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AN ECONOMIC MODEL FOR DETERMINING THE EFFECTS OF CHANGES IN VEHICLE LIMITS ON AUSTRALIAN ROADS

Abstract

The authors describe a predictive road model to investigate changes in mass limits for vehicles using Australian roads. The model can be used to research variations in roads policy including assessing road standards, road funding strategies, pavement loading and vehicle operations.

The model has been used to predict the effects of possible changes to road vehicle limits in Australia and to determine the most acceptable set of limits on the basis of economic analysis within the National Association of Australian State Road Authorities (NAASRA) Review of Road Vehicle Limits Study.

The model could be developed and applied to investigate the effects of other changes in road and bridge loading results from changes in policy or practice which would affect the commercial vehicle fleet. An example of this type of application is the assessment of separable costs between vehicle categories and road types.

AN ECONOMIC MODEL FOR DETERMINING THE EFFECTS OF CHANGES IN VEHICLE LIMITS ON AUSTRALIAN ROADS

INTRODUCTION

This paper describes a transport model developed for the National Association of Australian State Road Authorities (NAASRA) to research and assess the economic effects of a change in road vehicle limits. The model was developed as part of the Review of Road Vehicle Limits (RoRVL) Study (NAASRA, 1985). RoRVL was established to review mass and dimension limits and associated regulations with the objectives of achieving uniformity and of giving the Australian Road Transport Industry the opportunity of increasing its productivity.

The RoRVL study follows the Economics of Road Vehicle Limits (ERVLS) undertaken by NAASRA in 1973-6 (NAASRA 1976).

Road Transport makes a significant contribution to the movement of freight within Australia and contributes about 8% to the National Gross Domestic Product (BTE, 1985). The provision and protection of roads used by the Industry is largely the responsibility of the State Road Authorities and Local Governments whereas the provision of the road transport services is largely in private ownership.

RoRVL considered many factors including vehicle performance and safety, industry expectations, community views, enforcement strategies and economic and financial impacts. This discussion is limited to the modelling process used to analyse the financial and economic effects to both Industry and the Road Authorities. Because of data limitations, the modelling was limited to rural and outer urban arterial roads. The Study also considered the effects on urban and local roads but these are not discussed in this paper.

Prior to the analysis the Study undertook extensive roadside weighing and measuring of heavy vehicles to provide data on vehicle characteristics and traffic composition surveys which gave data concerning the transport task.

Viable sets of alternative mass limits were designed for analysis by considering industry submissions, efficiency and safety requirements. Industry, community, government and expert opinions were collected by a process of extensive consultation involving public meetings and written submissions. The many permutations of possible limits were reduced by a preliminary assessment which optimised payload in terms of pavement damage potential.

THE ROAD ANALYSIS MODEL

The road analysis model computed the changes in both State Road Authority (SRA) costs and road user costs resulting from changes in vehicle mass limits. To facilitate this process a computer system was developed which simulated both traffic operations and SRA operations on the road system.

A Model for Assessment of Road Vehicle Limits (MARVL) was developed from several computer models established by the previous ERVL Study and modified models from the NIMPAC suite (NAASRA, 1981). A simplified flow chart of the MARVL system is shown in Figure 1. The system computes annual road user vehicle operating costs, travel time costs and accident costs for various vehicle categories. It also estimates costs which are likely to be incurred by SRAs including routine road maintenance costs, reseal costs and reconstruction or rehabilitation costs.

The MARVL System

The MARVL system consists of several sub-systems each containing one or more computer models. Each system requires various sets of data and parameters. The relationships between the more important models, data and parameters are discussed briefly below.

The NAASRA Road Data Bank (NRDB)

The NRDB is a composite data bank maintained separately by each SRA according to general specifications. It includes data on road length, width, geometry, pavement roughness and vehicle volumes including an estimate of the heavy vehicle percentage on each road section. The data banks for each State were collected in their most current form and a simulated update performed to model the anticipated inventory at 1987. This was chosen as the reference date for the analysis as being the earliest time at which new limits are likely to be introduced.

