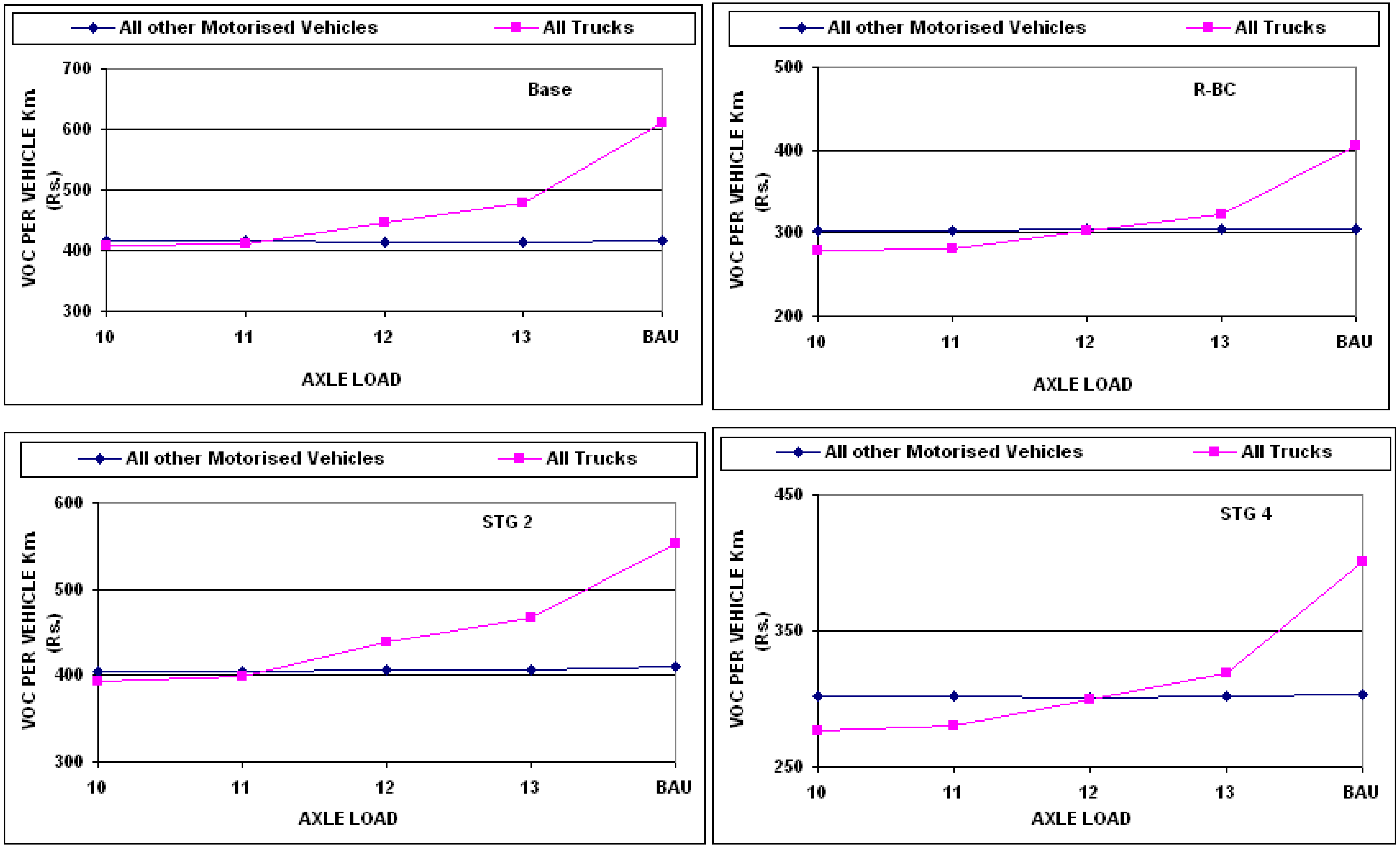


FIGURE 13 COMPARISON OF VOC FOR MOTORISED VEHICLES (PER VEH-KM): 12% DISCOUNT RATE (AGRA-BHARATPUR CASE STUDY)

