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TRAFFIC LOADING FOR PAVEMENT AND REHABILITATION DESIGN

DECEMBER 1991

TECHNICAL RECOMMENDATIONS
FOR HIGHWAYS

Draft TRH16

TRAFFIC LOADING FOR PAVEMENT AND REHABILITATION DESIGN

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PREFACE

The TECHNICAL RECOMMENDATIONS FOR HIGHWAYS (TRH) series is written for the practising engineer and describes current, recommended practice in selected aspects of highway engineering. The series is based on South African experience and on results of research and has the full support of and is issued under the auspices of the Committee of State Road Authorities (CSRA).

This document has been compiled by a subcommittee of the Highway Materials Committee of the CSRA. To confirm its validity in practice, it will be circulated in draft form for a trial period before being submitted to the CSRA for approval. This document, Draft TRH16, will therefore be in use for a limited period during which you are welcome to send suggestions for improvement to Mr F C Rust, Programme Manager, Asphalt Technology, Division of Roads and Transport Technology, CSIR, P O Box 395, Pretoria, 0001.

Eventually a revised document, approved by the CSRA, will be issued as a full TRH in both official languages.

SYNOPSIS

This document deals with the methodology for obtaining reliable traffic loading information for use in pavement design and rehabilitation and for planning in general.

A brief description of the nature of traffic loading and elements that should be considered when collecting information is given. A number of techniques may be used to obtain traffic loading information; guidance is given regarding the applicability of these techniques under different circumstances. The method of calculating the equivalent standard axles (E80s), the potential corrections which may have to be applied and evaluation of the sensitivity of the final result to the inputs are also discussed.

SINOPSIS

Hierdie dokument handel oor die metodologie om betroubare verkeerslasinligting te verkry vir gebruik in plaveiselontwerp en plaveiselherstel, asook vir beplanning.

'n Bondige beskrywing oor die aard van verkeersbelasting en die elemente wat in ag geneem moet word gegee. 'n Aantal tegnieke is beskikbaar om verkeerslasinligting te verskaf, en riglyne word gegee aangaande hul toepaslikheid onder verskillende omstandighede. Die berekening van die ekwivalente standaard asse (E80), moontlike korreksies wat aangebring moet word, asook 'n evaluasie van die sensitiwiteit van die finale uitslag tot die insette, word ook bespreek.

KEYWORDS

Traffic, loading, damage, equivalent standard axles.

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TRAFFIC LOADING FOR PAVEMENT AND REHABILITATION DESIGN (DRAFT TRH16 : 1990)

1. INTRODUCTION

1.1 BACKGROUND

Roads and streets are provided to serve the road transportation needs of the country. The travelling public expects to travel safely and comfortably at its desired speed. This means that the road or street should exhibit the desired geometric characteristics to ensure that overcrowding of the available road space does not occur, while providing an even road surface to ensure that the comfort criteria are fulfilled.

In the broadest context, traffic loading could be seen as the placement of the traffic on the network, which includes both the use of space and stressing of the pavement or structures. However, in this document, traffic loading is restricted to the stressing of pavement layers, as the document is written for application in pavement and pavement rehabilitation design.

Traffic loading could also be considered to consist of three elements:

- vehicle loading, i.e. the force and consequently damage applied to the pavement by a legally-loaded vehicle;

- vehicle overloading, i.e. the force and consequent damage applied by an overloaded vehicle;

- vehicle lading, i.e. the extent to which the vehicle's load capacity is utilised.

For specific applications the details of each element may be required. These can usually be obtained from traffic counting and weighing information collected when it is necessary to apply this document. No distinction between the different elements of traffic loading will be made.

1.2 SCOPE OF THE DOCUMENT

Pavement and rehabilitation design methods and road management are dependent on reliable traffic loading information as incomplete or inappropriate methods of data collection or interpretation could have serious and costly consequences. These technical recommendations were developed to provide guidance for collecting the relevant information and are aimed at the practitioner. This document not only covers current practice as a guide for practitioners (as is the objective of TRH documents), but also describes techniques which show potential and which may be useful under certain circumstances. There are, however, a large number of factors that affect the traffic loading values. These will be discussed below. Although this document provides guidance and recommendations, the practitioner cannot dispense with engineering judgement in critically evaluating all aspects which may impact on the situation being analysed.

A schematic outline of the procedure for obtaining traffic loading information is shown in Figure 1. Sections in this document where the different aspects are discussed are indicated in brackets.

Companion documents, TMH3 on "Procedures for vehicle weighing"[1] and TMH8 "Traffic counting procedures for rural roads"[2], deal with specific aspects pertinent to the topic of this document. The specific information will not be repeated, but will be referred to where relevant. Readers are encouraged to study the companion documents on items of detail.

1.3 EXPLANATION OF TERMS

1.3.1 Legal axle loads

There are three factors that play a role in determining the legal axle load:

- vehicle manufacturer's specification,
- tyre load rating, and
- permitted axle loadings.

On heavy vehicles, the permitted axle loading which is related to the number of wheels per vehicle axle, is generally, the limiting one except in the case of steering axles. It is governed by Regulation 365(a) and (b) of the Road Traffic Act, Act No 29 of 1989. Two wheel axles, such as rear axles fitted with super-single tyres, are permitted to carry up to 7 700 kg. Front axles are, however, limited to the manufacturer's specification which is 6 000 to 6 500 kg for heavy trucks. Rear axles fitted with dual tyres may carry up to 8 200 kg, except in the case of a bus where one axle may carry up to 10 200 kg. The bridge loading formula (Regulation 365(c) of the Road Traffic Act) places a further restriction on the permissible load of groups of axles and gross vehicle mass, but it is not directly applicable to pavement design.

1.3.2 Equivalent standard axle loads

Research at the AASHO Road Test found that pavement damage is not proportional to axle load, but is governed by a power relation. From this research the equivalent standard axle concept was developed, which is used to express a range of axle loads such as applied by mixed traffic, in terms of a common denominator. In South Africa, an 80 kN axle is used as the standard axle load, and the damage caused by any other axle load relative to the standard axle is defined as the equivalent standard axle (E80). For mixed traffic the total E80s is the number of 80 kN axle loads which causes the same damage as the actual spectrum of axle loads imposed. The 80 kN standard axle load does not have to bear any relation to the legal axle load and may be used without regard to the legal limit even if this is changed.

For most applications it is sufficient to accept that the E80 of any axle load, P_j, is $(P_j / 80)^n$, where P_j is expressed in kN and n is the load equivalency exponent with an average value of 4. This expression is derived from the AASHO Road Test, where equivalent damage was defined in terms of riding quality. The same type of expression may be used to define load equivalency for rutting or strain, but care must be taken not to confuse the terminology with the original definition.

Pavements that are sensitive to overloading, such as shallow-structured pavements with thin cemented bases, may have n-values greater than 4, whereas less sensitive deep-structured pavements may have n-values of less than 4 (see Table 9). Furthermore, the n-value may change over the pavement's design life. These deviations from the average n-value of 4 may be considered in special instances, but for general purposes the exponent of 4 is adequate.

1.3.3 Average daily E80 (ADE)

The average daily E80 is the E80 per lane per day averaged over the survey period during which the axle load survey was conducted.

1.3.4 Annual average daily E80 (AADE)

The annual average daily E80 is the total E80s <u>per lane</u> applied during one year divided by 365 days. The AADE cannot be determined from a single survey conducted over a short period of time because of cyclic and random variations in traffic loading which occur during a calendar year. Ideally, on existing paved roads data should be collected continuously, but this is not feasible. Some type of sampling has to be used. This can consist of surveying over short periods, e.g. days, several times during the year, or weighing selected vehicles.

Since axle load surveys are normally conducted over short periods ranging from several days to two weeks, adjustment factors derived from permanent classification count stations are often applied to convert the measured average daily E80 to estimated AADE values. Adjustment for cyclic variations is based on the premise that these are well-defined and consistent fluctuations. No adjustment can be made for random fluctuations, and it is best to avoid conducting surveys under abnormal circumstances (see Section 4).

1.3.5 Annual average daily traffic (AADT)

The annual average daily traffic (AADT) is expressed as the total traffic during a year, in both directions, divided by 365, and is thus calculated differently from the AADE.

1.3.6 Traffic classes for structural design purposes

For structural design purposes, seven different traffic classes, shown in Table 1, have been defined in terms of the cumulative equivalent traffic in the design lane over the structural design period of the road. TRH4[3] gives recommendations on the structural design period. These traffic classes are related to practical differences in pavement layer thicknesses and provide an indication of the level of accuracy required to determine traffic loading. Although this type of traffic classification is a useful method for communication, the actual equivalent traffic may be required for specific purposes.

1.4 CHANGES IN TRAFFIC LOADING

Variations in traffic loading may be either short or long term. Components of short-term variations are

- seasonal variations, and
- random fluctuations.

On the other hand, long-term variations include the following:

- long-term growth or decline in traffic loading,
- cyclical variations related to economic activity,
- fluctuations related to changes in regulations or government policy.

1.4.1 Short-term variations

Short-term variations reflect those changes that take place within a period of a year. Seasonal variations are regularly recurring periodic patterns in the traffic flow that take place each year and are usually caused by factors such as weather or agricultural activities such as planting or harvesting. Although adjustment factors may be used to convert ADE during this period to AADE, it is recommended that ADE be obtained not only for normal operations but also during times of seasonal activities.

TABLE 1 Definition and description of traffic classes[3,4]

TRAFFIC CLASS	CUMULATIVE EQUIVALENT TRAFFIC (E80/lane)	DESCRIPTION
E_R	< 0,05 million	Residential access roads; very lightly trafficked, very few heavy vehicles
E0	< 0,2 million	Very lightly trafficked roads, very few heavy vehicles
E1	0,2 - 0,8 million	Lightly trafficked roads, mainly cars, light delivery vehicles and agricultural vehicles, very few heavy vehicles
E2	0,8 - 3 million	Medium volume of traffic; few heavy vehicles
E3*	3 - 12 million	High volume of traffic and/or many heavy vehicles
E4*	12 - 50 million	Very high volume of traffic and/or high proportion of fully laden heavy vehicles
E5*	50 - 200 million	Exceptionally heavily trafficked roads

* For design purposes actual cumulative E80s would be required.

Irregular fluctuations are very short-term changes in the traffic flow and may, for example, be caused by temporary building or construction work. Such activities could also affect normal traffic flows and surveys during such periods should be avoided. School holidays would not normally affect heavy vehicle operations, except possibly during the Christmas recess, and may therefore be disregarded for the assessment of the ADE.

