

The South African heavy vehicle load limit study

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The presentation relating to the South African Heavy Vehicle Load Limit study was made, unprepared, at the Third International Symposium, and this paper was produced after the Symposium to be included in the proceedings. The study was of interest as it represented the latest application of the principles being researched by other members of the symposium. A brief outline of the study was given, covering the effect of changing axle and vehicle loads in South Africa. This involves analysing the economic issues as well as briefly examining other issues related to the subject.

BACKGROUND

The Department of Transport, assisted by a team of consultants (Lexetran Pty Limited, Van Wyk and Louw Inc., Transportek (CSIR), Van Niekerk Kleyn and Edwards Inc., Jordaan and Joubert Inc. and Transport Research Associates) has for the past eighteen months been reassessing the axle and vehicle loading limits as contained in the Road Traffic Act, 1989 (Act No. 29 of 1989) (RTA) and the Consolidated Road Traffic Regulations (the Regulations) promulgated thereunder. The RTA and Regulations contain provisions, that, as well as giving legal force to vehicle manufacturers loading ratings for their heavy vehicles, limiting loading on heavy vehicles to the load capacities of the tyres of the vehicles concerned and setting a lower limit to power/mass ratio, also set definite maximum limits for axles, groups of axles and permissible combination loads, to protect road infrastructure. The axle and axle unit loads are controlled by direct limits, while the loads on groups of axles and on vehicles (and vehicle combinations) are controlled by a bridge formula. These limits are as shown in Table 1.

Table 1

AXLE, AXLE UNIT AND AXLE GROUP LOAD LIMITS

Axle/Unit/ Group	Two wheel axle (tonnes)	Four wheel axle (tonnes)
Single	7,7	8,2
Tandem	15,4	16,4
Tridem	21,0	21,0
Group/ vehicle/ combination	1.8L+16*	1.8L+16*

*L = distance in metres between the extreme axles of the group or of the vehicle or combination

* Maximum combination length = 22,0 m

* Maximum articulated vehicle length = 18,5 m

These limits mean that a 7 or more axle vehicle combination can carry 52 tonnes while a 5 or 6 axle articulated vehicle may carry 41 tonnes.

The limits have been in the law for many years, some since before 1966, some since 1972. These limits were therefore due for review and possible revision.

This situation was aggravated by a severe crisis that had developed in the road freight transport industry. This crisis was due in part to the fact that the economy generally was in recession, and in part due to the effect of a policy of deregulation in the transport sector. This has meant increased competition and aggressive pricing tactics by operators. The entire situation had been exacerbated by a poor load limit enforcement strategy which has recently been revised and was demanding better compliance with the law. The fact that all vehicles in South Africa are sourced from Europe, UK, USA or Japan and as such are all capable of exceeding both the axle load and vehicle load limits in the RTA and Regulations, also contributed to dissatisfaction. The transport operators were requesting larger legal axle and vehicle load limits to assist them to smooth out and recoup the deficits due to low pricing of transport services. Against this the pavements in South Africa were generally designed for relatively light traffic with thin, granular pavement layers, while bridges have been generally designed to British design codes. The assessment of the effect of a change in load limits on these was essential.

OBJECTIVES OF THE STUDY

The Department of Transport therefore wished to review the load limits as a part of a strategy to assist the transport industry, while also demanding better compliance. The load limits should be changed to the extent this could be done efficiently in economic terms. It is generally accepted that higher loads on vehicles means lower average transport operating and fixed costs (vehicle costs) per tonne of payload carried. It is also accepted that higher loads also mean greater road rehabilitation and maintenance costs (road costs). The Department set as its objective, the determination of the economic optimum level

of load limits, where the sum of the road and vehicle costs is a minimum.

The Department also wished to examine the impacts on safety, traffic, environment and social considerations, and on other modes of freight transport.