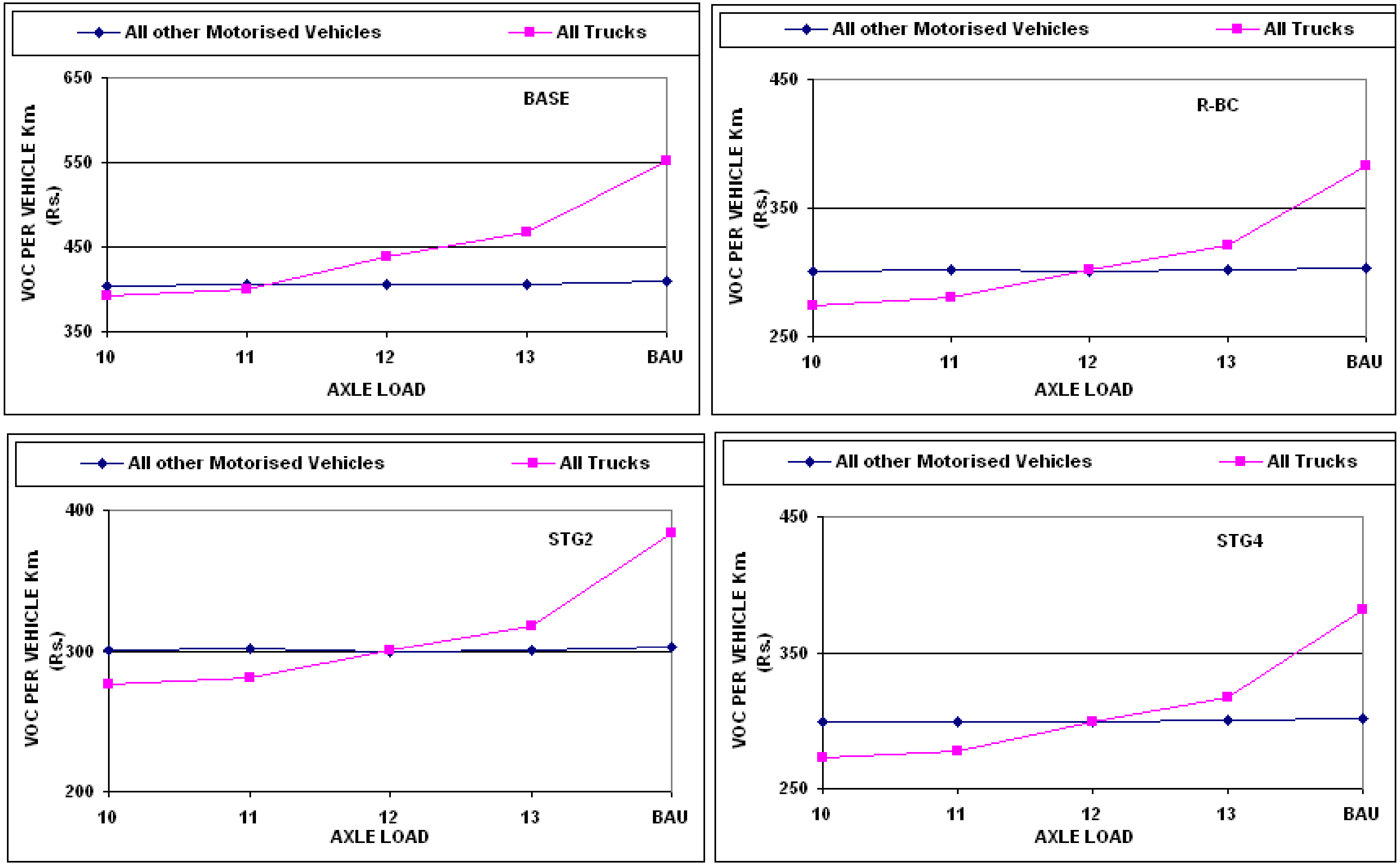


FIGURE 14 COMPARISON OF VOC FOR MOTORISED VEHICLES (PER VEH-KM): 12% DISCOUNT RATE (BHARATPUR JAIPUR CASE STUDY)