1.4.2 Long-term variations

The long-term growth or decline in traffic loading, (referred to as the "trend") over a period of many years is determined by factors such as changes in population, industrial growth, etc. Moreover, traffic loading is influenced by changes in the demand and supply of goods, in locations of demand and supply and in the type of goods. For example, the information explosion and computer networking could have a material effect on future public transport demand. In defining potential changes it is important to take the National Physical Development Plan of South Africa into account. This plan, shown in Figure 2, indicates in broad terms where growth can be anticipated to take place. Furthermore, the long-term change in traffic loading on specific roads, could be markedly influenced by the establishment of new industries, e.g. a coal mine or a quarry. Although the managers of these industries may give an indication of future transport demand, acceptance of such statements has to be tempered by past experience with such industries. Often engineering judgement will have to be combined with facts to arrive at the most likely estimate of growth.

Traffic loading is also influenced by changes in the way transport between the different modes (road, rail, sea, air and pipeline) is supplied to satisfy the demand. Any improvement in the level of service of any one mode would attract goods from other modes. Efficient management of road transport can lead to higher load factors (fewer vehicles running empty and better utilisation of capabilities) with a resultant change in the type and size of vehicle used. In South Africa there has been a steady increase in the E80 per heavy vehicle during the 1980s as will be discussed below.

Cyclical variations refer to the recurring fluctuations which have a period of several years around the trend levels. These are usually related to the levels of economic activity of the country. It is not advisable to correct for these cyclical variations as their average impact will correspond with the trend.

Government regulations and policies control the demand and supply of goods and the way goods are transported directly and indirectly. Any changes in these regulations and policies (such as changes in the legal axle load or gross vehicle mass of vehicles and deregulation of transport) may have a significant effect on traffic loading. Mode choice is controlled to a large extent by regulations and deregulation may, for example, cause a shift from rail to road. The degree to which law enforcement to control overloading is applied would have an impact on traffic loading.

From the foregoing it is apparent that adjustment for long-term variations in traffic loading is complex. Consequently any adjustment factors should be developed over at least a five year period, and should consist of mathematically fitting the "best" line to AADE collected. Growth should be compound growth and an exponential form should be expected for the "best" fit. Because of all these variations it is important to analyse the sensitivity of changes as discussed in Section 4.

2 CONSIDERATIONS FOR DETERMINING TRAFFIC LOADING

2.1 INTRODUCTION

Broadly speaking the method for determining traffic loading consists of obtaining the AADE in the first analysis year and then calculating the future cumulative E80s over a structural design period or analysis period by applying suitable factors.

2.2 LEVEL OF SOPHISTICATION FOR DIFFERENT APPLICATIONS

For different purposes different levels of sophistication or accuracy may be required. Three potential applications may be identified:

(a) detailed rehabilitation design for existing road projects;
(b) detailed pavement design of new road projects; and
(c) network level management, which includes long-term planning.

The importance of the road plays a major role in defining the sophistication level of data required for these applications. In this document the importance of the road is described according to the categories used in TRH4[3], which are detailed in Table 2.

Traffic loading information may be obtained from the following sources or methods:

(a) tabulated average E80 values
(b) published results of surveys
(c) transportation planning models
(d) estimation procedures based on visual observations
(e) weighing methods.

TABLE 2 **Definition of the four road categories**

	Road category			
	A	B	C	D
Description	e.g. interurban freeways, major interurban roads	e.g. interurban collectors, major rural roads, major industrial roads	Lightly trafficked rural, rural, strategic roads	Special pavements innovations, costsavings ideas
Importance and Service level	Very important Very high level of service	Important High level of service	Less important Moderate level of service	Important to less important Moderate to low level of service
Total equivalent traffic over structural design	3-50x10^6E80/lane over 20 years	0,2-12x10^6 E80/lane depending on design strategy	<3x10^6 E80/lane depending on design strategy	3x10^6 E80/lane depending on design strategy

For existing roads the simplest and most reliable method of obtaining the average daily E80s (ADE) is to conduct a traffic load survey. Ideally, the survey should be conducted over a long period of time, such as at permanent stations. However, this may not be feasible at all important sites. Consequently, short-term surveys of traffic loading are required. It is recommended that on Category A and B roads[3], i.e. major rural or industrial roads, the minimum duration of surveys should be seven days. Surveys should be carried out during periods of normal flow and seasonal activities. When calculated as a percentage of the cost of rehabilitation or reconstruction, the cost of such axle load surveys is negligible. Depending on the traffic volumes, and consequently the implications of gross errors in the estimated traffic loading, traffic surveys shorter than one week may be used on Category C roads[3], which are lightly trafficked.

For less important roads, e.g. category C roads carrying fewer than 300 heavy vehicles per day in one direction, static weighing surveys may be feasible. With static surveys, monitoring at night would not be possible, and some adjustment would have to be made to obtain the ADE. Surveys in such cases should preferably be conducted over at least a 12-hour period from 06:00 to 18:00. Typically about 70 per cent of the daily traffic loading would use the road during this 12-hour period, although this proportion has been found to vary between 40 per cent for through rural routes and 90 per cent for urban freeways. Projection of the survey data to 24-hour results should thus be done on the basis of local knowledge on traffic flows, and if possible, by using classification counts during the 24-hour period. Classification counts usually provide the number of vehicles of each type for each hour of the day and night. Assuming that the vehicles are similarly loaded during the day and at night, the survey data can be extended to give the ADE.

Sometimes only an approximate estimate of the loading on Category C roads is desired where traffic surveys are not warranted. In such cases three possible methods may be applied:

- relate a visual inspection of the loading to E80[5],
- use E80 factors of another road in the same area or tabulated values, or
- apply the stratification method proposed by Bosman[6] or the one used by the TPA[7].

For a new road along a new alignment it is not possible to capture the actual traffic loading spectrum. In such a case the design or predicted traffic has to be converted to design traffic loading. The method proposed by Bosman[6] shows potential for application as in the case given in Section 2.3. Alternatively tabulated values or factors from another road with similar characteristics in the same area can be applied.

The South African Rural Traffic Model (SARTM)[8] is a powerful procedure which has been calibrated for use in South Africa to estimate future transport volumes on existing links and on new links. Another example of such a procedure is the one employed in analyzing transport in the PWV area[9].

Recommendations for the use of the different procedures in specific applications are summarized in Table 3. Note that these recommendations may be overruled if the specific circumstances permit.

TABLE 3 Suitability of different procedures for specific applications

	Rehabilitation of existing roads	Pavement design of new roads	Network level management
Tabulated average E80 values	≤E1	≤E1	*
Published results of surveys	Category C, ≤E2	All roads	All roads
Transportation planning models	For growth rates	**	All roads
Visual estimation methods	Category C, ≤3	N/A	***
Weighing methods	All roads	N/A	***

* Where other data are not available
** For supplementing published results of surveys, and for growth rates
*** Only in exceptional circumstances where high quality data is required

2.3 VEHICLE CLASSIFICATION

The aim of collecting axle loading information is to gain an idea about the potential damage which the traffic causes to the road. Therefore, in theory, information should be collected on all vehicles. It is well-known that heavy vehicles cause more damage than light vehicles, and where sampling has to be used, more attention will be paid to those vehicle categories which cause more damage. Each method of collecting axle load information will have a specific definition for the vehicles it considers, and this should be borne in mind. The recommended definition of a heavy vehicle is a vehicle with axle loads greater than 4 000 kg, gross vehicle mass greater than 7 000 kg and a carrying capacity greater than 3 000 kg[3]. Such vehicles would be fitted with dual tyres on axles other than steering axles, unless wide-based super-single tyres are used.

Traffic loading information related to a vehicle type classification provides a more powerful basis for manipulating information than one simply related to heavy vehicles. Such a classification has to be simple and readily applicable in the field without losing power. Systems that use different axle configurations have been used, but the recommended system is based on the number of axles of a heavy vehicle. Although different axle configurations may be found, the damage caused by vehicles with the same number of axles is similar.

Care should be taken that an E80 per heavy vehicle factor based on one classification system is not used in another one which does not have an equivalent classification. Major differences often occur in the classification of what constitutes a heavy vehicle.

2.4 SOURCES OF INFORMATION

2.4.1 Tabulated factors

The simplest form of information is the tabulated values representing average conditions. In TRH4 : 1985[3] such average values are presented. These have been updated with 1990 information. A rough estimate is made of the type of heavy traffic that uses different road categories, and average **E80s per heavy vehicle** are then read from a table such as Table 4. This factor is then multiplied by the number of heavy vehicles in each lane to obtain the ADE. As can be appreciated, this method is approximate, and could result in serious errors. For example, this technique was applied recently to results obtained by the dynamic monitoring of axle loads on a Category B road. An error of 100 per cent in the lifetime E80s was found. For this reason use of tabulated results is recommended for up to E1 traffic.

TABLE 4 Average E80s per heavy vehicle

LOADING OF HEAVY VEHICLES (OR TYPE OF ROAD)	E80/HEAVY VEHICLE 1990
Mostly unladen (Category C, farm to market)	0,6
50 % of the heavy vehicles laden and 50 % unladen (Category A or B, major interurban)	1,2
> 70 % of the heavy vehicles fully laden (Category A or B, main arterials or major industrial routes)	2,0

For the recommended vehicle classification system, more reliable estimates are shown in Table 5. The damage caused by a bus is shown separately in this Table. The damage caused by a legally fully-loaded bus is 2,77 E80, since one axle of a bus is permitted to carry up to 10 200 kg. Although minibuses are often overloaded, their influence on pavement damage is negligible.

TABLE 5 Average E80s for different heavy vehicle configurations

Vehicle type	Average E80s	Range in average E80s per vehicle found at different sites
2-axle truck	0,,70	0,30 - 1,10
2-axle bus[10]	0,73	0,41 - 1,52
3-axle truck	1,70	0,80 - 2,60
4-axle truck	1,80	0,80 - 3,00
5-axle truck	2,20	1,00 - 3,00
6-axle truck	3,50	1,60 - 5,20
7-axle truck	4,40	3,80 - 5,00

2.4.2 Published results

Often there is the temptation to use published results for other roads in the vicinity of the road under consideration and to extrapolate the findings. Depending on the purpose for which the data are required and the level of accuracy required, such an approach is permissible. However cognisance should be taken of potential errors which may occur by such extrapolation. Published results include documents produced by the Division for Roads and Transport Technology of the CSIR, the system of Comprehensive Traffic Observations (CTO)[11] carried out on behalf of the Department of Transport (DOT), and data collected by the Road Authorities.

