Axle Load Surveys

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DECEMBER 2000

ISBN 99912 - 0 - 358 - 3

ROADS DEPARTMENT

Under the policy direction of the Ministry of Works, Transport & Communications, Roads Department is responsible for providing an adequate, safe, cost-effective and efficient road infrastructure within the borders of Botswana as well as for facilitating cross-border road communications with neighbouring countries. Implied in these far-ranging responsibilities is the obligation to:

1. ensure that existing roads are adequately maintained in order to provide appropriate level of service for road users;

2. improve existing roads to required standards to enable them to carry prevailing levels of traffic with the required degree of safety;

3. provide new roads to the required geometric, pavement design and safety standards.

The Department has been vested with the strategic responsibility for overall management of the Public Highway Network (PHN) of some 18, 300 km of roads. This confers authority for setting of national specifications and standards and sheared responsibility with the District Councils and Department of Wildlife and National Parks for the co-ordinated planning of the PHN.

Roads Department is also responsible for administering the relevant sections of the Public Roads Act, assisting local road authorities on technical matters and providing assistance in the national effort to promote citizen contractors in the road construction industry by giving technical advice wherever possible. This task is facilitated by the publication of a series of Technical Guidelines dealing with standards, general procedures and best practice on a variety of aspects of the planning, design, construction and maintenance of roads in Botswana that take full account of local conditions.

Guideline No. 1 The Design, Construction and Maintenance of Otta Seals (1999)

Workshop Proceedings, September 2000, Addendum with reference to
Guideline No. 1 The Design, Construction and Maintenance of Otta Seals (1999)

Guideline No. 2 Pavement Testing, Analysis and Interpretation of Test Data (2000)

Guideline No. 3 Methods and Procedures for Prospecting for Road Construction Materials (2000)

Guideline No. 4 Axle Load Surveys (2000)

FOREWORD

The Government of Botswana has during the last 20 years spent scarce resources developing Road Infrastructure for the benefit of her people. The paved road network comprising of about 5500 kilometres at an asset value of 4 billion Pula. This Road Infrastructure needs to be properly utilised and maintained.

Accurate traffic information is essential for transportation planning, road pavement design and maintenance. Whereas traffic volumes, traffic composition is important for planning and geometric road design, vehicle loading characteristics are important for road pavement design and maintenance. Hence, Axle Load Surveys and analysis is essential to assist in planning and the design phases of roads.

To assist in correct prioritisation of available maintenance funds a Pavement Management System (PMS) has been introduced. The PMS needs local calibration of the pavement deterioration parameters, whereby the knowledge of the vehicle loading is an essential parameter.

The axle load surveys, also give information whether the roads are abused or not by the transporters, and hence assist Roads Department in deciding on appropriate measures.

In appreciation of the significance of the Axle Load Surveys, it was resolved that a Guideline which provides both practical and theoretical guidance on how to conduct an Axle Load Survey and how to analyse and present the data in a provisional manner should be prepared.

I am sure that the Guideline which is another in a series of documents will ensure consistency of how such Axle Load Surveys are conducted and continuity of the best practices that have been developed over time.

Gaborone
December 2000

A Nkaro
Director of Roads

Roads Department
Ministry of Works, Transport and Communications

ACKNOWLEDGEMENTS

This Guideline is one of a series that is being produced under the Institutional Co-operation Agreement that exists between the Roads Department and the Norwegian Public Roads Administration (NPRA). This Agreement falls under a NORAD Technical Assistance Programme to Roads Department, which is co-funded by the Kingdom of Norway and the Government of the Republic of Botswana.

The production of the Guideline has been a joint effort between the Roads Department and the NPRA. The authors of the Guideline has been:

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1. Introduction

1.1 Background

During the last 20 years, Botswana has made tremendous efforts in developing and improving the road network to enable efficient development of the country infrastructure. At present, the asset value of the paved road network alone is estimated to be about 4 billion Pula, and which comprises of about 5500 km. In order to secure and preserve such valuable asset timely and appropriate maintenance/rehabilitation interventions must take place. Further development of the road network is expected to continue and both the maintenance/rehabilitation activities and the design of new roads will require traffic load data as one of the basic inputs. This information needs to be collected as accurately as possible since the importance of reliable and correct information on axle loads for pavement design can not be overemphasised.