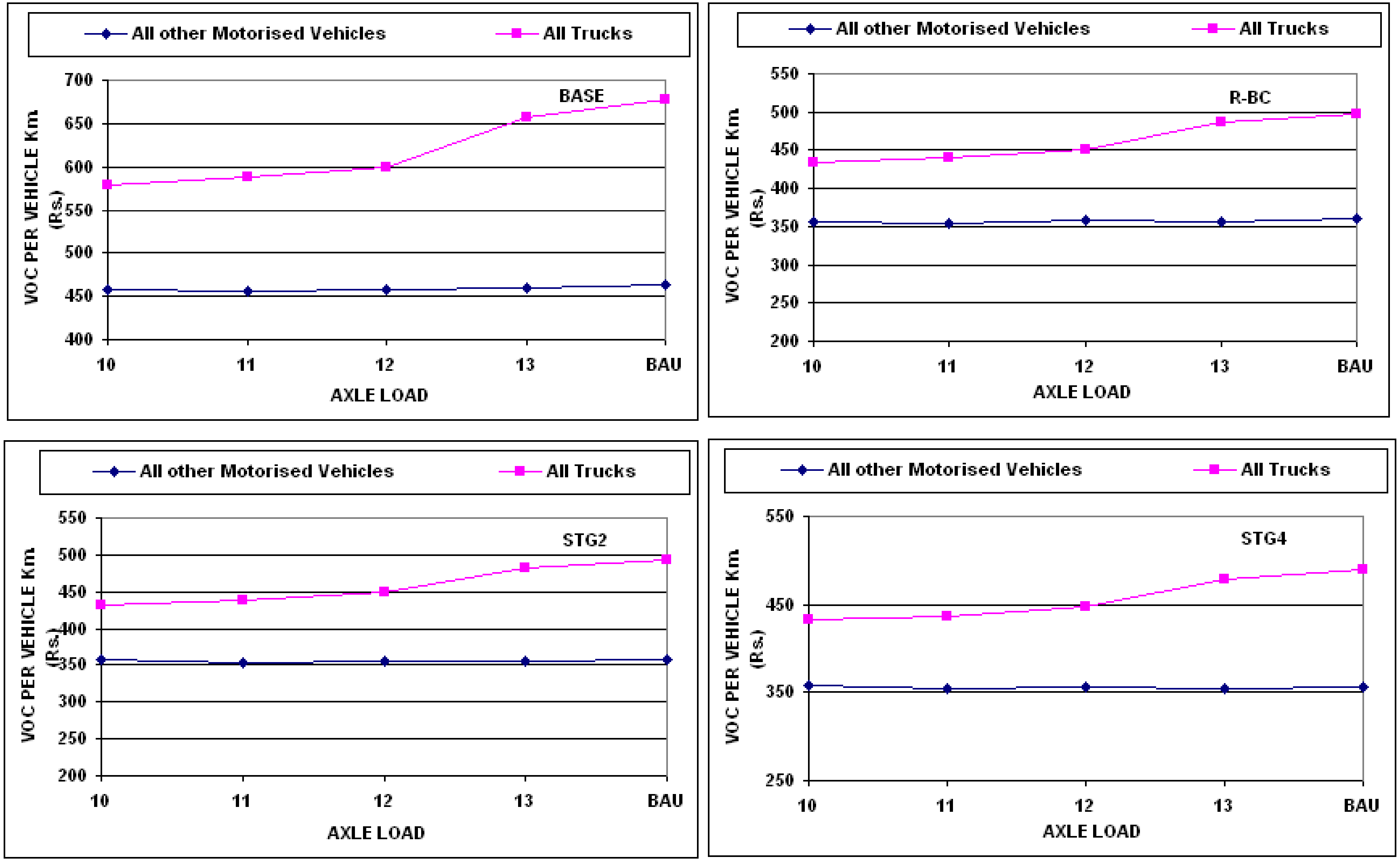


FIGURE 15 COMPARISON OF VOC FOR MOTORISED VEHIVLES (PER VEH-KM): 12% DISCOUNT RATE (MORINDA-ROPAR CASE STUDY)

5. ANALYSIS AND RESULTS

5.1 Approaches for Analysis

It is logical to think that the existing scenario of uncontrolled axle loads (violation of legal axle load limits) of the trucks have a serious damaging effect on the road (pavement) in comparison to controlled regime of axle loads. The permissible limit of axle load is 10.2 tonnes as per the Motor Vehicle Act 1988. Thus, the aim of this study has been to identify the scenario of controlled and optimum axle weight, assuming a seriously enforced regime of legal axle load limits, which will have minimum total transportation cost (TTC). The TTC is comprised of road agency cost (RAC) for the maintenance and renewal interventions and the vehicle operating cost (VOC), which is a part of the total road user cost. The VOC is directly related to the overall condition of the pavement resulting from the deterioration process during the service life, and uncontrolled overloading of axles by the trucks makes this deterioration much faster implicating higher VOC. Five different scenarios were considered as described in section 2.1 for simulation/prediction of the pavement deterioration behaviour and its implication on TTC. While the BAU (business as usual) was the existing uncontrolled situation, the other four were assumed control regime of axle loads from 10 to 13 tonnes and modified the vehicle fleet composition in each for using HDM-4 to predict the pavement deterioration scenario and consequent VOC and RAC (and also the TTC). The TTC predicted under alternative scenarios, when plotted against the chosen scenarios, suggest that the optimal axle load for the prevailing and commonly used road maintenance and renewal technologies is between 10 and 11 tonnes. With the vehicle technologies available in the country (larger proportion as 2 and 3 axle trucks, and small proportion as multi-axle vehicle) at this time, the scenario of TTC predicted by HDM-4 cannot be changed significantly.