In order to examine the effects of a possible change in the axle and vehicle load limits on bridges, these were examined separately, as decisions relating to these would be based on the extent of a once off investment, which could be discounted against any nett benefit received from the changes for the road transport system as a whole.

To achieve the maximum co-operation and dissemination of information, a Working Group of transport operators, vehicle manufacturers, road authorities, enforcement agencies and other interested parties was convened to provide a consultative forum through which to obtain and discuss various view points, and to assist in formulating final recommendations.

PHILOSOPHY OF THE STUDY

As a basis to carry out the economic analysis of the study a constant payload was initially assumed to be travelling on the roadway system. The effect on other modes and the resulting mode transfer or change in market share was examined after the economic optimum was determined for the road transport sector. The basis for the study was the determination of the effect of the change in axle and vehicle loads upon the vehicle costs and the road costs, each in respect of transporting one tonne of payload. Figures 1 and 2 show the schematic relationships derived in the study.

Figure 1 shows that for each type of vehicle, the vehicle cost per payload tonne kilometre reduces with an increase in axle and vehicle loads. The vehicle costs are higher for the smaller vehicles, and the rate of reduction in cost with increase in load is lower for the larger vehicles, due to the lower percentage change in total load on each vehicle. Figure 2 shows that the road cost per payload tonne kilometre increases with increasing axle load. This figure shows that for the lightly constructed pavements (those designed to carry less than 1,0 million equivalent single axle loads ESAL) the rate of increase in cost with increase in axle load is very rapid, upon the exponential curve, while for stronger pavements, costs increase more slowly over the range of interest.

In analysing the costs and benefits the effect of each type of vehicle on each type of pavement must be determined. Figure 3 shows typical results for a three axle vehicle. In determining the total cost and benefit the distance travelled by each vehicle on each pavement must be determined to provide a weighted average of the optimum axle load - as shown in Figure 4. The overall benefit of changing to the optimum limit is then the sum of all the benefits (or disbenefits) of the total vehicle kilometres travelled by each type of vehicle on each type of pavement.

With regard to bridge structures the principle was slightly different in that these create a constraint upon the gross vehicle loads and the concentration of the load on vehicles. The approach was to determine the theoretical load carrying capacity of the bridges on the network, with the cost implications, if any, of a change to the existing

legal limits. These cost implications could then be discounted as an investment cost against the benefits derived from the first part of the study.

EXECUTION OF THE STUDY

With regard to the analysis of the vehicle and road costs and benefits, the following steps were followed.

Traffic flow and vehicle loading data was required. General statistics on traffic on the road network were reasonably available from the Departments Comprehensive Traffic Observations (CTO) system, but the loading data was not generally available. A number of specific vehicle load surveys were conducted on a number of different road categories. These surveys were conducted with weigh-in-motion devices, and allowed the categorisation of the general traffic information obtained from the CTO. It also provided a database of axle and vehicle loadings on each category of vehicle, to be used in the later stages of the study. Six categories of heavy vehicle or vehicle combination were used.

Network data was also required. The length of each category of pavement in the network was obtained, partly from pavement data and partly from traffic data. The latter was not an accurate representation of the actual pavement, but was an indication of what the pavement for a particular section of road should be. The heavy vehicle traffic on each section of each category of pavement was then estimated from traffic data and the generalised categorisation of the traffic from the detail loading surveys was applied to this information to provide an estimation matrix of the number of kilometres travelled by each category of vehicle on each category of pavement.

A prediction model was then developed to attempt to determine the number of vehicles that would utilise the new loading limits if they were changed. A number of complex models were considered and tried but a simplistic model using eighty percent of vehicles within 0,6 tonnes of the present legal limit increasing their loads was used. The load increase was then determined in a distribution between the present limit and the new legal limit. This model was then used for a number of different options of bridge formula and axle load. The model was complicated by the fact that the data showed considerable occurrence of overloaded vehicles and axles, some of which were already above the proposed new legal limits. In the final analysis it was assumed that all these overloaded vehicles were at the present legal limits and would move according to the prediction model to maximum of the new legal limits.