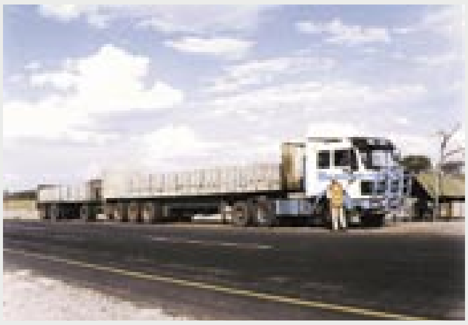
A newly constructed road is a valuable asset to the country.

Overloaded vehicles causes serious damage to all roads, however, the problem may be even more serious in Botswana as most of the country's first generation roads are reaching the end of their design life.

Furthermore, overloaded vehicles also become a traffic hazard, especially regarding the heavy vehicles braking system and additional braking distance involved.

1.2 Purpose and scope

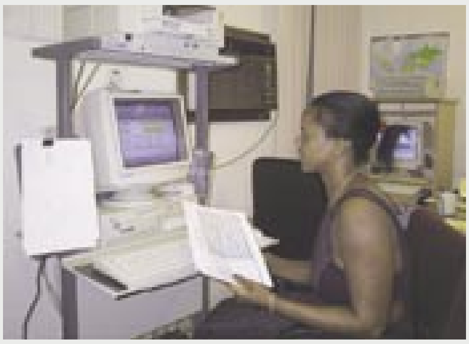
The main purpose of this guideline is to provide both a practical and a theoretical guidance on how to conduct an axle load survey and how to analyse and present the data in a professional manner. The Guideline also gives a brief understanding on how road pavements deteriorate under wheel loads and the environment.



Axle load survey.

The Guideline should be used for the purpose intended, i.e. as a guideline, bearing in mind that not all axle surveys are similar, and minor adjustment may have to be enforced in order to meet the goal with the axle load survey. However, saying so, by following the guidance described in the Guideline the axle load survey will be give concise results in a cost-effective manner.

The Guideline is intended for use mainly by the staff of the Central Materials Laboratory. However, the Guideline will also be important in the preparation of Terms of Reference for the design of new roads and roads to be rehabilitated.



Entering the axle load data into the computer.

The axle load weighing described in this Guideline deals only with static weighing and does not deal with the weight of moving vehicles commonly termed Weigh - in - motion (WIM).

1.3 Structure of the Guideline

Following the general introduction, given in this Chapter, Chapter 2 provides an overview of the damage to pavements and bridges caused by loaded vehicles. The staffing and equipment requirements for the axle load surveys, condition of survey sites and the traffic safety involved are dealt with in Chapters 3, 4 and 5, respectively. Chapter 6 describes in details the axle weighing procedure. It deals with factors that affect the weighing, distribution of wheel load, measuring accuracy, step by step procedures for the weighing, vehicle categories and axle configurations. Chapter 7 describes, in detail the layout of the computer analysis program, the entry of data into a spreadsheet together with the tabulated and graphical presentation of the axle load data.

Eleven Appendices are provided showing the field working sheets used in axle load surveys, data and presentation sheets as print outs from the data analysis program, and finally, the manual tick offs sheets for the axle load grouping.