5.2 Discussion of Results

It may be seen from the **Tables 13** and **14** that proportion of trucks in the AADT is higher in case of Bharatpur-Jaipur section, and therefore, the TTC for BAU is significantly higher than the Agra-Bharatpur section. Volume of trucks in the Morinda-Ropar section is also significantly less. The variation of TTC across the different axle load scenarios can be seen in **Figures 7-12**. It is clear from the figures that the TTC (due to pavement deterioration) increases for all the maintenance strategies beyond the axle load level of 11.0 tonnes. These figures establishes that the optimum axle load obtained from this analysis is about 11.0 tonnes. But, with the variation of the proportion of trucks in the traffic stream, this optimum may change. The BAU (with rampant overloading) scenario of the present study clearly suggests that the extreme situations existing in the total network should be studied in more detail to clearly establish the cost economics of increased legal axle load limit. However, it is abundantly clear that the existing scenario (BAU) is the worst case.

The **Figures 13 and 15** show the variation of combined VOC per vehicle-kilometer for all trucks (normal and multi-axle trucks) and other motorized vehicles (car, 2-wheeler, LCV, Bus, etc) separately considering a 12% discount rate. The variation across the different axle load scenarios including the BAU presented in these figures clearly depicts that the combined VOC of motorized vehicles other than the trucks dominates in both the case studies of Agra-Bharatpur and Bharatpur-Jaipur upto and beyond the axle load scenario of 11.0 tonnes. In case of Morinda-Ropar road section, the scenario is reverse as the trucks are less (VDF = 6.55 for trucks) the suffering of other vehicles is less resulted from the deterioration. Moreover the condition of the road is also much better than the NH-11 (Agra-Bharatpur-Jaipur). Each of these plots shows clearly that the VOC per veh-km of trucks with any of the intervention strategies will rise steeply if the axle load limits are raised upwards beyond about 11.0 tonnes.

5.3 Axle Load Policy Analysis

A series of logical assumptions were involved in the analyses which were described in the report. These assumptions are naturally related to the detailed level data that is required for using HDM-4 for a complete analysis. However, HDM-4 provides opportunity to use the default values logically within the ranges provided and this was fully utilized to make the two case studies most realistic using the available data.

But, even with some of the assumptions are removed with availability of more detailed data, the optimal axle weight is likely to be between 10 and 11 tonnes. This is because, a complete sensitivity analysis of the results were carried out for the ranges of default parameters in relation to the two case studies. Therefore, it will be always better to carry out a detailed and exhaustive study with full set of data collected from the actual road network which is having extreme variations across the various states of the country. For example, a wider spectrum of existing roads and traffic are to be considered for such an analysis. The calibration factors of HDM-4 are to be tuned with much more rigor to provide more accurate simulation of the deterioration behaviour of the pavements. A wider range of maintenance technologies (including the new/modern ones) and more detailed specifications of the vehicle fleet (specially the trucks) with different weight-to-power ratios prevailing in India (with BHP as per their production ratings) are to be included in the analysis of axle load policy.

5.4 Analysis of Vehicle Operating Cost

The basic analysis using HDM-4 runs, for which all the results are reported in this report, assumed uniform vehicle operating costs for trucks carrying axle loads less than 10 tonnes as well as 10 tonnes and more. Thus, within HDM-4 the analysis adopts the same VOC parameters for all such categories of trucks. However, in actual scenario, the trucks with axle loads less than 10 tonnes (empty and othetrwise) and those with 10 tonnes and more are to be separately categorized for accounting separately with different sets of VOC parameters. Thus, to examine this aspect in a preliminary way, the trucks with axle load less than 10 tonnes and those with 10 tonnes and more were separated in terms of their VOC and plotted in **Figures 16-18** for Agra-Bharatpur, Bharatpur-Jaipur and Morinda-Ropar case studies with 12% discount rates. In section with truck propostion very less in traffic (i.e. Morinda-Ropar), the optimum VOC is tending towards 13 tonnes axle load. In case of the intermediate volume of trucks in case of Agra-Bharatpur, the tendency remains same as that of TTC with optimality near 13 tonnes. However, in case of Bharatpur-Jaipur section with heavy truck traffic, the tendency of lower VOC is for higher axle loads. But, in all these figures, it is evident that the VOC trend for trucks