Where other data sources are used, care should be taken with the vehicle classification system used, as well as the method by which the information was generated. For example, was the information collected from actual axle mass surveys, was it processed from secondary data sources, or was it obtained indirectly from vehicle information such as distance from the ground to the chassis or the vehicle length?

Two techniques still being developed show potential for extending published data to other roads. Future data collection may be tailored to validate these techniques. These techniques are that used by TPA[7] and the one proposed by Bosman[6,12]. They are presented below as they may be useful in specific situations.

2.4.2.1 The TPA method[7]

This method is an extension of the visual survey method presented in Section 2.3. It has been applied successfully in the Transvaal, but at present its application to other areas of the country has not yet been validated. The basis of this method is that routes with the same heavy vehicle spectrum will have the same axle load factor in terms of E80 per heavy vehicle axle. Furthermore, roads with the same axle load factor will have the same heavy vehicle spectrum. In developing this method an axle load factor was obtained for functional classifications of routes ranging from light to very heavy in terms of the type of heavy vehicles and their loads. Indications of the axle load factor on a number of roads are also given in the reference. A series of curves relating the percentage of axles in each axle load group, i.e. the axle load spectrum, to the average number of axles per heavy vehicle and the axle load factor, shown in Figure 3, was developed. This Figure may be used in two ways. If the axle load spectrum is known, then a vertical line closest to this spectrum gives the axle load factor at the bottom of the graph, and average axles per heavy vehicle at the top. Alternatively, for a given functional classification, e.g. medium, the average axles per heavy vehicle, axle load factor and spectrum may be read off. The ADE may be obtained by multiplying the axle load factor by the number of axles per heavy vehicle by the number of heavy vehicles per day. The details of Figure 3 are particularly relevant for the sensitivity analysis of the axle load factor which is discussed in Section 4.6.

2.4.2.2 Road network classification

In the method presented by Bosman[6,12], the road network is classified in terms of the heavy vehicle composition, and a consistent method of distinguishing roads was found. Heavy vehicles (HV) in this method were defined as any rigid vehicle or vehicle combination with a gross vehicle mass (GVM) of more than 5 500 kg. The road network is then split into two main classes: L-roads and S-roads. L-roads carry mainly smaller heavy vehicles, ie two and three-axle vehicles, whereas the heavier vehicles predominate on S-roads. A further subdivision was however necessary according to the following ranges:

L1	:	Two axle HV > 70 % of total HVs
L2	:	55 % < Two axle HV <= 70 % of total HVs
S1	:	35 % < Two axle HV <= 55 % of total HVs
S2	:	Two axle HV <= 35 % of total HVs

A provisional classification of the country's main road network according to this method is shown in Figure 4. In applying this map for planning or design purposes it must be borne in mind that sufficient HV-data was not available to classify the complete network. On route N3, for instance, counts were available at sites north of Estcourt, at Villiers and north and south of Heidelberg. Because they all showed an S2-classification, it was assumed that the rest of the route was also an S2-road. This assumption has to be ratified by more counts before applying it to the design of, for instance, the road pavement between Villiers and Estcourt. In addition results from the CTO[11] were used to assist in defining the classification. Note that a road's classification may change because of new industries or seasonal effects such as harvesting and even in the two directions. Preliminary results (1988) are given in Table 6 and were adjusted by results from some axle load surveys.

Although this method has not been validated by general application, the principles hold promise for implementation in situations where insufficient data are available or where a quick answer is required.

TABLE 6 Average E80s determined in the road network classification method (1988)

Road type	E80 per axle	E80 per vehicle	Number of axles per heavy vehicle
L1	0,2	0,5	2,3
L2	0,6	1,6	2,6
S1	0,6	2,2	3,7
S2	0,7	3,2	4,6

2.5 TRANSPORTATION PLANNING MODELS

Transportation planning models applicable to and calibrated for South Africa or for specific regions are becoming accessible to planners and designers in general. Details of these models are beyond the scope of this document, and the aim here is simply to alert the reader to the potential of such models.

One such package is the South African Rural Heavy Vehicle Demand Model which was commissioned by the Department of Transport[8]. The aim of this model is to predict future heavy vehicle trends with specific reference to future volumes, growth rates and E80s on the rural road network. A model of the same nature which is used in a regional context is the one applied in the PWV area[9].

These packages are based on the standard urban modelling procedure[9] which looks at the country or region from the perspective of a number of zones. The total number of trips generated and attracted to each zone is determined using the gross geographical product of the zones. These trips are divided between each origin and destination zone and between the different transport modes. Finally the resulting trips are assigned to each link of the network to obtain the traffic flows. These packages serve as a powerful aid for judging the future traffic on existing links and should be used in conjunction with axle load surveys.

Since development of these models is ongoing, a model applicable to the region under consideration and which gives the required outputs may be used. Further details about the application of the results are given in Section 3.

3 METHODS OF LOADING SURVEYS

3.1 ESTIMATION OF PROCEDURES BASED ON VISUAL OBSERVATIONS

This is a technique where an observer categorizes vehicles into different groups and uses an average E80 per axle to derive the ADE. It is a simple, inexpensive technique which can give acceptable results if used with circumspection. This procedure is used when axle load determinations are not justified nor a high level of accuracy required. Considering the importance of Category A and B roads it is unlikely that this technique would be applied to such roads. It is recommended that visual procedures should not be used for design traffic classes greater than E1[3].

A visual classification method was developed in South Africa[5]. In this method an estimation of the load carried by heavy vehicles is made by deciding on the extent to which the **volumetric** capacity is fulfilled. Note that this method is applied to all vehicles with an axle mass greater than 2 000 kg. These can usually be identified as those vehicles which are fitted with dual wheels. It would consequently exclude pick-ups and minibuses.

Forms suitable for use by visual survey personnel are given in Appendix A. For the application of this method the commodity transported is not required, but it may be useful for purposes of transportation studies also to note the type of goods transported. Table 7 gives typical axle load factors for various loading conditions. An example of the results of the calculations is given in Appendix B.

TABLE 7 Average axle load factors corresponding to various vehicle loading conditions to estimate E80s from visual surveys (n = 4)

DISTRIBUTION OF VEHICLE LOADING (MEDIUM-HEAVY AND HEAVY VEHICLES	AXLE LOAD FACTORS (E80s/AXLE) 1990
Predominantly lightly laden heavy vehicles (less than 35 per cent of the heavy vehicles fully laden; > 45 per cent empty)	0,3
Fully laden, partially laden and empty vehicles (40-45 per cent of the heavy vehicles fully laden; 35-45 per cent empty or partially laden)	0,5
Fully laden and partially laden heavy vehicles (60-75 per cent of the heavy vehicles full; < 30 per cent empty or partially laden)	0,7
Predominantly fully laden heavy vehicles (more than 75 per cent of the heavy vehicles full), which occurs in exceptional cases.	0,9

3.1.1 Combination of dynamic vehicle weighing and visual observations

A record is kept of the number of axles and axle loads of each vehicle with some of the sophisticated in-motion weighing systems. It is then possible to calculate the average E80 for each vehicle type, e.g. 2-axles, 3-axles, etc. These E80s per heavy vehicle type can then be applied in a visual or mechanical classification count. The numbers of vehicles in each of the total number of axle categories is multiplied by the measured average E80 for that heavy vehicle type. It is then not necessary to record whether the vehicle is fully laden or empty. This method is potentially more accurate than those discussed in Sections 2.4.1 and 3.1 and can be used for design traffic classes up to E3[3].

A specific application of this approach is the obtaining of a better estimate of traffic along a corridor, without taking traffic loading observations at every junction. Traffic loading information for the different vehicle types may be collected in the middle, of a 50 km road length due for rehabilitation, for example. Classification traffic counts at every junction, together with the E80s per vehicle type, will then permit a detailed distribution along the length to be developed.

3.2 WEIGHING METHODS

Two types of axle mass survey methods are usually employed in South Africa, namely static or dynamic weighing. Draft TMH3 : 1988[1] contains a detailed methodology for conducting both these survey types, as well as the factors that should be considered. Relevant points will be repeated, but the reader is encouraged to review the details in the source document.

3.2.1 Static vehicle weighing

Static weighing, by virtue of its name, requires that a vehicle be completely stationary. This means that only a limited number of vehicles can be weighed, and on heavily trafficked routes this results in only a sample of vehicles being weighed. Static weighing is usually restricted to roads carrying relatively few heavy vehicles.

Weighing can be carried out with portable scales placed directly on the road surface on roads where the low traffic volume would not constitute a traffic hazard, or at a specially prepared site using either a permanent vehicle scale or portable scales that permit weighing of each axle in turn. Since the intention is to obtain a realistic idea about the axle weights on the road, weighings done for law enforcement purposes would be biased and should not be used.

Research carried out in South Africa[13] showed that the 95 % confidence interval of the individual axle mass is ± 1,4 % on a vehicle scale and ± 6 % on a static beam scale. However, because of the random nature of the variations, the error in E80s of the vehicles monitored during the survey period would be negligible for both systems.

Surveys are usually conducted during the day for safety reasons. Care has to be taken in selecting a random sample of heavy vehicles, and not only those that are laden. The information collected is usually presented as the number of axles in each of the predefined axle mass groups. This information is then used to calculate the ADE as described in Section 4, particularly Section 4.2.

3.2.2 Dynamic vehicle weighing

At sites such as multi-lane highways, or where the terrain and traffic flow do not allow for the static weighing of all vehicles or for a representative sample to be obtained, the in-motion or dynamic method of vehicle weighing is recommended. Typically at least a seven-day survey is carried out at a particular site. Results obtained during such a survey are the number of axles in each of the defined axle mass categories. In Section 4 the conversion of these data to ADE will be discussed. With the ready availability of portable dynamic weighing equipment in South Africa, this type of measurement would normally be taken.

Several types of equipment are suitable for monitoring axle masses dynamically, eg bending plates, piezoelectric cables or capacitive mats or strips. Since the aim of these measurements is to obtain results which correspond to static measurements, the dynamic equipment has to be installed on a road which is suitably even (a riding quality of at least a 3,0 PSI is recommended) and calibrated to reflect the static mass. All the dynamic systems have been shown to be suitable for collecting traffic loading information[13,14].