The next step was to calculate the road costs per payload tonne kilometre. Typical cross sections for the various categories of road pavement were assumed and the rehabilitation cost per kilometre for each was determined.

This was converted to a cost per ESAL kilometre for each cross section and pavement. The number of ESAL's were then calculated for each category of vehicle under firstly the present load limits and secondly the new load limits. The AASHTO relationship using an exponent of 4,0-4,5 was used in this calculation. These were then multiplied by the cost per ESAL and divided by the payload in each case. The result showed the road cost for each type of vehicle per payload tonne kilometre and the

VEHICLE COST AGAINST AXLE LOAD

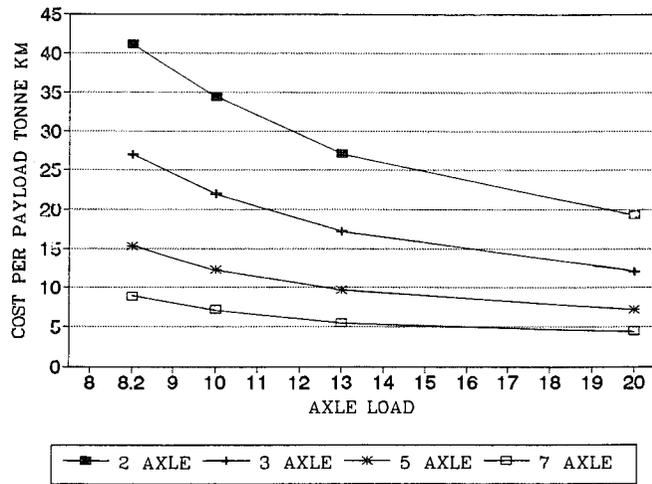


FIGURE 1

ROAD COST AGAINST AXLE LOAD 3 AXLE VEHICLE

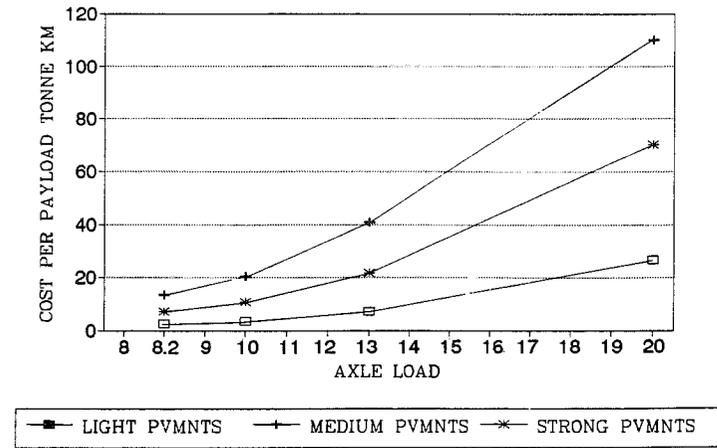


FIGURE 2

TOTAL COST AGAINST AXLE LOAD 3 AXLE VEHICLE

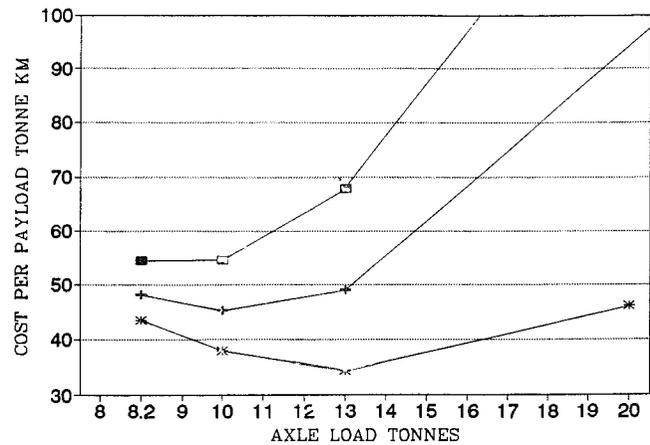


FIGURE 3

TOTAL COST AGAINST AXLE LOAD ALL VEHICLES

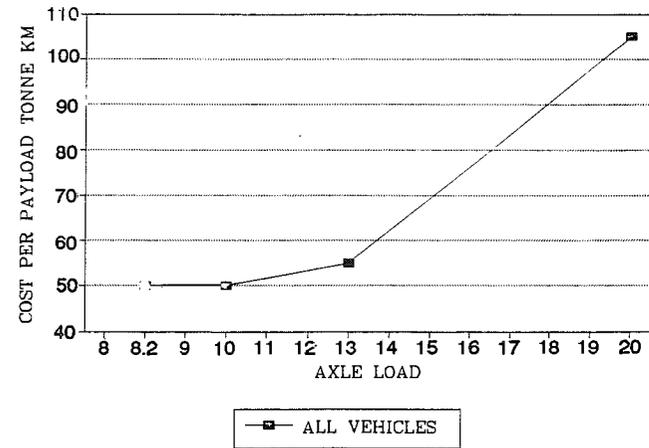


FIGURE 4

difference was the increase in road cost as a result of the load limit change for the vehicle concerned. This process was repeated for each vehicle on each pavement and the additional cost was summed for all vehicles on all pavements.

The following step was to calculate the vehicle costs per payload tonne kilometre. Vehicle operating and fixed costs were obtained from the Road Freight Association Vehicle Costs Schedules and the cost per payload tonne kilometre were determined using firstly the present load limits and secondly the proposed limits. The change in payload was assumed to induce an operating cost change in the vehicles given by the following formula, but the result was tested and found to be largely insensitive to the relationship assumed.

$$\delta c = 0,231 \frac{\delta W}{W}$$

where C = vehicle operating cost and
W = total weight of the vehicle.

The difference in vehicle cost per payload tonne kilometre was then the benefit for the particular vehicle category, and these were aggregated for the amount of travel of the various vehicle categories on the network.