The Road System

The road inventory obtained from the NAASRA Road Data Bank was sampled in accordance with a random stratified procedure developed by the Bureau of Transport Economics (BTE, 1984). The sample strata covered road functional class, area class, length of section, traffic volume and general terrain type. This procedure reduced the volume of data contained in the inventory for each State to manageable proportions and significantly reduced the computer time required for the analysis.

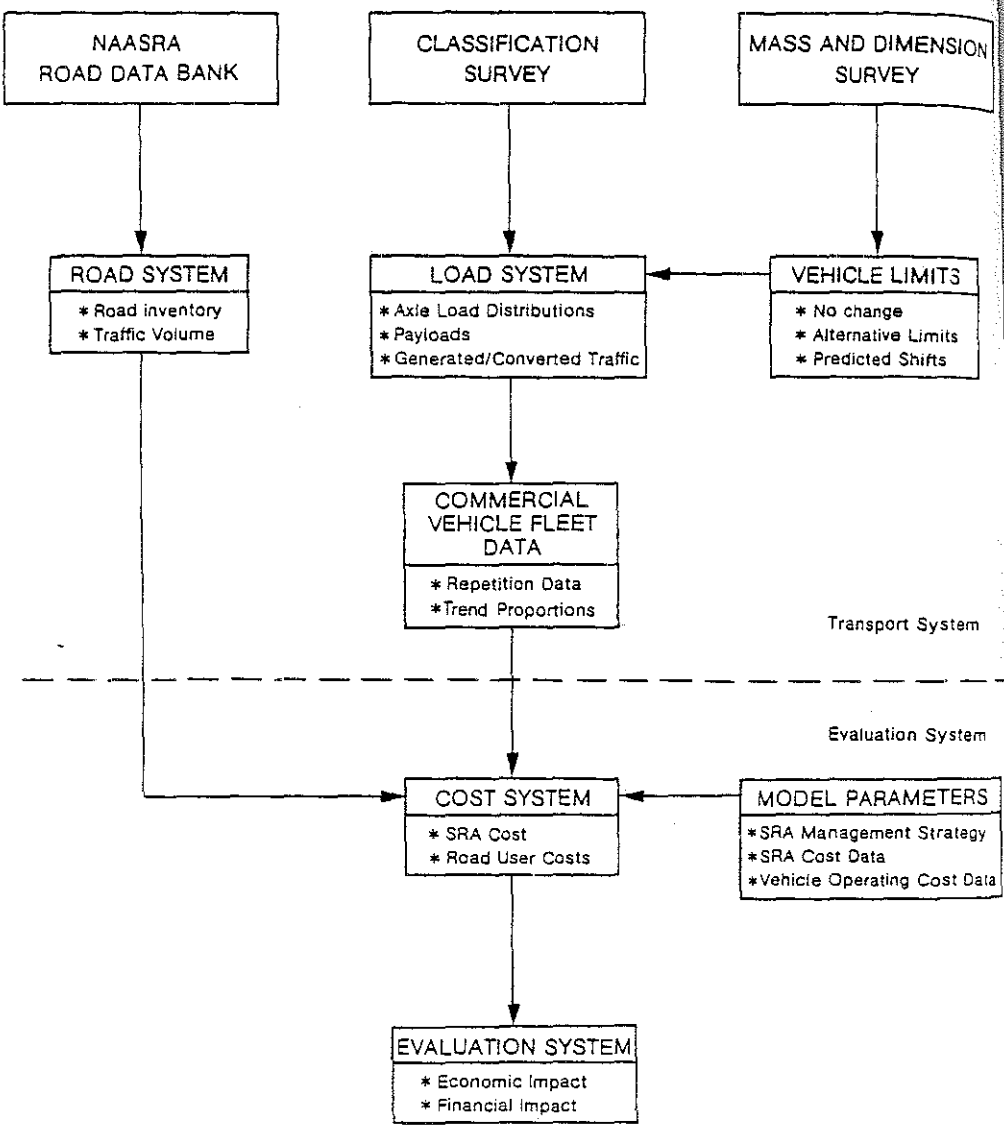
Level Of Analysis

In order to represent variations in traffic composition, axle loading and SRA costs the analysis data was aggregated at the level of road functional class by region. Each State was divided into regions representing a reasonably homogeneous data area (one or two regions per State) and generally included lengths of functional class 1, 2, 3, 6 and 7 roads. The analysis system produced road costs totalled by functional class and by State.