4. CALCULATION OF DESIGN E80s

4.1 INTRODUCTION

In the first two sections of this document the requirements for traffic loading information, as well as the techniques available for collecting this information, were discussed. In this section, details about the way the calculations are performed and factors that should be taken into account are presented.

4.2 CALCULATING THE AVERAGE DAILY E80

4.2.1 E80 calculations

As was seen in Section 1.3.2 the load equivalency factor relates the application of any given axle load to the damage caused relative to the standard axle, which is taken as 80 kN. Although the equivalency factor is a function of pavement composition, material types, the definition of the terminal pavement condition and the pavement state, an average value is usually computed from the following relation :

$$F = (P / 80)^n$$

where F = load equivalency factor
P = axle load
n = load equivalency exponent, usually taken as 4 (see discussion below in this section)

Table 8 gives average load equivalency factors based on the above relation. Note that F in this Table is calculated as

$$F = ((P_{lower\ limit} / 80)^n + (P_{upper\ limit} / 80)^n) / 2$$

Often the average F of an interval of grouped data is calculated from the average load of the interval, which then gives an erroneous result particularly if the interval is large. This same procedure can be used to calculate a table which has different groupings or for a different exponent.

TABLE 8 80 kN single-axle load equivalency factors, derived from $F = (\frac{P}{80})^4$

SINGLE-AXLE LOAD, P kN	80 kN AXLE EQUIVALENCY FACTOR, F
Less than 15	0,000
15 - 24	0,004
25 - 34	0,019
35 - 44	0,062
45 - 54	0,15
55 - 64	0,32
65 - 74	0,59
75 - 84	1,00
85 - 94	1,6
95 - 104	2,4
105 - 114	3,6
115 - 124	5,1
125 - 134	7,0
145 - 154	9,4
155 - 164	12
165 - 174	16
175 - 184	20
185 - 194	26
195 - 204	32
	39

Pavements that are sensitive to overloading, such as shallow-structured pavements with thin cemented bases, may have n-values of more than 4, whereas less sensitive deep-structured pavements may have n-values of less than 4[15]. Table 9 gives an indication of the conditions under which the exponent may be different from 4. Note that the n-value would have to relate to the structural design method used. An evaluation of the sensitivity of the exponent is discussed in Section 4.6.

TABLE 9 Factors that influence the load equivalence exponent

Average traffic category for general purposes	Determine equivalent traffic over a range of n-values varying from n=1 to n=6. The value at n=4 is generally used to indicate the average traffic category		
To establish remaining structural life	Material type	Important parameters	n coefficient
	Granular	Pavement category A B C	 3 2 1
	Cemented	State of cracking Pre-cracked Post-cracked	 6 1-3 as for granular above
	Bituminous	Thin surfacing (20-70 mm thick) Thick base	1 4
	Concrete	Acting as a slab Granular state	7 1-3 as for granular above

The E80 for the information collected during a traffic load survey is determined by multiplying the number of axle loads (N_j) in each interval (j) by the appropriate equivalency factor (F_j) in Table 8 and by summing over all load intervals:

$$E80 = \Sigma N_j \, . \, F_j$$

4.2.2 Lane distribution

If actual surveys are conducted, a lane distribution estimate is not necessary for multilane facilities. However, if the ADE is calculated from traffic counts, or from the results of transportation planning models, a distribution between lanes is necessary. Note that the distribution of traffic volume and traffic loading will normally not be the same. Furthermore, the distribution is also likely to change along the length of the road, depending on geometric factors, climbing lanes or interchange ramps. Suggested lane distribution factors for total traffic (B) or traffic loading (B_e) are given in Table 10. The design E80 for each lane per day is calculated by multiplying the daily E80s in one direction by the distribution factor B_e. These factors incorporate the change of lane distribution over the geometric life of the facility. The factors should be regarded as maxima and decreases may be justified.

TABLE 10 Design factors for distribution of traffic and equivalent traffic amongst lanes and shoulders

Total number of traffic lanes	Design destribution factor, B_e or B				
	Surfaced slow shoulder	Lane 1*	Lane 2	Lane 3	Surfaced fast shoulder**
(a) Equivalent traffic (E80) Factor B_e					
2	1,00	1,00	-	-	-
4	0,95	0,95	0,30	-	0,30
6	0,70	0,70	0,60	0,25	0,25
(b) Traffic (total axles or e.v.u.)***					
Factor B	1,00	1,00	-	-	-
2	0,70	0,70	0,50	-	0,50
4	0,30	0,30	0,50	0,40	0,40
6					

* Lane 1 is the outer or slow lane
** For dual-carriageway roads
*** e.v.u. = equivalent vehicle unit; one commercial vehicle = 3 e.v.u.

4.3 COMPUTING THE ANNUAL AVERAGE DAILY E80

Ideally the application of correction factors should be avoided as the data should be collected over long enough periods to ensure that extraneous influences are minimal. Unfortunately that is not always possible. In converting the information collected over a short period, whether by a new survey or previously collected information, to an average annual E80, cognisance has to be taken of

- variations between weekdays and weekends;
- variations between exceptional circumstances (which may be holidays) and normal days; and
- variations between in-season and out-of-season periods.

Correction for these variations is also standard procedure in the traffic counting process detailed in Draft TMH8[2]. Figure 5 shows the type of variation which may be encountered in schematic form.

4.3.1 Variations between weekdays and weekends

Traffic loading is normally lower during weekends than on weekdays. If the ADE during weekdays only is known the ADE for the full week can be obtained by multiplying with the 7/5-day factor. The 7/5-day ($F_{7/5}$) factor is defined as :

$$F_{7/5} = E_7 / E_5$$

where E_7 = ADE of a seven-day week

E_5 = ADE of weekdays

The 7/5-day factor typically varies between 0,7 and 1,0.

4.3.2 Variations between normal and exceptional periods

During holiday periods when businesses, factories or the construction industries are closed, the traffic loading will not be normal and is usually lower than during normal days. A factor called the "exceptional/normal day factor" (F_E) is used to convert the exceptional day's traffic to the equivalent for normal days as follows :

$$F_E = E_E / E_N$$

where E_E = average ADE during exceptional days

E_N = average ADE during normal days

The factor F_E is normally less than one.

4.3.3 Variations between in-season and out-of-season periods

Depending on the demand and supply of goods, traffic loading will reach a peak during the in-season period and will decrease during the out-of-season period. The harvest season constitutes the in-season period for agricultural products. Similar seasons may exist for other products, eg coal transport for heating in winter. The seasonal factor (F_s) is defined as follows :

F_s = E_{OUT} / E_{IN}

where E_{OUT} = ADE during the out-of-season period

E_{IN} = ADE during the in-season period

The factor F_s is normally less than or equal to one.

4.3.4 Use of the correction factors

The correction factors defined above need only be used in those instances where non-consideration would affect the accuracy of the results beyond the limits required. The way in which the factors F_E and F_s are used to calculate the AADE is as follows :

ADE_1 = $(K1.ADE + (365 - K1).F_s.ADE) / 365$

and AADE = $(K2.ADE_1 + (365 - K2).F_E.ADE_1) / 365$

where ADE_1 = seasonally corrected ADE

ADE = ADE of a seven-day week

K1 = number of days per year of in-season traffic

AADE = annual average daily E80s

K2 = number of days per year of normal traffic

4.4 DETERMINATION OF FUTURE TRAFFIC LOADING

The determination of traffic loading after the date on which the information was collected is done by projecting the loading using an appropriate growth rate. The E80 growth rate comprises two components:

- the growth rate in heavy vehicle traffic volume. This may be considered to consist of the overall traffic growth rate and the growth of heavy vehicles as a percentage of total traffic ; and
- the growth in the loading of heavy vehicles.

The growth rate expresses a long-term trend and therefore short-term variations in traffic loading should not be considered. The E80 growth rate should therefore be calculated from a comparison of the AADE from two or more years of traffic on a specific route, preferably over a five-year span, using as much information as is available. It is important to note that if the ADE from short-term surveys are used, the growth rate obtained may be biased by short-term variations and may not necessarily reflect a long term trend. Preferably data from permanent survey stations should be used to ensure a reasonable accuracy. In this section methods for handling this problem are discussed.

4.4.1 Methods for estimating the E80 growth rate

4.4.1.1 Using historical growth rates

Historical E80 growth rates on a given route may provide an anchor for evaluating potential future growth rates. There is however no reason why historic growth rates should relate to future growth rates, as circumstances are continually changing. Each situation should be evaluated afresh. If the review suggests that the future scenario will be relatively stable insofar as changes in heavy vehicle transport is concerned, then there is no reason to doubt that the historic trend will continue.

If historical data are available over at least two years, then the E80 growth rate (r) may be calculated as follows :

$$r = \left[\left(\frac{AADE_n}{AADE_1}\right)^{1/n} - 1\right] 100 \text{ per cent per annum}$$

where $AADE_1$ = AADE of year 1

$AADE_n$ = AADE at a time n years after year 1

If only the change in the heavy vehicle traffic counts are known, then the E80 growth rate may be calculated by assuming an average or typical growth rate of the E80 per heavy vehicle, as follows :

E80 growth rate = $((1 + h / 100)(1 + v / 100) - 1)\ 100$

where h = heavy vehicle traffic volume growth, as a percentage

v = E80 factor growth, as a percentage

Sometimes the heavy vehicle growth rate (h) may have to be deduced from the total traffic growth rate. If the percentage of heavy vehicles in the traffic at some future time is known or may be estimated, then the following formula may be used:

$$h = \left[\left(\frac{f}{p}\right)^{1/n} \left(1 + \frac{t}{100}\right) - 1\right] 100$$

where f = percentage of heavy vehicle at time n_1, in future

p = percentage of heavy vehicle at time n_0 (present)

n = time period in years between n_1 and n_0

t = total traffic growth rate, as a percentage.

The application of the above formulae in a sensitivity analysis is discussed in Section 4.6.

The E80s per heavy vehicle on South African roads have grown between 4 and 8 per cent per annum during the 1980s. Note that in an analysis the sensitivity of the design to alternative growth rates to has to be evaluated. This is discussed in Section 4.6.

4.4.1.2 Using the South African Rural Traffic Model (SARTM)

The SARTM simulates the average annual daily traffic on an extensive network of South Africa's rural roads. Results of the model may be obtained from the Traffic Demand Modelling Working Group of the Department of Transport. The model can provide the growth rate of the heavy vehicle traffic on all the major corridors at future times. It would also be possible to evaluate the effect of new routes in terms of attracted traffic and growth rate.