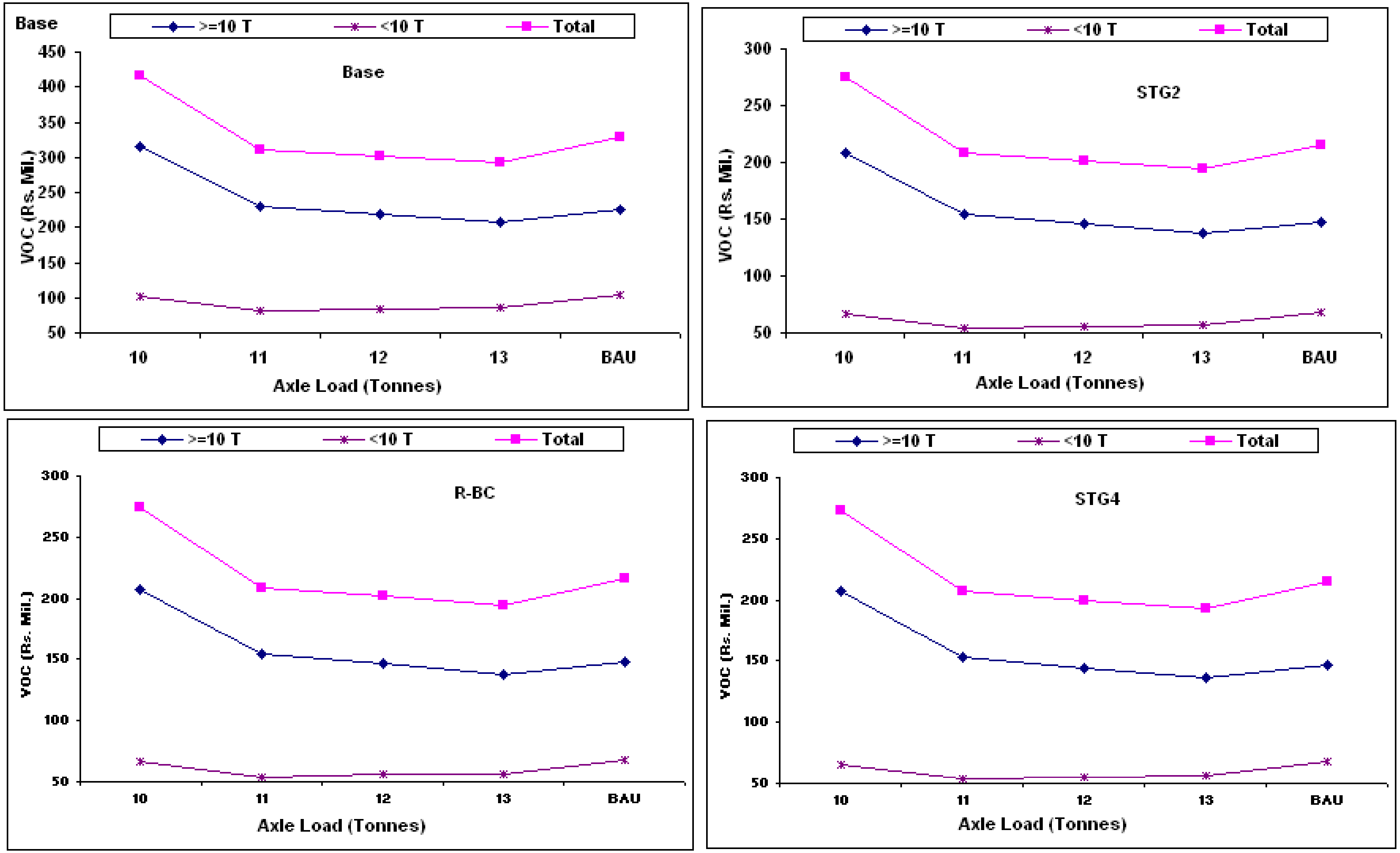


FIGURE 16 Total VOC for 2-Axle Trucks on Agra-Bharatpur Road Section for Different Maintenance Alternatives