A number of axle load changes were tested to provide a trend to indicate the approximate order of magnitude of the optimum axle load. Then a number of specific options of axle and axle unit load limits and bridge formulae were tested.

As an additional assessment the change in transport operating cost as a result of the necessary road rehabilitation not being done was calculated.

In the analysis of the effect of a change in axle and vehicle loading on bridges, a theoretical comparison of the traffic loads and the design loads for the bridges was carried out. From the traffic survey data, traffic streams were simulated using statistical techniques, and these were passed over a range of representative bridges. The effects in terms of bending moment and shear forces were then compared with the effects induced under the design loadings for which the bridge had been designed. In calculating the effects under traffic loading, allowance was made for impact and dynamic effects. It was further realised that if better control of overloading could be obtained, then the traffic load simulation would change. A simulation using "ideal" overloading control conditions was then also used. Simulations under the present load limits as well as a number of options of increased axle and vehicle load limits were then tested. It was found that certain short span (5-15 m) bridges were experiencing stresses exceeding those provided for in the design loading cases, under the present simulation of overloading. If the axle loads were increased then the number of bridges experiencing this overstress also increased. Using this number of bridges the cost to strengthen all the relevant bridges was estimated. If the overloading can be properly controlled then fewer bridges will be affected, but a number of these will still experience stresses in excess of the design limits. The most important results of the analysis are shown in the following section.

RESULTS OF THE STUDY

The first assessment showed the tendency of costs and benefits with changes in axle load.