The Classification Survey

The RoRVL Classification Survey provided an estimate of the proportions of heavy commercial vehicle types on each class of road analysed. This data was required because the NRDB contained only a single percentage representing the average proportion of heavy commercial

Fig. 1 THE MARVL SYSTEM



vehicles in the average daily traffic on each road section, while the model required a detailed breakdown of heavy vehicle class and axle configurations so that pavement loadings and vehicle operating costs could be more accurately estimated.

The Mass and Dimension Survey

The Mass and Dimension survey provided truck data which was then input into the load system. This survey collected detailed information on vehicle dimensions, payload, body type, load distribution, axle configuration and origin and destination. Information was aggregated by region and by functional class in each State to give representative data on the heavy commercial vehicle fleet.

The Vehicle Limits System

This system contains a predictive model which generated new vehicle fleet characteristics for the alternative vehicle limit options. The model processed vehicle records from the Mass and Dimension survey and generated a new set of vehicle records in accordance with modelled response to the proposed alterations in limits. The model hypothesised that, subject to various threshold conditions, various vehicle characteristics would be changed in proportion to both the utilisation of the existing limit and the amount of change for the new limit.

For the base case, where no limit changes were proposed, unaltered survey results were used for subsequent processing to calculate base case costs over the assessment period. For an alternative limit option, a new set of vehicle records generated by the Vehicle Limits System was used to calculate the costs and benefits of that option. The system also provided for input of estimated shifts between the proportion of the various vehicle types in the revised commercial vehicle fleet.

The Load System

The primary function of the Load System was to estimate the changes to pavement loading resulting from changes to vehicle limits. For the base case this estimate was derived in the following manner:

(i) the Classification Survey data and the Mass and Dimension survey data were combined to give the best estimate of commercial vehicle numbers and the proportions of each axle group type;

(ii) the Mass and Dimension survey data was used to derive the axle load frequency distribution for each axle group type; and

(iii) the axle load frequency distributions and pavement damage functions were combined with the commercial vehicle numbers to estimate the pavement. This pavement load was expressed in terms of Equivalent Standard Axles (ESAs).

For the alternative limit options the process to estimate the pavement loading was similar to that for the base case, but with the following adjustments:

(i) the vehicle numbers were adjusted to account for changes in the total number of vehicles required to perform the base transport task. This adjustment was based on the payloads estimated from the base case Mass and Dimension survey vehicle records and the option case generated Mass and Dimension vehicle records;

(ii) the vehicle numbers were again adjusted to account for freight generated or converted from road to rail. This adjustment was based on changes in freight rates and on assumed demand elasticities for road and rail freight transport; and

(iii) the vehicle numbers were further adjusted to account for the estimated shifts in the proportional use of various vehicle types.

Hence for each option the pavement loading was estimated using adjusted vehicle numbers, the axle group proportions, and the altered axle load distributions generated from the Vehicle Limits System.

The Load System expressed the change in pavement load that resulted from a change in vehicle limits as a ratio of the option case pavement load to the base case pavement load. This ratio was defined as the Repetition Ratio (RR) and is expressed as follows:

$$\text{Repetition Ratio} = \frac{\text{Number of ESAs for the option case}}{\text{Number of ESAs for the base case}}$$

Commercial Vehicle Fleet Data

In addition to estimating the Repetition Ratio for each option the Load System also calculated the proportion of each heavy commercial vehicle class in the heavy commercial vehicle fleet. These proportions were applied to the heavy vehicle percentage supplied in the NRDB.