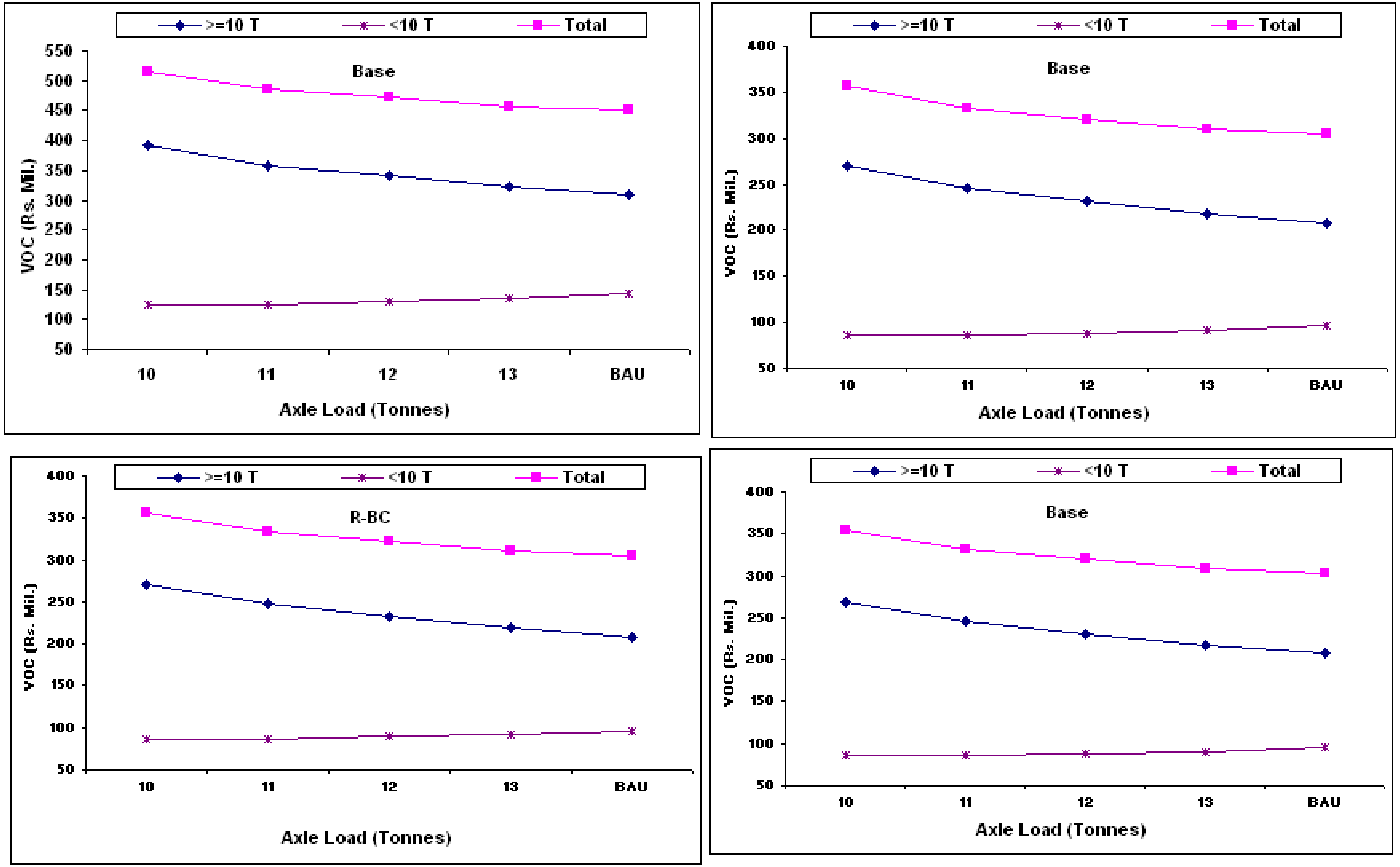


FIGURE 17 Total VOC for 2-Axle Trucks on Bharatpur - Jaipur Road Section for Different Maintenance Alternatives