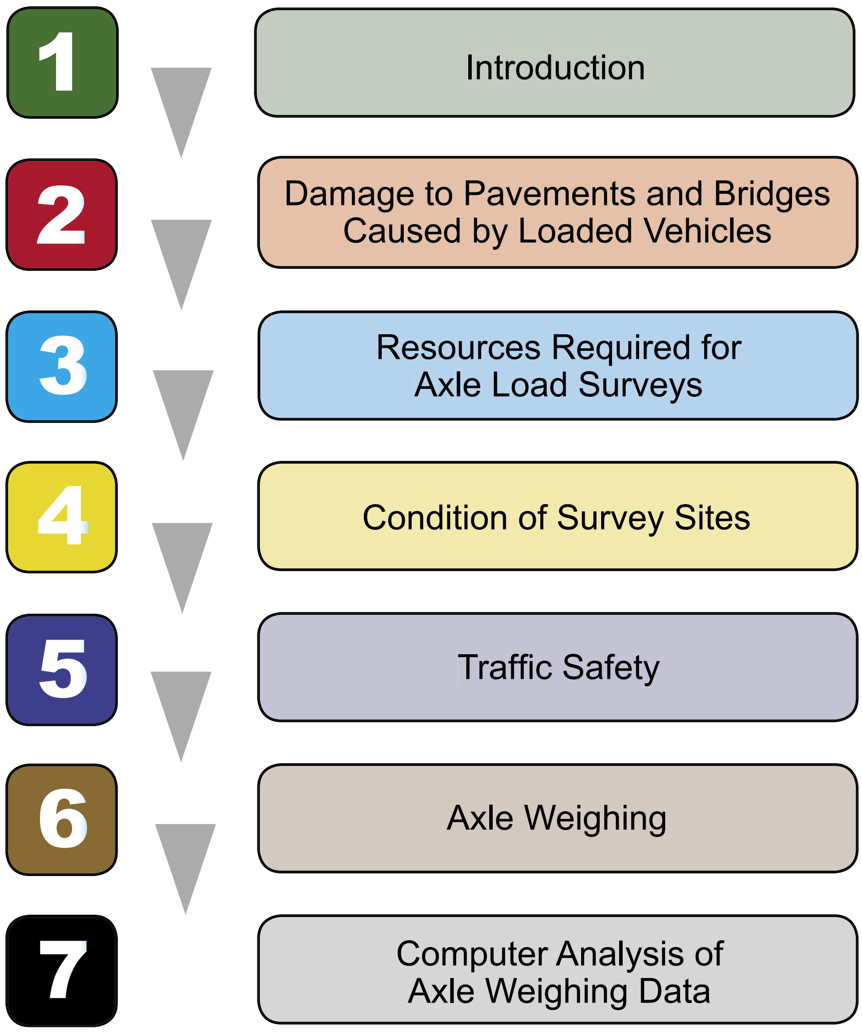


Figure 1.2 Structure of the Guideline.

2. Damage to Pavements and Bridges Caused by Loaded Vehicles

2.1 General

The paved road network carries the bulk of the national freight traffic. With time the road deteriorates due to primarily two main reasons:

- Traffic volumes and induced loading
- environment (climate)

Traffic is regarded as the key parameter in road deterioration. It is therefore essential to know its composition in terms of:

- total traffic volume (AADT)
- magnitude of the loads (axle load)
- axle configuration
- contact pressure from the loads (mainly from tyre pressure)
- number of load repetitions

It is well known that pavement design and its performance are influenced by the traffic loading on the pavement. The same applies for bridges, although in a different manner. Light vehicles such as cars and delivery vans make a very small contribution to the structural damage of a pavement in comparison to the heavy vehicles. Heavy vehicle wheel load, tyre pressure, frequency and duration together with environmental factors are all important to the performance of the pavements. However, the most significant parameter is the axle load.

Light vehicles contribute very little to the damage of the pavement.

Heavy trucks and in particular those which are overloaded contribute significantly to the damage of the pavement, thus giving a shorter pavement life than designed for.

2.2 Load spreading to a pavement

The two main functions of a pavement structure is to provide a suitable running surface for movement of traffic and a means of reducing the pressure from the wheels of heavy vehicles to a value that the foundation soil (subgrade) under the pavement can support.

The wheels of a truck standing on the road pavement exert a direct pressure on the small area of contact between its tyres and the road surface. When the vehicle is moving there is an additional dynamic stress applied ("hammering effect") due to the up and down movements caused by the slight unevenness of the surface.

The intensity of the pressure is greatest at the surface of the road and spreads in a pyramidal shape through the thickness of the pavement structure and the underlying soil, usually named subgrade.

As the area of influence widen the intensity decreases until at the subgrade level the pressure is low enough for the soil to support the traffic load without deforming and causing damage to the pavement.

Figure 2.1 shows a typical load spreading in a road pavement.