The Cost System

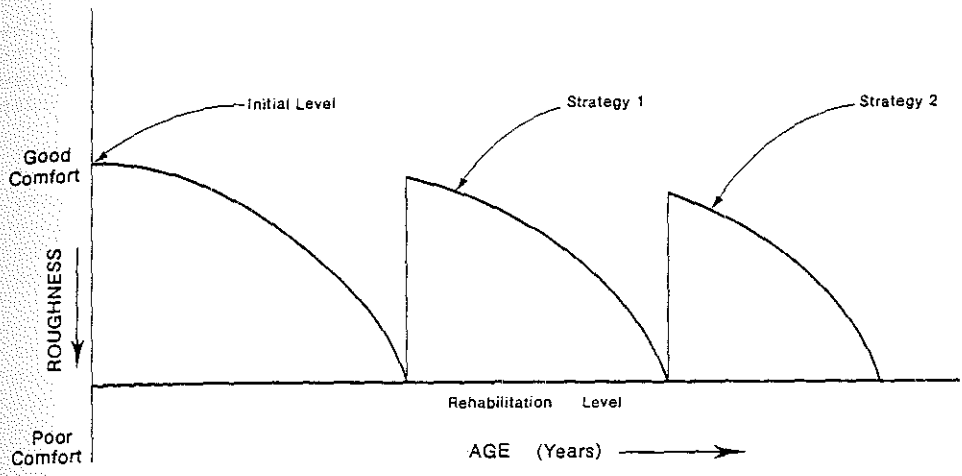
The Cost System is based on the NIMPAC suite which was previously developed by NAASRA for the purpose of assessing the effects on roads and road budgets resulting from alternative engineering standards and road improvement strategies (NAASRA, 1981).

The program modules adapted from NIMPAC were modified to allow for variations in pavement loading and heavy commercial vehicle categories.

The model considered each road section of the road network represented by the inventory. For each road section a projection of costs was determined as follows:

(i) the model simulated the performance of the road section according to a predetermined pavement life cycle. When pavement management strategy parameters were satisfied a project such as reseal, reconstruction or rehabilitation was generated and the appropriate costs estimated in accordance with cost parameters

Fig. 2 PAVEMENT LIFE CYCLE



provided. The annual cost for maintenance of the road section under analysis was also estimated. In this manner the SRA cost profile for each road section was simulated over the assessment period.

(ii) for each year of the analysis the model estimated the operating costs for the various vehicle categories. Each category of vehicle has its own set of cost models specified by parameters which form part of the model input. These costs were accumulated for each year to give operating costs and travel time costs for each vehicle category and accident costs.

Critical to the simulation of the predicted life of a road section s the concept of a pavement life cycle. This is shown diagramatically in igure 2. The concept considers that immediately after construction a avement has an acceptable level of performance. Then, with the progress f time, traffic and weather, the pavement performance deteriorates to a tate which is unacceptable and rehabiltiation or reconstruction takes lace according to an appropriate predetermined strategy. These trategies restore the pavement to an acceptable level and deterioration ommences again. The model adopts the NAASRA roughness as a measure of avement performance.

The relationships between roughness and time were first pothesised by ERVLS and have since been absorbed into the NIMPAC model. general, research has shown that roughness may be satisfactorily pressed in terms of a quadratic function of time. The equations are of e form:

$$NRM = An^2 + Bn + C$$

ere NRM = the NAASRA roughness measurement
n = the pavement age in years
A,B, C are constant parameters.

Field observations were used to determine the appropriate parameters for these relationships.

For the alternative options the parameters governing the age/roughness relationship were altered to reflect the new rate of deterioration resulting from a change in pavement loading. The new deterioration rates were calculated to give a remaining life under alternative loading conditions in accordance with the relationship

$$(t_2 - T) = \frac{1}{RR} \times (t_1 - T)$$

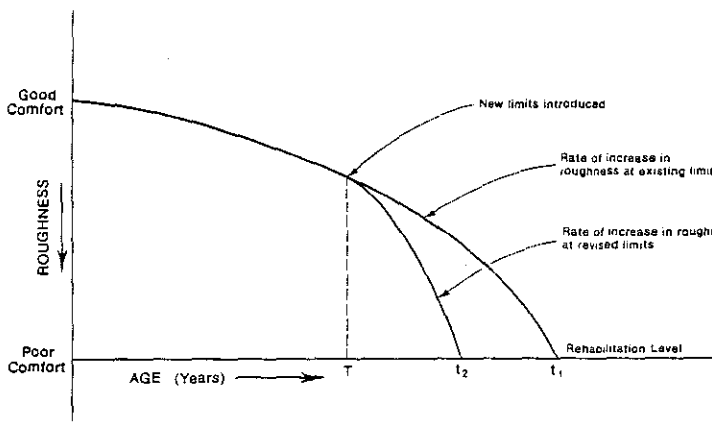
where: RR = repetition ratio calculated by the load system

$(t_1 - T)$ = the remaining service life of the pavement for the base case

$(t_2 - T)$ = the remaining service life of the pavement for the option.