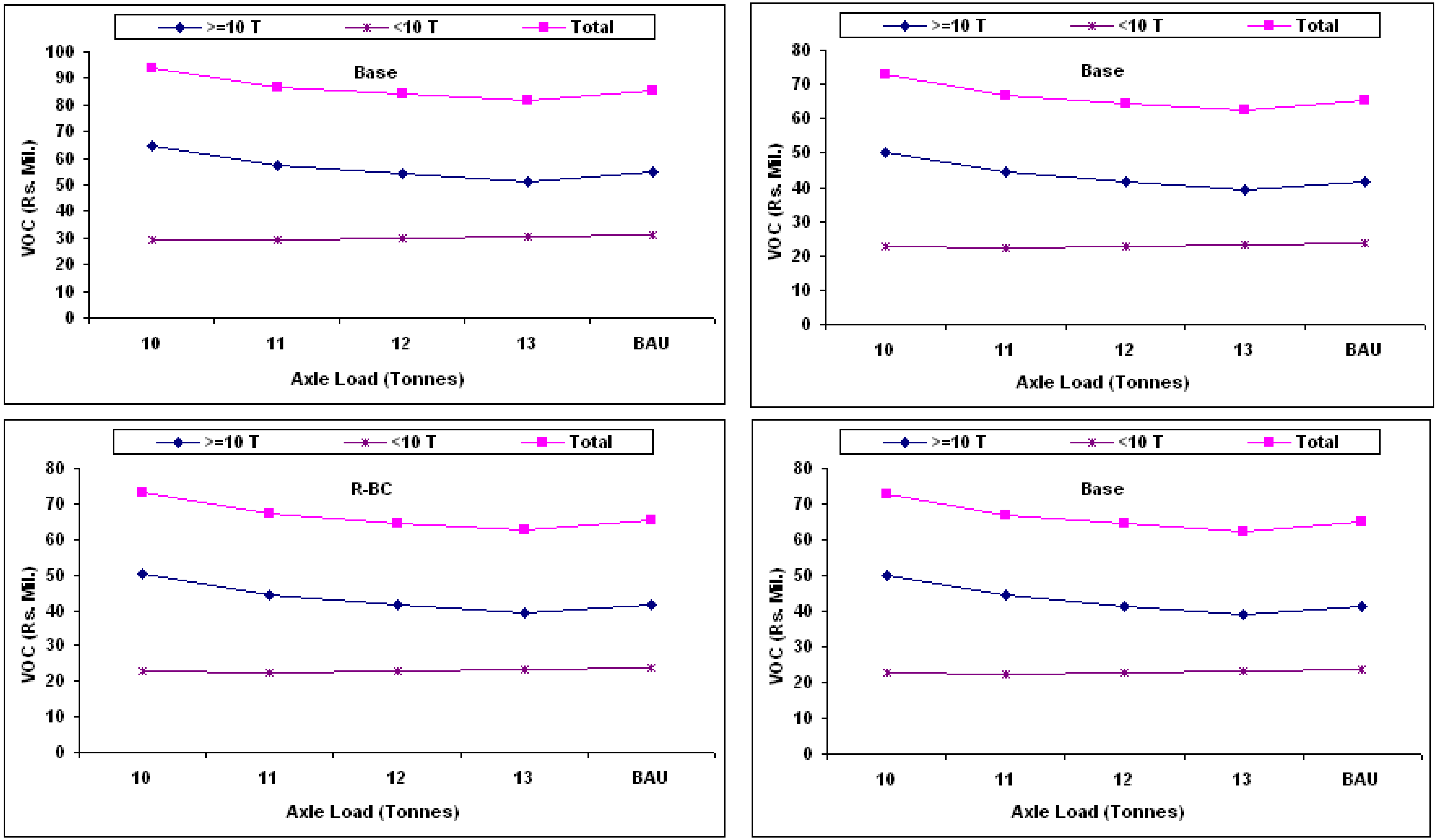


FIGURE 18 Total VOC for 2-Axle Trucks on Morinda-Ropar Road Section for Different Maintenance Alternatives

with lower than 10 tonnes axle weight and those for 10 tonnes and more are different. Even an increasing trend of VOC is observed for trucks with less than 10 tonnes axle load in all the three case studies. Thus, while the heavier trucks gain advantage in total VOC by virtue of the lowered rate of VOC per tonne, the same is neutralized by the increased VOC of the trucks carrying lighter loads and all other motorized vehicles in the traffic stream due to the deterioration inflicted by the heavier trucks. **Figure 19** shows the decreasing trend of VOC per tonne for trucks with 10 tonnes and more axle load for all the three road sections.