4.4.1.3 Subjective adjustment of the E80 growth rate

The designer should always critically evaluate the growth rate figures that are obtained from whatever source. The first step would be to consider whether the figures are realistic in the light of knowledge about local conditions. Local knowledge can be supplemented by a survey of the major heavy vehicle trip generators in the area and their future strategy. This would then permit evaluation of the feasibility of a uniform growth rate over the full period or the possibility of changes in the growth rate. Cognisance should also be taken of the designated national growth points. During the construction phase heavy vehicle traffic patterns may be completely different from the traffic when the facility is operational. For example, during the development of a residential area the construction traffic would yield an initial high growth rate. Once the area is fully built up, the heavy traffic may initially decrease, and remain fairly uniform thereafter.

When a new link is constructed or an existing link is improved, some traffic would be diverted from other routes. Care should be taken not to confuse the diverted traffic with the growth rate, as the former should be included separately in the calculations.

Growth rates may not always be positive. If the factors that affect traffic loading are carefully considered, they may lead to a negative growth rate on specific roads. It is important to note that normally the growth rate over a long period is smaller than the growth rate over a shorter period of time.

Table 11 shows ranges of the E80 growth rate for various road categories defined in TRH4[3]. Evidence suggests that on some routes in South Africa higher growth took place than was expected at the time. This is reflected in the maximum rates given in the Table. Distinct regional influences have been found, and designers need to take such influences into consideration.

TABLE 11 Typical ranges of growth rate in total E80s for different road categories

Road category	A	B	C
Range of growth rates (%) Typical growth rate (%)	6 - 20 8	4 - 12 6	2 - 10 4

4.4.2 Geometric capacity

There is an obvious maximum traffic volume that any road can carry. To ensure that realistic traffic growth figures are used, the traffic volume at the end of the analysis period should be calculated. The E80 growth rate should be converted to a heavy traffic volume growth rate as suggested in Section 4.4.1.1. In addition, a light traffic growth rate is also needed. The total traffic (N) at the end of the analysis period is then calculated from

$$N = HVV_e (1 + 0{,}01\ r1)^n + LVV (1 + 0{,}01\ r2)^n$$

where HVV_e = equivalent heavy vehicle volume at the start of the analysis period, i.e. heavy vehicle volume x 3, to convert to light vehicles

LVV = light vehicle volume at start of analysis period

r1 = heavy vehicle volume growth rate

r2 = light vehicle volume growth rate

n = analysis period, in years

The total equivalent light traffic volume (N) at the end of the analysis period must be compared with the capacity of the particular road as defined in TRH17 "Geometric design of rural roads"[16]. If N exceeds the capacity, then either the road needs geometric upgrading, or the assumptions need to be reviewed. For example, for the latter case the growth rate may be too large, or too large for a sustained period, and adjustments may be necessary.

4.5 PROJECTION OF THE TRAFFIC LOADING DATA OVER THE STRUCTURAL DESIGN PERIOD

4.5.1 Projection to initial design year

The AADE obtained at a time earlier than the start of the design period may be projected to the initial design year by multiplying by a growth factor, which is a function of the growth rate, as follows :

$g = (1 + 0{,}01.i)^x$

where g = growth factor, which is given in Table 12

i = growth rate of E80s

x = time in years between determination of axle load data and start of design period

The AADE in E80 per lane per day in the initial year is given by :

$AADE_{initial} = AADE.g$

4.5.2 Computation of cumulative E80s

The cumulative E80s over a period, (e.g. the structural design period), may be calculated from the AADE in the initial design year and the E80 growth rate over the period. Note that different growth rates may apply to different parts of the analysis period.

The cumulative E80 per lane may be calculated from :

$E80_{total} = AADE_{initial} . f_y$

where f_y = cumulative factor given in Table 13

y = structural design period

For varying growth rates the AADE at the start of each growth period would be calculated using the growth factor g. Then the cumulative E80 over each growth period is calculated using the cumulative growth factor f_y and the cumulative E80 during each growth period is then summed for the design period.

The cumulative E80s during a given historic period of x years knowing the growth rate (i) and the annual average E80 per day at the end of the period ($AADE_{end}$), may be calculated from

$$E80_{total} = \frac{AADE_{end}}{g} . f_x$$

where g = growth factor, given in Table 12

f_x = cumulative factor given in Table 13

4.6 SENSITIVITY OF TRAFFIC CLASS TO GROWTH, LOADING AND OTHER FACTORS

If a pavement design is to be developed according to TRH4[3] or the corresponding manuals for the urban situation, then the traffic class (E0 to E5) has to be defined. This would then simply be comparing the total E80 computed above with the ranges for the different classes. Alternatively, the nomogram shown in Figure 6 can be used. Nowadays, with the ready availability of computers, it is often easier to develop a small program to perform the necessary calculations than to use a less accurate and more tedious

TABLE 12 - Traffic growth factor (g) for calculation of future or initial traffic from present traffic

Time between determination of axle load data and opening of road, x (yrs)	*g for Traffic Increase, i (% per annum)								
	2	3	4	5	6	7	8	9	10
1	1,02	1,03	1,04	1,05	1,06	1,07	1,08	1,09	1,10
2	1,04	1,06	1,08	1,10	1,12	1,14	1,17	1,19	1,21
3	1,06	1,09	1,12	1,16	1,19	1,23	1,26	1,30	1,33
4	1,08	1,13	1,17	1,22	1,26	1,31	1,36	1,41	1,46
5	1,10	1,16	1,22	1,28	1,34	1,40	1,47	1,54	1,61
6	1,13	1,19	1,27	1,34	1,42	1,50	1,59	1,68	1,77
7	1,15	1,23	1,32	1,41	1,50	1,61	1,71	1,83	1,95
8	1,17	1,27	1,37	1,48	1,59	1,72	1,85	1,99	2,14
9	1,20	1,30	1,42	1,55	1,69	1,84	2,00	2,17	2,36
10	1,22	1,34	1,48	1,63	1,79	1,97	2,16	2,37	2,59

*$g = (1 + 0{,}01.i)^x$

TABLE 13 Traffic factor (f) for calculation of cumulative traffic over prediction period from initial daily traffic

Prediction period (years)	Compound growth rate (% per annum)									
	2	4	6	8	10	12	14	16	18	20
4	1534	1611	1692	1776	1863	1953	2047	2145	2246	2351
5	1937	2056	2180	2312	2451	2597	2750	2911	3081	3259
6	2348	2517	2698	2891	3097	3317	3551	3801	4066	4349
7	2767	2998	3247	3517	3809	4124	4464	4832	5229	5657
8	3195	3497	3829	4192	4591	5028	5506	6029	6601	7226
9	3631	4017	4445	4922	5452	6040	6693	7417	8220	9109
10	4076	4557	5099	5710	6398	7173	8046	9027	10130	11369
11	4530	5119	5792	6561	7440	8443	9588	10895	12384	14081
12	4993	5703	6526	7480	8585	9865	11347	13061	15044	17336
13	5465	6311	7305	8473	9845	11458	13352	15575	18183	21241
14	5947	6943	8130	9545	11231	13242	15637	18490	21887	25927
15	6438	7600	9005	10703	12756	15239	18242	21872	26257	31551
16	6939	8284	9932	11953	14433	17477	21212	25795	31414	38299
17	7450	8995	10915	13304	16278	19983	24598	30346	37500	46397
18	7971	9734	11957	14762	18308	22790	28458	35625	44680	56115
19	8503	10503	13061	16338	20540	25934	32859	41748	53154	67776
20	9045	11303	14232	18039	22995	29455	37875	48851	63152	81769
25	11924	15808	21227	28818	39486	54506	75676	105517	147559	206727
30	15103	21289	30587	44656	66044	98656	148459	224533	340661	517664
35	18612	27958	43114	67927	108816	176464	288595	474509	782431	1291373
40	22487	36071	59877	102120	177700	313586	558416	999544	1793095	3216609

Based on $f = 365.(1 + 0{,}01.i).[(1 + 0{,}0.i)^y - 1]/(0{,}01.i)$

graphical procedure. Note that design methods other than TRH4 or rehabilitation methods may require the traffic loading information in a different format.

Whatever method is used, it should be appreciated that the traffic loading information collected is not exact, but is stochastic in nature. This is equally true for estimates of the traffic growth. An important design step is thus to consider the influence of changes to the basic data used, eg growth rate, E80 per vehicle or E80 per axle, initial E80 per lane per day, structural design period and conversion factors. Certain factors may be more uncertain or may have a larger influence than others for a specific design. Typically, however, the traffic loading information and growth rate would require evaluation, and a graphical plot as shown in Figure 7 may be used. Plotted on this Figure are the cumulative E80s for a selected design period and initial traffic, but varying axle load and traffic growth factors. The most likely position is also shown on this graph. For the data on this Figure it may be seen that changes in the growth rate and/or axle load factor would not affect the traffic class of the projected situation. However, had the axle load factor been 0,2 and the growth rate 2 %, then the traffic class would have been on the boundary between E2 and E3 - a fact which may not have been evident from a simple calculation. Any small change in either the axle load factor or growth rate would then place the traffic into the next higher traffic class.

TABLE 14 E80 growth rates (%) calculated for various future scenarios

		E80/veh growth rate (%)	Total traffic growth rate (%)		
			Low	Probable	High
			4	5,5	7
Future % heavy vehicles (present 25 %)	Low 25	Low 0	4	5,5	7
		Probable 2	6,1	7,6	9,1
		High 4	8,2	9,7	11,3
	Probable 30	Low 0	5,9	7,4	9,0
		Probable 2	8,0	9,6	11,1
		High 4	10,2	11,7	13,3
	High 35	Low 0	7,6	9,1	10,7
		Probable 2	9,7	11,3	12,9
		High 4	11,9	13,3	15,1

The expected E80 growth rate on a specific road can be determined for a range of scenarios as given in Table 14. This type of sensitivity analysis is useful for developing a realistic range for the vertical axis as given in Figure 7.

Although the exponent in the equivalency relationship is usually taken as 4, it has been shown[15] that if deterioration other than roughness is considered, then the exponent, called the damage exponent, could vary between 2 and 10. This aspect is also discussed in Section 4.2.1. The impact of different damage exponents on equivalent damage of the axle load data collected on any road cannot be estimated by simple inspection. A sensitivity analysis has to be performed. This would take the form of calculating the percentage ratio between the E80 calculated with a variable damage exponent and the E80 calculated with the normal exponent of 4. If the equivalent damage is insensitive to the traffic load spectrum, then the ratio would be about 100 per cent. The percentage ratio, multiplied by the selected axle load factor in Figure 8, would permit evaluation of this sensitivity.