This is indicated schematically in Figure 3.

Fig. 3 AGE/ROUGHNESS RELATIONSHIP



The Evaluation System

For the base case and for each option the cost system produced an estimated stream of road user costs and an estimated stream of SRA costs for each road section in the road inventory over a period of 30 years. The cost evaluation system performed three functions as follows:

(i) the road user costs stream and SRA cost stream for the base case on each section were subtracted from those for the option case to give additional costs on each road section;

(ii) the portion of the additional vehicle operating cost attributable to generated and converted traffic was adjusted in accordance with traditional consumer surplus theory giving estimates of benefit streams to both the revised traffic and to the generated and converted traffic; and

(iii) the additional cost and benefit streams were discounted as appropriate and totalled by road functional class to give totals of road user benefits and costs and additional SRA costs over the assessment period.

Analysis of the Effects of Overloading

The system provided a method for estimating the effects of overloading on the Arterial road network. The predictive model of the Vehicle Limits System was adjusted so that for an overloaded vehicle the payload was reduced to the legally allowable amount and the fleet proportions adjusted to provide for additional vehicles required to carry the overload. The resulting savings in SRA costs represented costs attributable to those overloaded vehicles.

It was realised that bias in the Mass and Dimension survey would cause a bias in the overload estimates. This bias arises from either overloaded operators avoiding survey sites or by the omission from the survey of most night time movement. To measure the extent of this bias data from a Weigh-in-Motion Survey (WIM) was used. Weight-in-motion survey equipment enables trucks to be weighed at highway speed and is virtually undetectable by truck operators. The WIM data, although limited in extent, provided a basis on which to adjust the apparent bias in the overloaded range of the Mass and Dimension Survey.

The Effects of Wide Single Tyres

The system also provided a means by which the damaging effects of wide single tyre triaxle groups could be estimated. For evaluation of this option the pavement damage function equivalencies for dual tyre triaxles were changed to those for wide single tyre triaxles. The resulting additional road costs represent costs attributable to a change of all triaxle groups on the road to wide single tyres. These additional costs were compared with estimated benefits to Industry.

THE BRIDGE ANALYSIS METHOD

The bridge analysis estimated changes in bridge costs which would result from changes in both the axle spacing mass schedule (or bridge formula) and in vehicle axle load limits. A system was developed which firstly estimated bridge loading in terms of bending moment, under a given axle spacing mass schedule and a given set of axle load limits. The system then compared the estimated load to the estimated load capacity for each bridge in the bridge inventory and determined whether the bridge was satisfactory or required signposting or replacement. Signposting or replacement costs were then estimated and compared with a base case analysis to obtain the additional costs for each option. A simplified diagram of the bridge analysis is shown in Figure 4.

The Bridge Inventory

Each SRA provided an inventory of bridges and culvert structures on National Highways, Rural Arterial Roads and Urban Arterial Roads (all urban areas). This inventory contained a description of the bridge location, length, width between kerbs, maximum and minimum span, superstructure and substructure material and type, and most importantly, the design load of the structure.