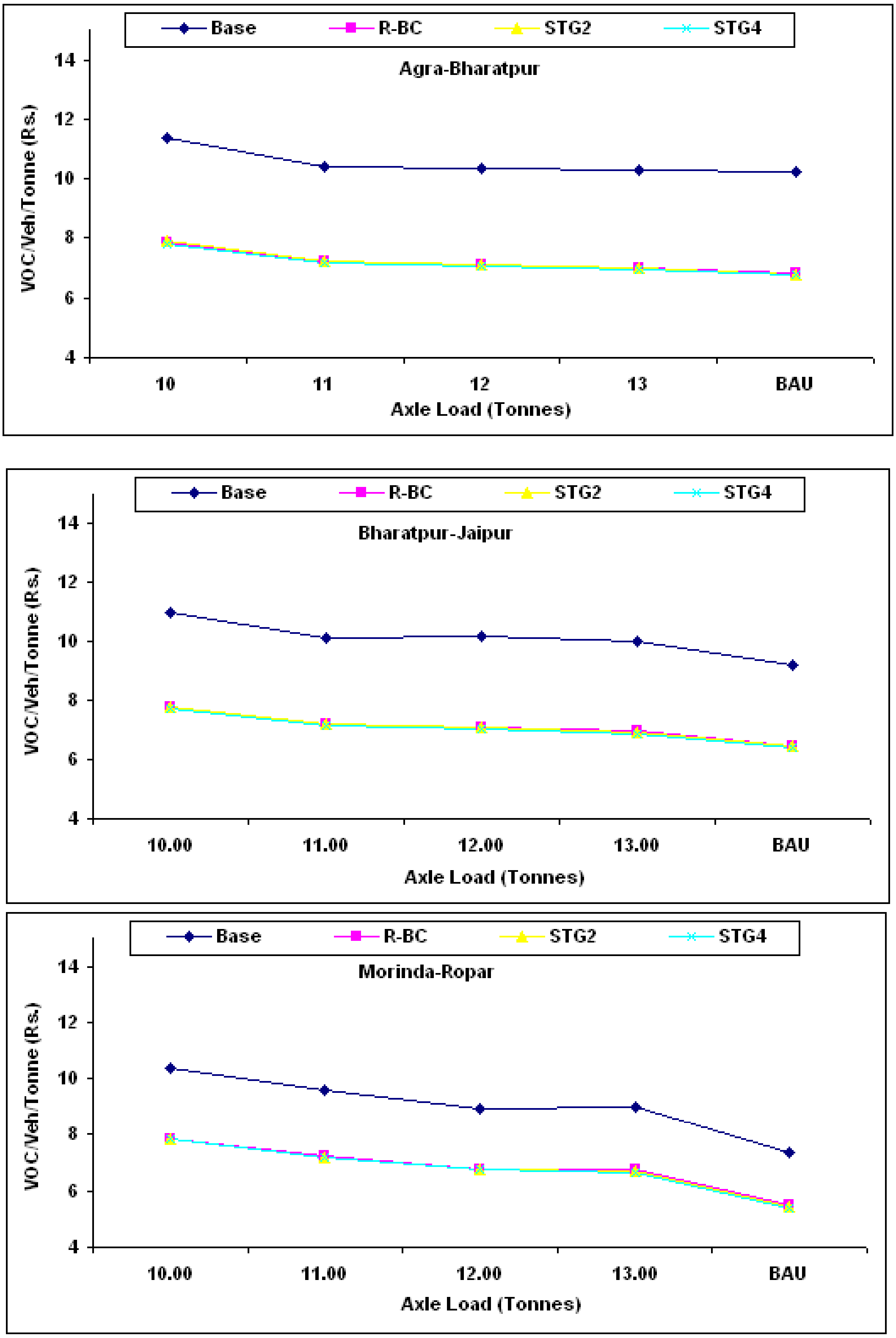


Figure 19 Per Tonne VOC for 2-Axle- Trucks (Discout Rate 12%)

6. CONCLUSIONS & RECOMMENDATIONS

The analysis based on three case studies of north Indian road network suggests the following:

a) The existing scenario (BAU) of uncontrolled regime of axle load, though the legal axle load limit exists as 10.2 tonnes, is the most damaging one and produces worst case of TTC.
b) The optimal axle weight of approximately 11 tonnes (actually below 11.0 tonnes) produces minimum TTC, based on the analysis presented in this report.
c) A detailed evaluation of sensitivity of control parameters, examined for the calibration of HDM-4 for validating deterioration pattern of the road sections under the case study, revealed that even with some of the assumptions removed, the optimum axle weight is likely to be in the range of 10 to 11 tonnes.
d) The other motorized vehicles (other than the trucks) are also paying the heavy penalty in terms of increased VOC per vehicle-kilometer which is the result of damage caused to the pavement by the overloaded commercial vehicles.
e) The proportion of trucks in the composition of total AADT plays a significant role in terms of its contribution to the total VOC. Thus, the technology of commercial vehicles fleet (specially the trucks) will make important difference in the deterioration pattern of the pavement and in turn on the VOC.

The study has certain limitations in terms of detailed data that were not available. However, these in no-way limit the validity of the results derived from the analysis. An axle load policy study for a country like India needs much more data, covering wide ranges of significant road types in the network (e.g. NH, SH and MDR) and their corresponding traffic (with axle load spectrum recorded in detail). Therefore, sufficient resources and time are to be mobilized to add further precision to the results obtained in this present study.

ASIAN INSTITUTE OF TRANSPORT DEVELOPMENT