Usually axle load survey data is graphically presented as in Figure 8, showing the sensitivity of the axle load distributions to changes in load equivalency exponent. From experience three types of axle load distributions have been identified based on the E80 sensitivity to the exponent:

- light-biased distribution consists mainly of light traffic, with most of the axle masses in the lower load categories with little overloading. Typically such roads carry light rural or urban traffic. Exponents lower than 4 have a marked increase in the total E80s, hence for an exponent of 2 the total E80s could be greater than for an exponent of 4 by 60 per cent;

- heavy-biased distribution is found mainly on heavily trafficked routes where a high degree of overloading is likely. The effect of axle loads greater than 80 kN is accentuated by exponents greater than 4. Hence for such situations the percentage ratio could be as high as 160;

- unbiased distribution is an axle load distribution which is relatively insensitive to changes in the load equivalency exponent. This distribution typically occurs on major interurban routes where a relatively low degree of overloading is found.

As was shown in this Section, there are a variety of ways of presenting the results of sensitivity analyses. The method of representation is frequently in a format that the users find most comfortable. Most importantly, however, is the need to consider the influence of variations on the traffic loading figures used in the design.

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APPENDIX A

FORMS SUITABLE FOR VISUAL SURVEYS

RECORDER: ....

LOCATION: ....

DATE: ....

DIRECTION: ....

TIME: ....

LANE: ....

DATA SHEET No	NUMBER OF HEAVY VEHICLE AXLES	NUMBER OF HEAVY VEHICLES		
		Empty	Partially laden	Fully laden
TOTALS →				
TOTAL HEAVY VEHICLES →		$\sum =$		
% OF TOTAL HEAVY VEHICLES →		%	%	%

TOTAL HEAVY VEHICLE AXLES	X	AXLE LOAD FACTOR	E80/period

SHEET No ....

RECORDER: .... LOCATION: ....

DATE: .... DIRECTION: ....

TIME: From .... To .... LANE: ....

NUMBER OF AXLES PER HEAVY VEHICLE	DEGREE OF VEHICLE LOADING			TYPE OF GOODS
	Empty	Partially laden	Fully laden	
TOTAL:				

EMPTY: less than 25 per cent laden by volume

PARTIALLY LADEN: more than 25 per cent and less than 75 per cent laden by volume

FULLY LADEN: more than 75 per cent laden by volume

APPENDIX B

EXAMPLE OF A VISUAL HEAVY VEHICLE SURVEY

On completion of the survey the information recorded on each field sheet, Appendix A, is totalled, and transferred to the summary sheet. The following Table shows the summary for 24 hours.

Field sheet number	Number of heavy vehicle axles	Number of heavy vehicles		
		Empty	Partially laden	Fully laden
1 2 3	47 44 39	7 10 4	2 2 5	6 4 8
4 5 6	73 46 74	6 6 7	7 2 1	9 7 3
7 8	49 34	7 8	0 0	9 4
Totals	406	55	19	50

The relative proportion of fully laden, partially laden and empty heavy vehicles are determined as follows:

Proportion of heavy vehicles:

fully laden $= \frac{50}{124} \cdot 100 = 40\ \%$

partially laden $\frac{19}{124} \cdot 100 = 15\ \%$

empty $\frac{55}{124} \cdot 100 = 45\ \%$

From Table 7, for the above proportions, p = 0,5 E80s/axle E80s per day = 0,5 x 406 = 203.

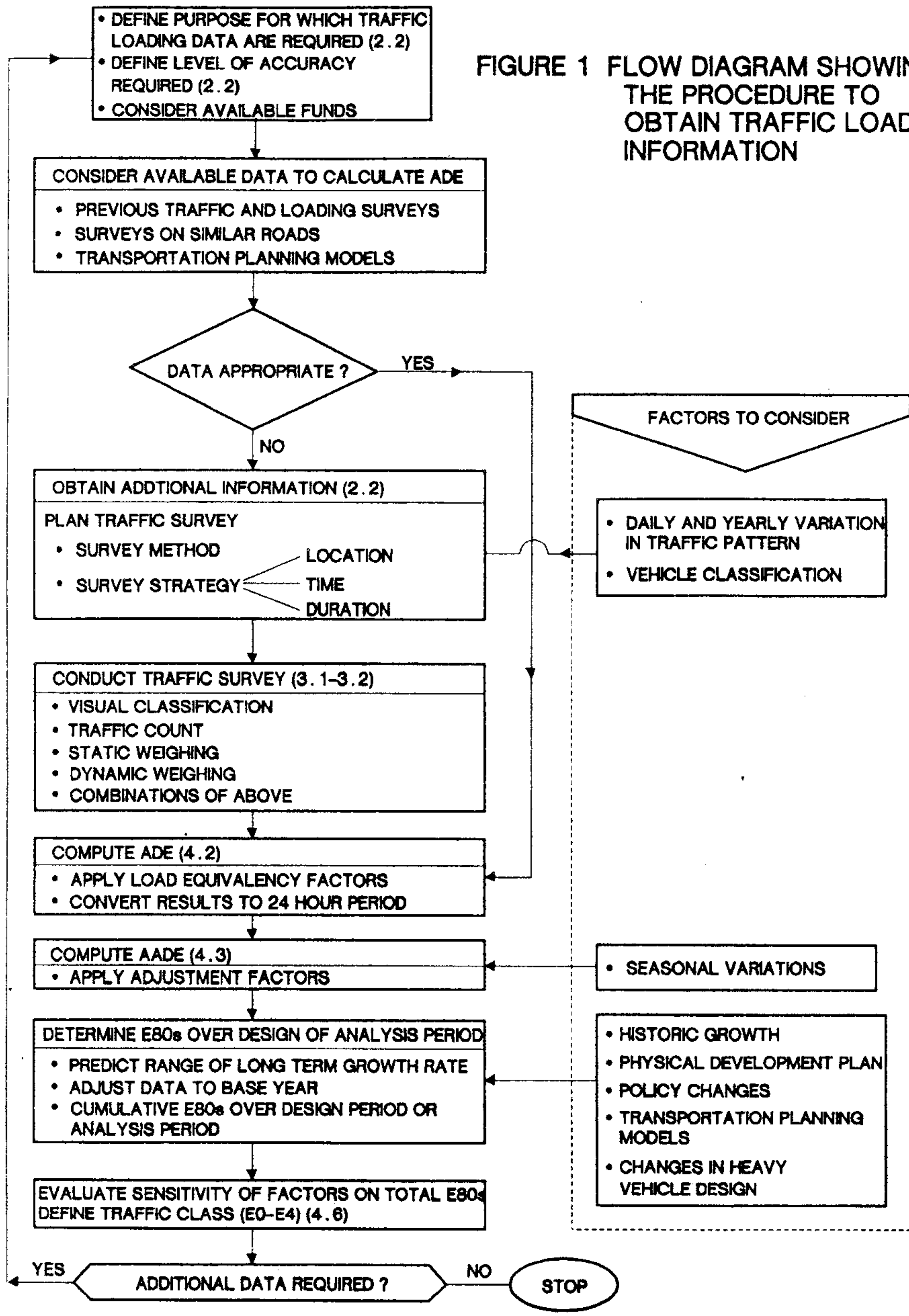


FIGURE 1 FLOW DIAGRAM SHOWING THE PROCEDURE TO OBTAIN TRAFFIC LOADING INFORMATION

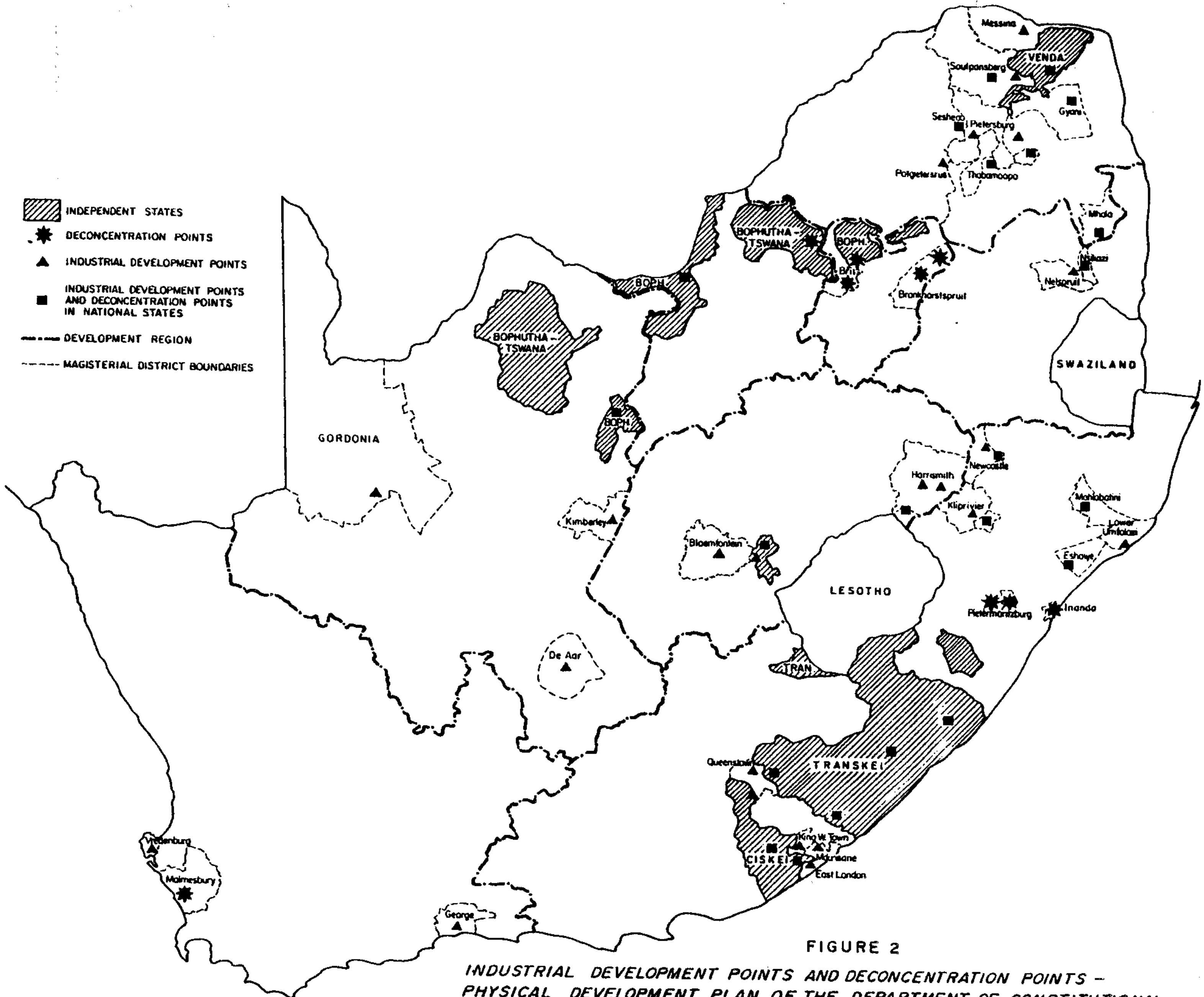


FIGURE 2

INDUSTRIAL DEVELOPMENT POINTS AND DECONCENTRATION POINTS - PHYSICAL DEVELOPMENT PLAN OF THE DEPARTMENT OF CONSTITUTIONAL DEVELOPMENT AND PLANNING