The Mass and Dimension Survey

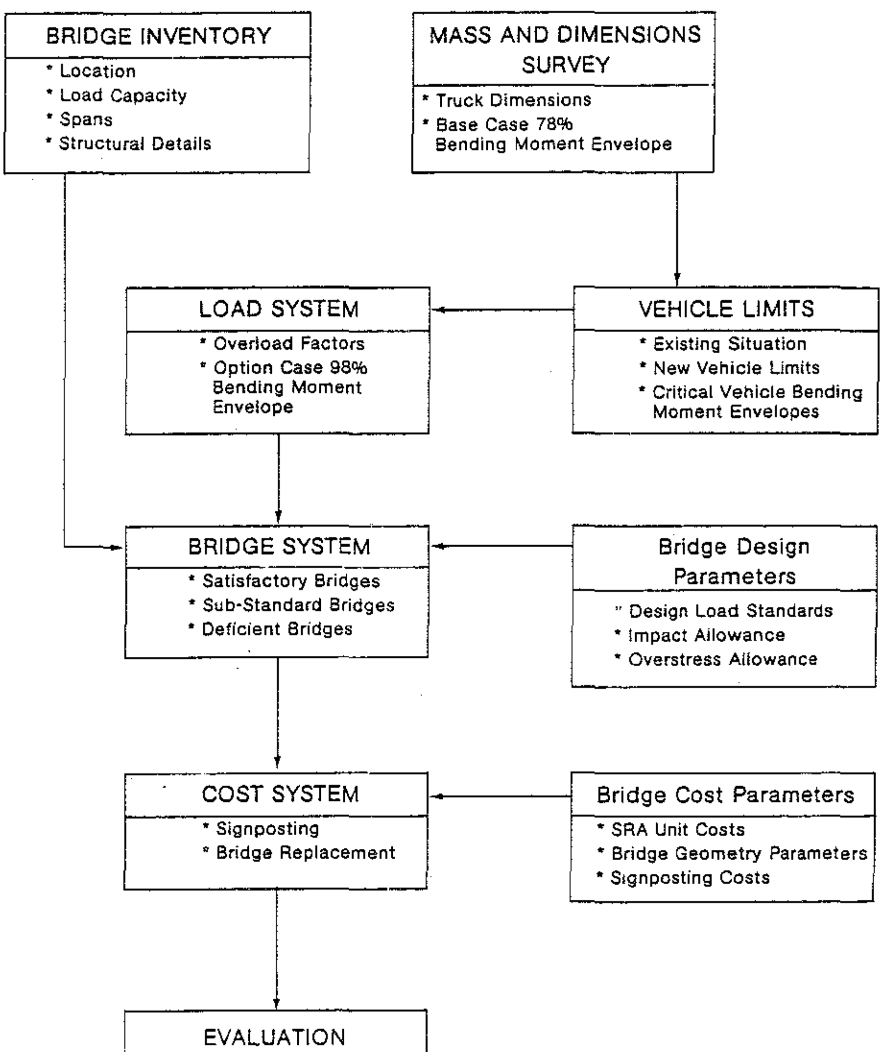
The Mass and Dimension survey results were used in the bridge analysis to provide:

(i) the dimensions of long, short and typical vehicles; and

(ii) estimates of bending moments generated by the existing vehicle fleet.

In each State, the truck records from the Mass and Dimension survey were analysed by a computer model which calculated the 98th percentile envelope of maximum bending moment against span length for the base case. These envelopes represented the bending moments which are exceeded by 2% of existing trucks.

Fig. 4 THE BRIDGE ANALYSIS



The Vehicle Limits System

This system used vehicle dimensions provided by the Mass and Dimension survey to estimate the maximum bridge bending moment for each bridge span under each axle spacing mass schedule and axle limit option analysed. A fleet of long, short and typical vehicles of each category from two-axle rigid trucks through to large truck and trailer combinations was synthesised. These vehicles were allocated maximum loads allowed by the axle spacing mass schedule and axle load limits under analysis. The vehicle type producing the maximum bending moment on each bridge span was referred to as the critical vehicle. The output of this system was:

(i) a critical vehicle bending moment envelope under existing limits; and

(ii) a critical vehicle bending moment envelope for the eastern States and for the western States of Australia for each axle spacing mass schedule and set of load limits considered.

The Load System

This system performed the following functions:

(i) for the base case, the ratio of the 98th percentile bending moment to the critical vehicle bending moment for each span was calculated. This conversion ratio allowed critical vehicle bending moment envelopes under alternative limits to be converted to 98th percentile bending moment envelopes; and

(ii) for option cases, the 98th percentile bending moment envelopes were computed. If the moment estimated for the option case was less than that for the base case, the base case moment was adopted.

The Load System output consisted of 98th percentile bending moment envelopes for each axle spacing mass schedule and axle load limit option.