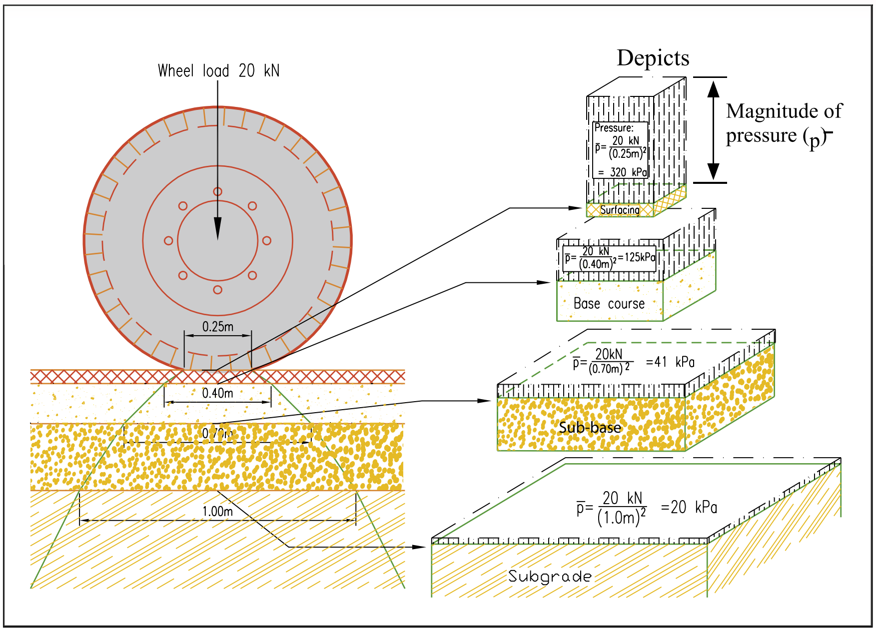


Figure 2.1 Typical load spreading in a road pavement.

2.3 Magnitude and effect of load repetitions

2.3.1 General

The most well known road research project in modern history is the AASHO Road Test conducted in Illinois in 1958 - 60. One of the main objects of this full scale trial was to study the damaging effect of heavy vehicles on different pavements.

Based on an assessment, made by road users, the functional condition of the surface was expressed as present Serviceability index (PSI) and a correlation between the observed pavement distress and the road user rating was established taking into account measurable properties such as roughness, rutting, cracking and patching of the road surface.

The most common legal axle limit in the USA at that time of the AASHO Road Test was 18000 kips or 8200 kg for a single axle with bias tread dual wheels with a 75 psi. tyre pressure. Therefore this axle was used as a reference when comparing the damaging effects from different axle configurations with varying axle loads.

One of the most important findings from the AASHO Road test was that the damaging effect of an axle, with a given axle load P, can be related to that of the reference axle, with axle load P_r, with a load equivalence factor (LEF) according to the equation below:

$$LEF = (P/P_r)^{4,5}$$

This relationship can be illustrated by the following example:
Increasing the axle load by 32 % from 80 kN to 105 kN will triple the damaging effect and a 32 % reduction in axle load from 80 kN to 54 kN will reduce damaging effect to 20 %.

Figure 2.2 shows three groups of heavy vehicles with equal damaging effect.

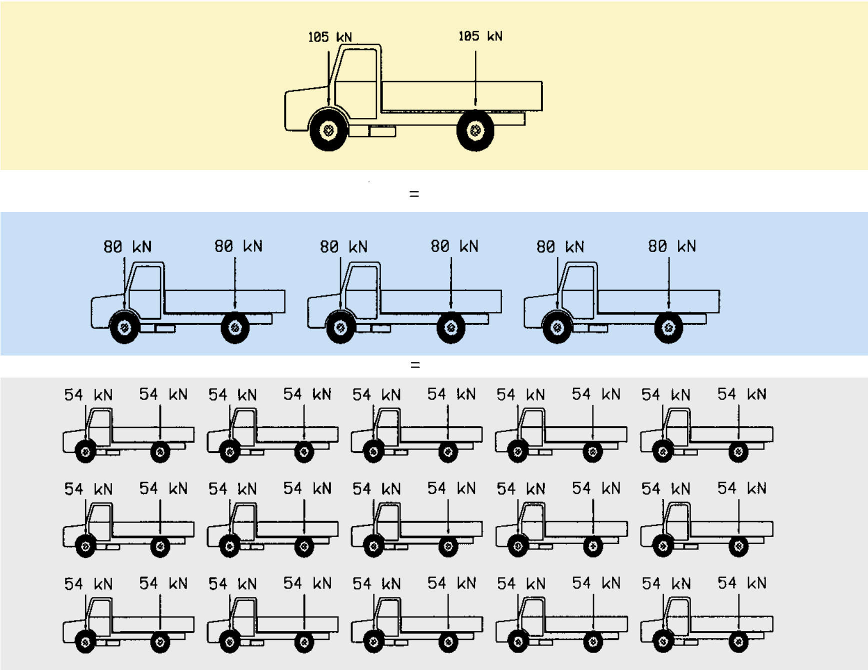


Figure 2.2 Three groups of heavy vehicles with equal damaging effect.