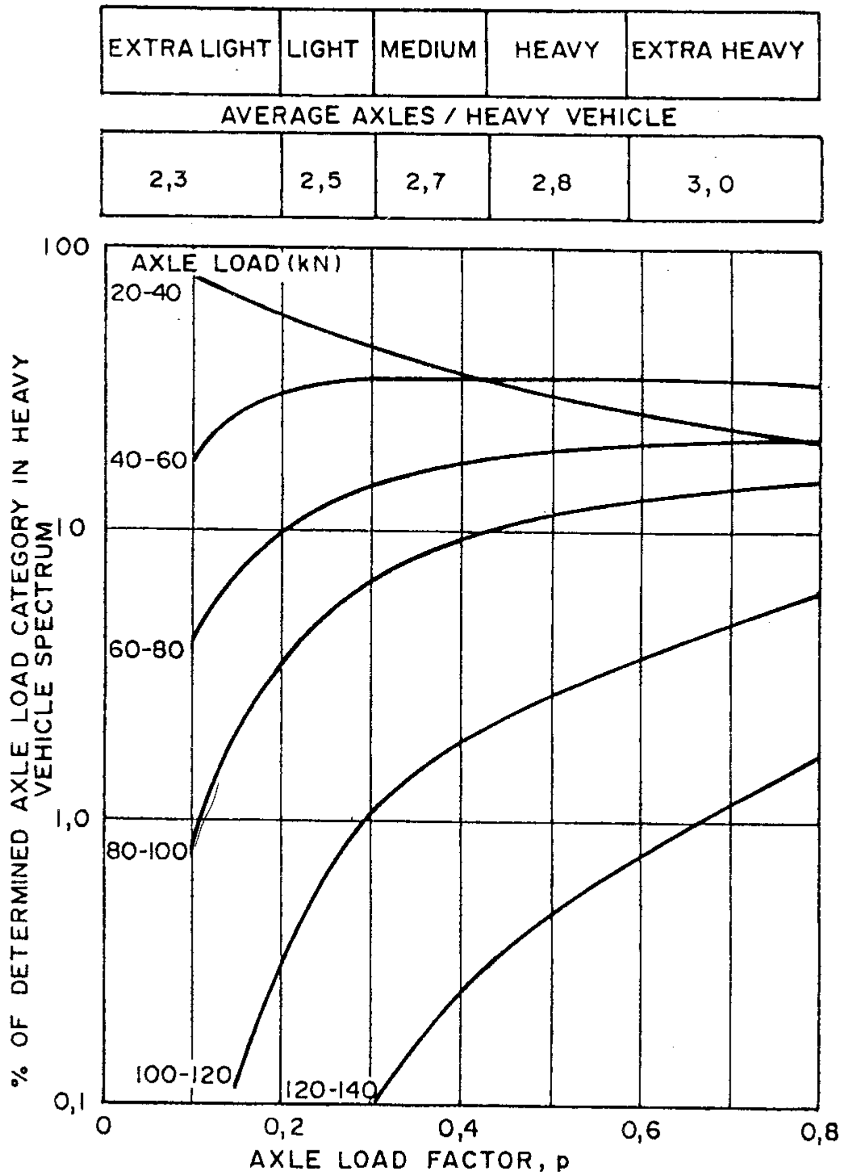


FIGURE 3

RELATIONSHIP BETWEEN THE AXLE LOAD FACTOR, p, AND THE HEAVY VEHICLE SPECTRUM FOR n=4,2

940-4-6040/2 BD

0-4-6046 BD

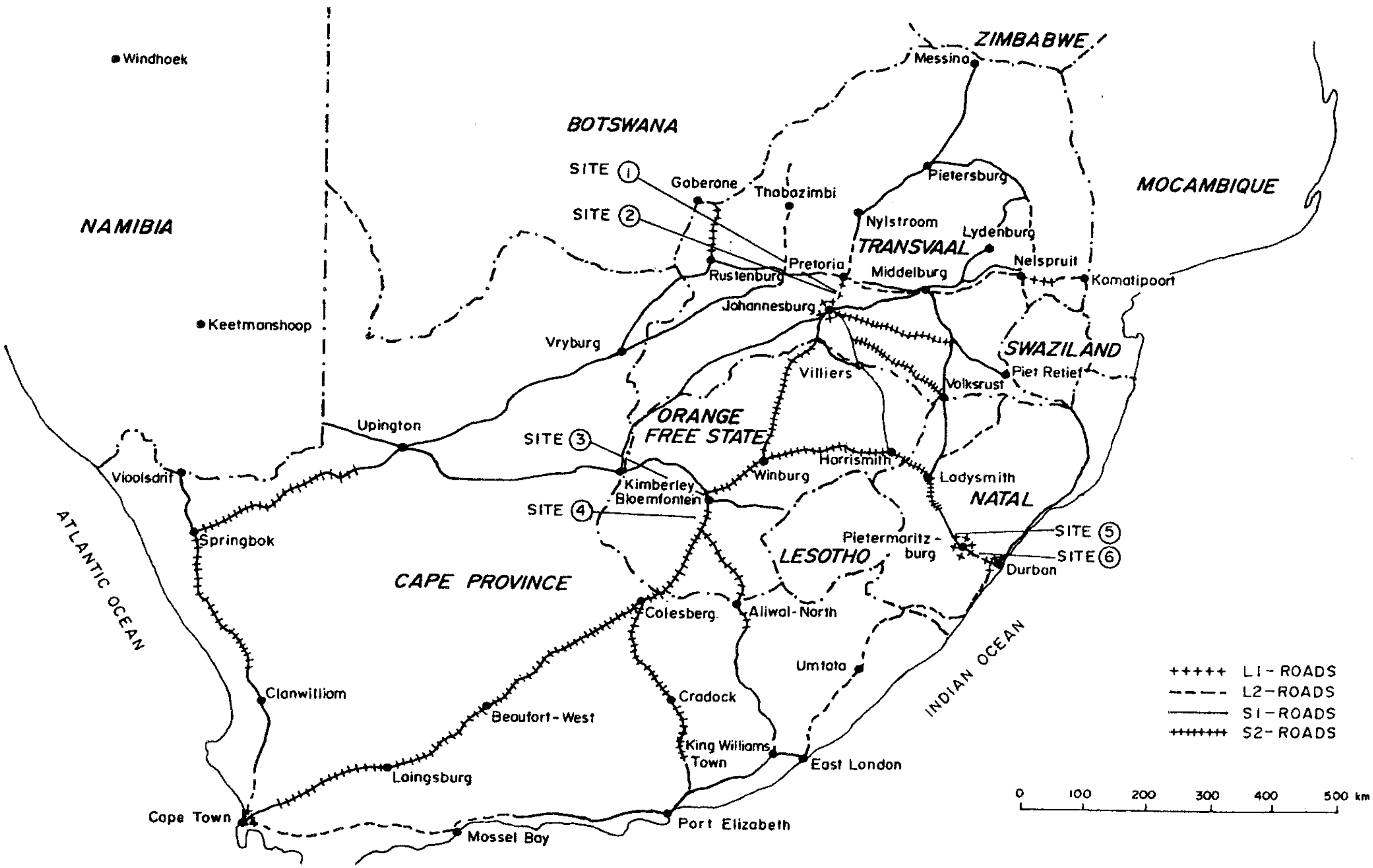


FIG. 4 : PROVISIONAL CLASSIFICATION OF RSA's MAIN ROAD NETWORK ACCORDING TO THE HV-COMPOSITION

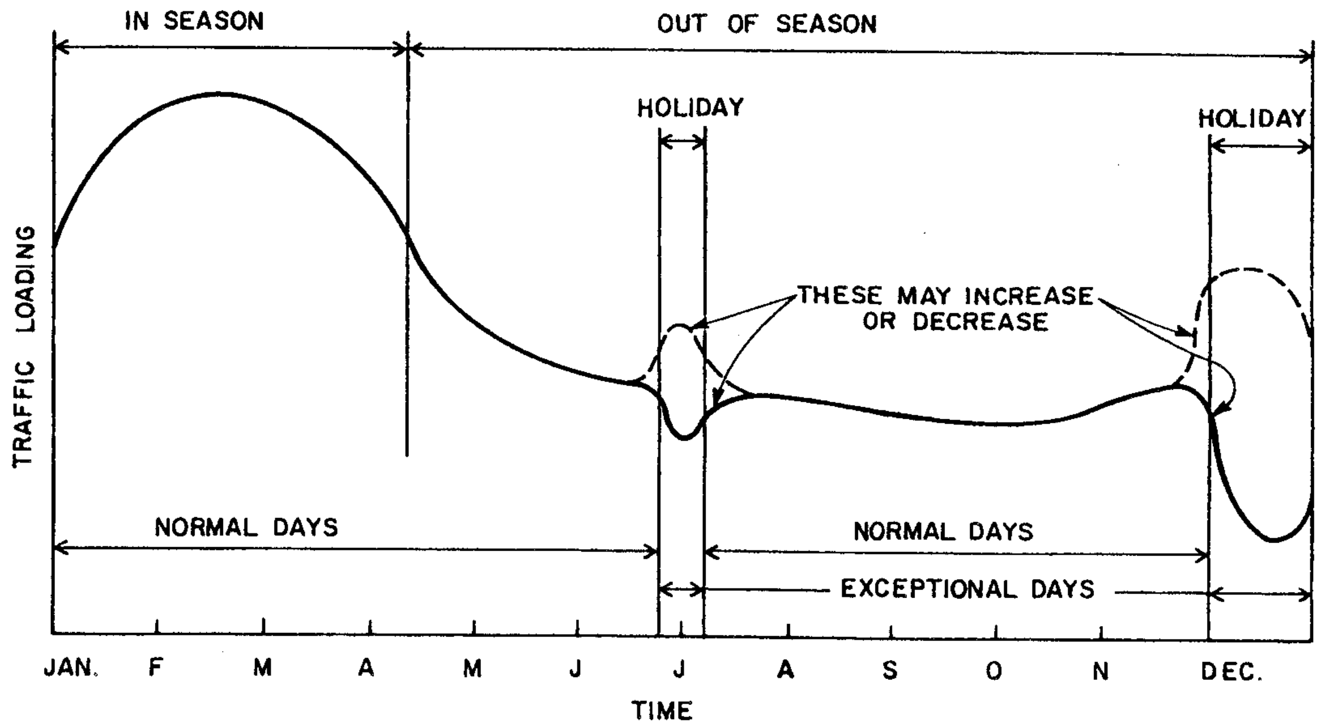


FIGURE 5

SCHEMATIC REPRESENTATION OF THE VARIATION IN TRAFFIC LOADING OVER A ONE YEAR PERIOD

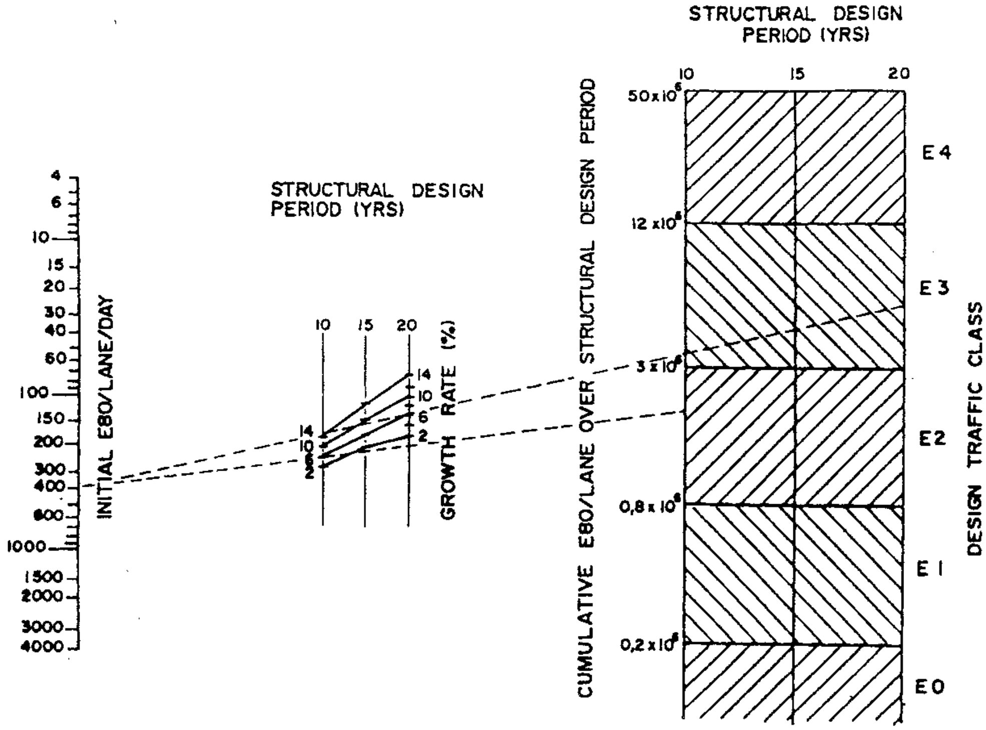


FIGURE 6

NOMOGRAM FOR DETERMINING DESIGN TRAFFIC CLASS FROM THE INITIAL E80/LANE/DAY, THE GROWTH RATE AND THE STRUCTURAL DESIGN PERIOD