The Bridge System

The Bridge System assumed that the strength of bridge spans is governed by bending moment capacity and that, if bending stresses are acceptable, then shear stresses, deflections, cracking and other failure criteria would also be acceptable. The system also assumed that all bridge spans analysed were simply-supported and that conclusions based on simply supported span analysis could be extended to continuous spans.

For both the base and option cases, the Bridge System examined the minimum and maximum span of each structure on the inventory and calculated:

(i) the 98th percentile bending moments;

(ii) the design bending moment capacities, based on the design loading specified in the inventory, adjusted by the appropriate impact allowance; and

(iii) the overstress bending moment capacity, based on the design loading and adjusted by the appropriate overstress allowance(1).

The system then classified each bridge in the inventory into one of three categories:

(i) satisfactory, where the 98th percentile bending moment was less than the design bending moment capacity; or

(ii) substandard, where the 98th percentile bending moment exceeded the design bending moment capacity but was less than the overstress bending moment capacity; or

(iii) deficient, where the 98 percentile bending moment exceeded the overstress bending moment capacity.

The Cost System

The Cost System examined the lists of bridges categorised by the Bridge System. For substandard bridges signposting costs, were calculated. Where bridges were deficient, the cost of a replacement bridge was estimated based on a bridge cost model with parameters supplied by the SRAs. This process was carried out for both the base and option cases. The difference in total costs between the base and option cases represented the additional bridge costs attributable to changes in axle spacing mass schedules and axle load limits.

The Evaluation

The additional bridge costs produced by the Cost System were total costs in 1984 prices. For the purpose of further evaluation these costs were converted to a cost stream over a ten year period on the basis that each SRA could accelerate bridge programmes and replace deficient bridges within ten years following the introduction of any new limits.

THE EVALUATION METHOD

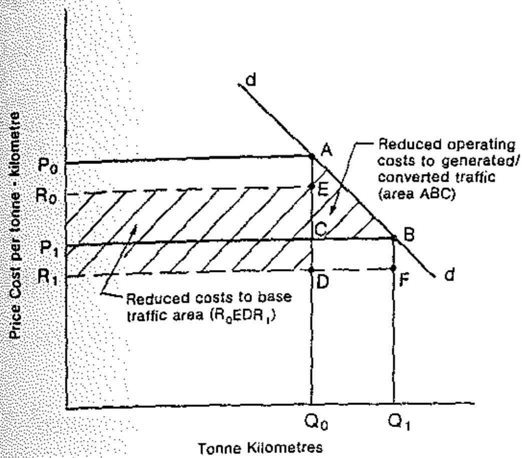
Economic Analysis

The cost streams from both the road and bridge models were combined to assess each option's economic worth.

The evaluation assumed the relationship between industry benefits and changes in transport price as illustrated in Figure 5. This relationship is consistent with the conventional approach for such analyses.

1 Overstress allowances for bridge construction materials, superstructure types and span lengths were based on those adopted by the ERVL Study.

Fig. 5 TRANSPORT INDUSTRY BENEFITS FROM A CHANGE IN VEHICLE LIMITS



The benefits to existing road traffic (ETB) are given by
igure 5):

$$ETB = (R_o - R_1)\, Q_o$$

ere: Q_o = quantity of freight moved in the base case
R_o, R_1 = resource cost per unit volume in the base case (R_o) and alternative case (R_1).

The benefits to generated and converted traffic (GCIB) are given
:

$$GCTB = 1/2\ (Q_1 - Q_o)\ (P_o - P_1)$$

ere: Q_o, Q_1 = quantity of freight moved in the base (Q_o) and alternative case (Q_I)
P_o, P_1 = perceived cost per unit of volume in the base case (P_o), and alternative case (P_I).

the purpose of the analysis it was assumed that resource costs R_o and
are the same as perceived costs P_o and P_1.

The results indicate that with changed limits, the amount of
efit to traffic converted from rail to road is likely to be small. The
unt of generated and converted benefit as shown in Figure 5 is
ggerated.