Expressed in trems of number of passes this relationship will read: A pavement designed to sustain one million passes with an 80 kN axle load would show the same amount of damage after only one third of a million passes with a 105 kN axle, while it would tolerate five million passs with a 54 kN axle.

2.3.2 Pavements

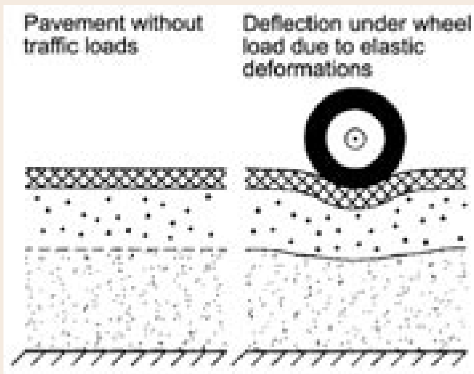
Every moving wheel induces dynamic deflections which alternately causes tensile and compressive stresses in the road structure. The damage that vehicles do to a road structure depends greatly on the magnitude of the axle loads. This is reflected in the system used for determination of design loading, where the damaging effect of an axle loading follows an exponential function which was derived from the AASHO Road test. This road test, carried out in the USA in the middle of the nineteen-fifties to the early nineteen-sixties led to the well-known Power Law, and resulted in the following equivalency formula:

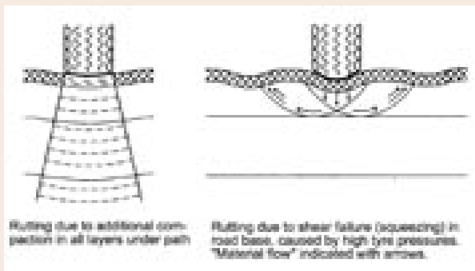
$$\text{Load Equivalency Factor} = \frac{\text{Actual axle load (ton)}^{4,5}}{\text{Standard axle load (8,2 ton)}}$$

The relative damage to a pavement is the number of repetitions of a load that will result in pavement failure and increases very rapidly with increasing axle loads. This means, if the axle load is doubled the damage will not be merely doubled but will be increased twenty fold (because the damage increases exponentially).

This relationship indicates, for example, that an axle carrying, twice the legal load has 22 times the damaging effect of a legal axle load.

Recent research has led to a number of modifications and additions to the equivalence factors from the AASHO Road Test. In addition to axle load the damaging effect from traffic has been found, amongst others, to depend upon the following factors:

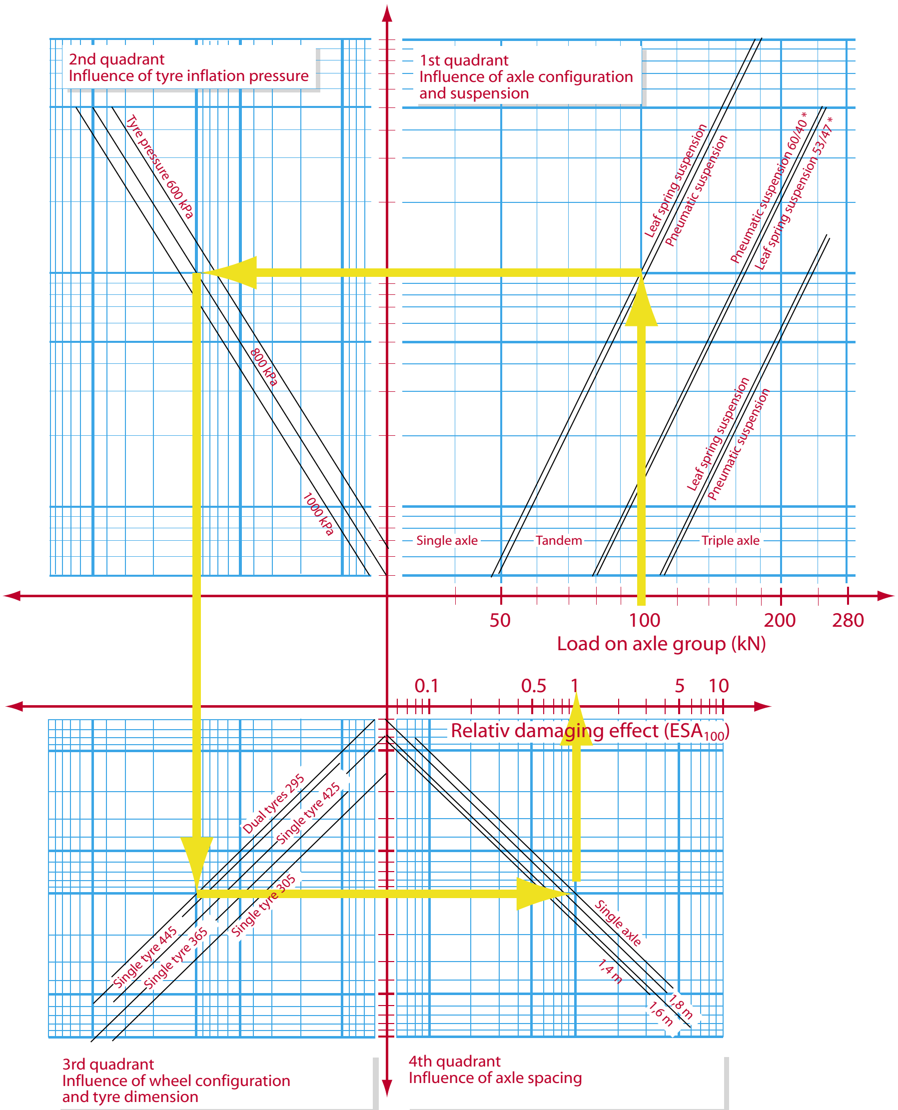




Although this relationship has been developed by virtually all design systems world-wide, it is far from the physical law. In fact, the exponent my be as high as 10 if the “weak link” in the pavement is to be found in the subgrade. Conversely, strong subgrades may exhibit an exponent as low as 1,5.

- axle type and spacing (single - tandem - triple)
- wheel type; dual - wide base single - normal single
- uneven load distribution on dual tyres
- tyre pressure

The relative influence of each of these factors is illustrated in the nomograms of Figure 2.3 which comprises a more complete procedure for determining the relative damaging effect for a given axle and wheel configuration.



Reference axle: 100 kN, single axle, dual tyres, 800 kPa inflation pressure.

Guidelines:

1. From load axis in 1 st quadrant draw vertical line to interception with curve for actual axle configuration and suspension type.
2. From interception in 1 st quadrant draw horizontal line to interception with curve for actual tyre inflation pressure in 2nd quadrant.
3. From interception in 2nd quadrant draw vertical line to interception with curve for actual wheel configuration and tyre dimensions.
4. From interception in 3rd quadrant draw horizontal line to interception with curve for actual axle spacing (for tandems and triple axles) in 4th quadrant.
5. From interception in 4th quadrant draw vertical line to axis for relative damaging effect. (ESA_{100})

Repeat procedure for each group on both truck and trailer in question and add up the induvidual damaging effect for all axle groups.

*) 60/40 and 53/47 refers to disribution on tandem axles.

Figure 2.3 Determination of relative damaging effect for different axle- and wheel configurations.

In Botswana the legal axle load limit is 8, 2 tons and even a small proportion of overloading will influence the pavement performance significantly. The effect of changes in axle load on pavement life is shown in Figure 2.4 which is self-explanatory and shows that the pavement life is extremely sensitive to changes in the axle loading. Even small changes can affect the expected pavement life significantly. The effect of the value of the damaging coefficient is also noticeable, with higher values causing large reduction in pavement life.