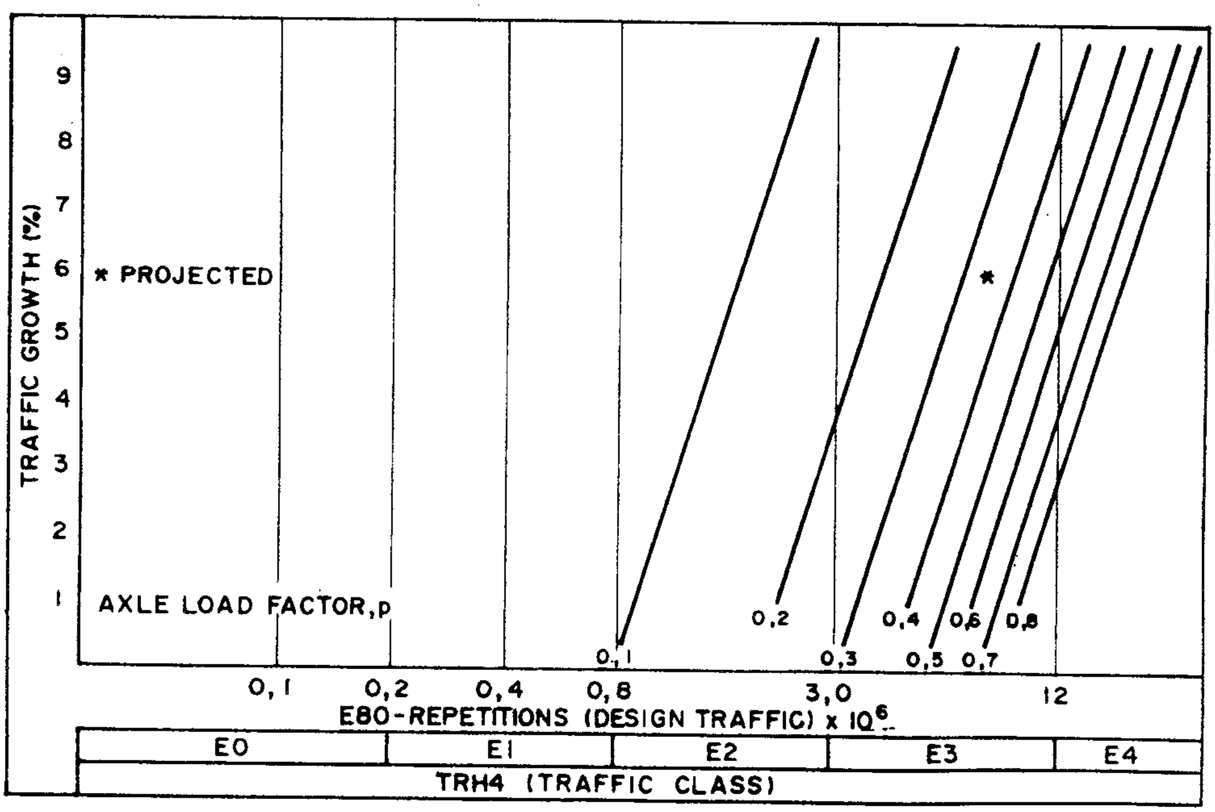
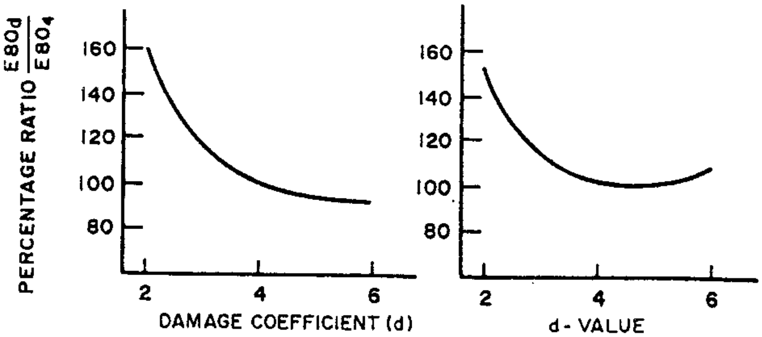
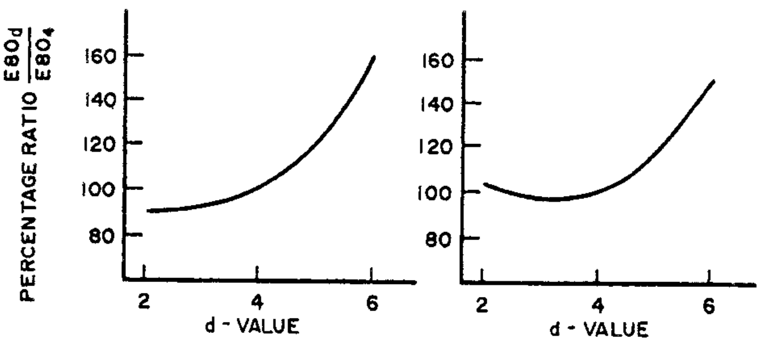


FIGURE 7

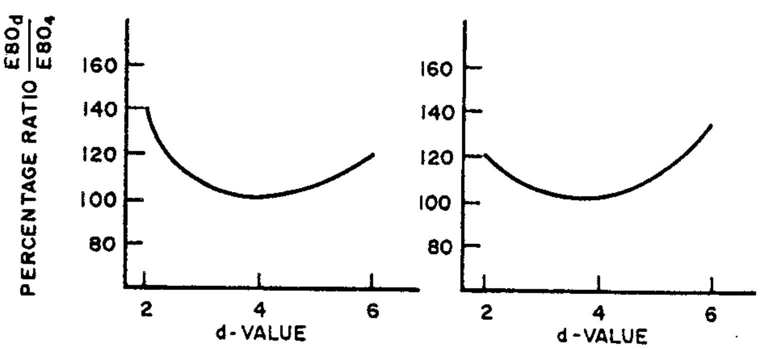
PLOT FOR EVALUATING SENSITIVITY OF AXLE LOAD FACTOR AND TRAFFIC GROWTH RATE



E80 SENSITIVITY OF TYPICAL LIGHT-BIASED AXLE LOAD DISTRIBUTIONS



E80 SENSITIVITY OF TYPICAL HEAVY-BIASED AXLE LOAD DISTRIBUTIONS



E80 SENSITIVITY OF TYPICAL UNBIASED AXLE LOAD DISTRIBUTIONS

FIGURE 8

TWO EXAMPLES OF EACH OF THREE TYPES OF E80 SENSITIVITIES OF AXLE LOAD DISTRIBUTIONS

GEDRUK DEUR V&R DRUKKERY, PRETORIA