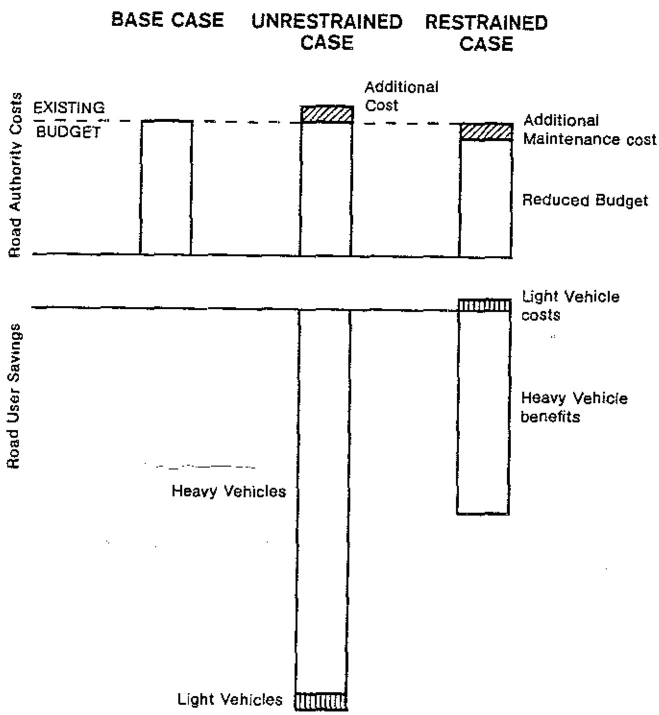
Annual resource cost streams (excluding taxes) were discounted
r the assessment period of 30 years in each case using an appropriate
count rate to give present value costs.

etary Conditions

The analysis system as described above represented situations
e road funding budgets were unrestrained. It assumed that SRA
nditure levels were determined, not by an annual budget, but by the
to maintain engineering standards.

To simulate a more realistic restrained budget condition, the critical management strategy parameter, the rehabilitation pavement roughness level, was adjusted iteratively to yield a minimum change in SRA costs for the option under examination.[1] This restrained budget analysis was performed for two States only. The results were used to estimate effects in other States. The unrestrained and restrained budgetary conditions are represented schematically in Figure 6.

Fig. 6 REPRESENTATION OF RESTRAINED AND UNRESTRAINED BUDGET CONDITIONS



1 Within the road analysis it was assumed that no additional road costs would be incurred. It was also assumed that no additional funds would be available for bridge improvement works.

Economic Criteria

Options were compared with the base case and each other using measures of benefit/cost ratio and net present value. Under a restrained budget condition where no additional funds are provided the present value of benefits determined the best option in terms of economic efficiency.

Financial Analyses

The financial analyses assumes the unrestrained budget conditions and were performed using costs that included transfer payment such as taxes and duties. Cost streams for each option were compared over the 30 year assessment period.

The average annual financial impact on individual SRAs was calculated as:

$$e = \frac{c}{C} \times E$$

where:

- e is additional annual expenditure
- c is the cumulative difference in cost after 30 years between the option and the base case
- C is the cumulative total cost of the base case over 30 years
- E is the annual expenditure for 1984/85

The financial impact on road users was estimated from the present value calculated over the 30 year analysis period by the computer models. The total 30 year costs were factored by the appropriate present worth factor assuming constant growth in costs over the assessment period. Because the growth in road user costs was not explicitly output from the model, the growth in vehicle kilometres was used as a substitute.

Conclusions

This paper briefly describes a model to investigate changes in road and bridge costs and road user costs resulting from alternative vehicle mass and dimension limits.

The model requires extensive data on the road and bridge system, traffic compositions and truck characteristics. It also requires a large number of parameters defining engineering standards, road and bridge costs and road maintenance, rehabilitation and reconstruction strategies.

The model was established with the most recent data available for Australia. The model can be used to research and investigate variations in roads policy including assessing road standards, road funding strategies, pavement loading and vehicle operations.

It has been used to predict the effects of possible changes to road vehicle limits in Australia and to determine the most acceptable set of limits on the basis of economic analysis.

An assessment was also made of the economic effects and financial costs of allowing different road loading characteristics including wide single tyres, axle equivalencies and extent of overloading.

The model could be further developed and applied to investigate the effects of other changes in road and bridge loading results from changes in policy or practice which would affect the commercial vehicle fleet. An example of this type of application is the assessment of separable costs between vehicle categories and road types.

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