Cost Tendency on Theoretical Axle Mass Changes (Approximate Values)

Axle Load Tons	TPT Cost Saving R mill/yr	Road Cost Increase R mill/yr	Nett Benefit R mill/yr
8,2	0	0	0
9,0	129	110	19
10,0	205	225	-20
11,0	245	335	-90

US\$ \$1.00 = R2,85

These results indicated that 9 tons was the approximate optimum axle load

As indicated a number of options of axle load and bridge formula were assessed, the most important of these were the following:

Most Important Options Assessed

Option No.	Axle Single	Loads Dual	Tons Tridem	Bridge Formula
0	8,2	16,4	21,0	1,8L + 16
1	8,2	16,4	21,0	2,1L + 15
2	9,0	18,0	21,0	2,1L + 15
3	10,0	18,0	21,0	2,1L + 20
4	10,0	18,0	24,0	2,1L + 20
5	10,0	18,0	21,0	1,8L + 16
6	9,0	18,0	27,0	2,5L + 20

Benefits and Costs of Specific Options

Option No.	TPT Cost Saving R mill/yr	Road Cost Increase R mill/yr	Benefit R mill/yr	Bridge Cost R mill
0	0	0	0	R 100
1	29	26	3	R 128
2	126	107	19	R 135*
3	217	212	5	R 146
4	235	225	10	R 200
5	102	72	30	R 100
6	220	235	-15	R 240*

* Obtained by interpolation.

These results high-lighted a number of points. Firstly if nothing was changed (option zero), R100 mill would have to be spent on bridges anyway. Secondly the highest benefit would be generated by increasing the axle load limits without increasing the bridge formula (option 5).

This could not be recommended however, because it would cause loads that could be carried by heavier vehicles, to move onto smaller vehicles, which would be less efficient. This effect was not taken into account in the calculations for the study.

The study therefore recommended option 2 as being the most beneficial and balanced option.

It was further recommended that an immediate change in bridge formula to accommodate higher vehicle loads was both affordable and economically advantageous, and also assisted in allowing better law enforcement by bringing the bridge formula limit in line with the axle load limits on most vehicles.

It was also determined that if the necessary funds were not made available to repair the additional road damage caused, the increase in vehicle operating cost would rapidly grow to a level exceeding any possible benefit.

Superficial assessment of safety, environmental factors and traffic indicated that although heavier vehicles affected these aspects negatively, the reduction in the number of heavy vehicles required to carry the same payload was reduced, indicating the nett change to be of a very low order. Social effects were not investigated in detail. The effect of possible changes on the other modes of transport was being assessed, but the results were not available at the time of going to press.

CONCLUSIONS

It was acknowledged that a number of parameters used in the calculation of the results of the study could not be determined precisely. However given the assumptions made the results provided a good indication of the economic benefit that may be obtained as a result of changing the legal axle and vehicle load limits, and of the costs that will be imposed on the road system as a result

of such change. The results were reasonably robust when tested for sensitivity against changes in the assumptions made.

It was concluded that a change in the legal axle and vehicle loads could be justified in terms of the overall benefit generated.

The need to analyse certain bridges in detail and possibly to strengthen such bridges, irrespective of whether the axle and vehicle load limits were changed, was identified. If the load limits were changed this analysis and strengthening (if necessary) would have to be expanded to more bridges.

The results indicate that there is no real economic justification in increasing the maximum axle loads above 9 tonnes, given the present road pavement inventory in South Africa. Changing the axle loads to option 2 generated an overall benefit of R19 million per year. To release this benefit an annual additional amount of R107 million would have to be invested in road maintenance and rehabilitation. This also induced an estimated extra R35 million cost for bridge strengthening.

The need to carry out the additional road maintenance was essential as the benefit generated would rapidly be negated by an increase in vehicle operating costs, if the road network was allowed to deteriorate more rapidly as a result of the change in legal limits.

It was therefore proposed that the change in limits be implemented only when a better loading control programme was in place, and when assurance of the necessary financial provisions has been obtained from Government.

To assist the transport industry the bridge formula controlling the axle group on vehicle combination loads was recommended for immediate change.