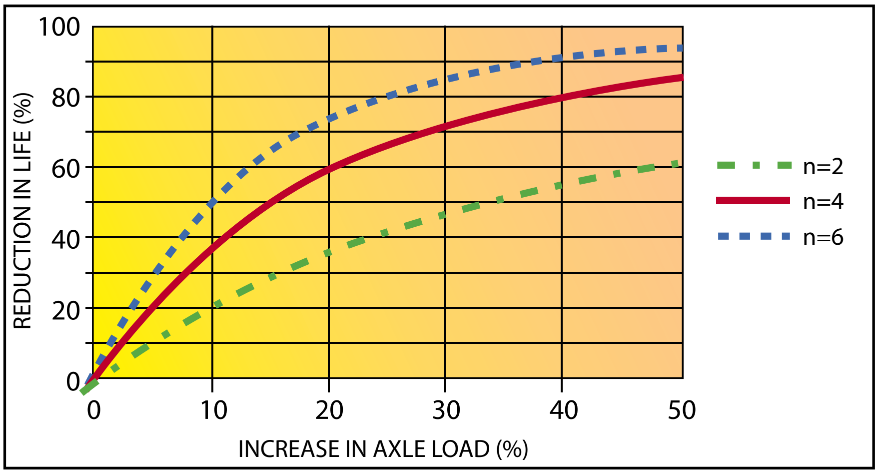


Figure 2.4 Effect of changes in axle load on pavement life.

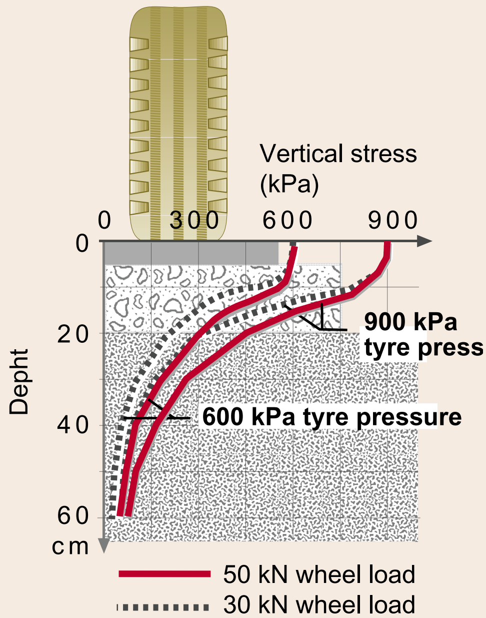
2.3.3 Bridges

Impact and effect of over loaded vehicles to damage on bridges differs from those generated on road pavements. This is because bridges have to carry the combined load of many or all the axles of a vehicle simultaneously. Therefore, not only the gross vehicle mass is considered, but also the axle weight and inter-axle spacing has influence on damage. The effect of increased vehicle loads impose additional stresses on the load carrying members of bridge structures and decreases the serviceability of the structure by accelerating deterioration.

2.4 Contact pressure

The main factors affecting the level of contact pressure from the traffic are well known and are primarily related to type of tyres used, tyre pressure and indirectly influenced by the axle loading. Research carried out in the southern Africa indicates that the measured contact stresses exceed the tyre inflation pressures by approximately 30%. Despite the significant damaging influence of over-inflated tyres, very few pavement design procedures take full account of the tyre pressure effects.

Heavy axle loads impose a different impact on a bridge than on a road pavement structure.



The damaging influence of tyre pressure tends to be much higher in the upper pavement layers.

Although all the above mentioned contribute to the damaging effect of a pavement it should be pointed out that tyre pressure plays a particulary important role in Botswana. A majority of roads in this contry have comparatively strong subgrades, but high tyre pressure will easily lead to over stressing in the unbound granular base materials of these roads.

3. Resources Required for Axle Load Surveys

3.1 General

Axle load surveys provide invaluable and essential information that are required for cost effective pavement design and preservation of the existing roads. However, such surveys can be expensive and must be carefully planned and organised to ensure accuracy and minimise resource wastage.

3.2. Staff composition and qualifications

The axle load survey team normally consists of about15 people working on a three shift basis with 4 - 5 people on each shift. The minimum qualifications of the team members should be as follows, however, proper training must have been executed prior to sending the team members into the field on their own. Such training should be conducted by an experienced engineer fully conversant with the technical and logistics details.

Team leader:	TO or higher (no 1)
Scale reading and data recording:	Matr. assistant (no 6)
Traffic officer(s):	Matr. Assistant/labours (no 5)
Vehicle operator(s):	Driver (no 3)

The exact number of people and number of shifts will vary slightly depending on whether the survey is carried out in conjunction with a border post gate or not. In conjunction with a border gate the survey will follow the border post gate opening and closing schedules.

3.3 Equipment requirements

The following equipment are required to conduct an axle load survey. Personal camping equipment is not included in the listing, as this will be individual responsibility of the team members.

Preparation of mobile weigh bridge site.

Required equipment:

- flatbed truck (no 1)
- backies (no 2)
- 1 water tank
- Reflective traffic safety vests (no 15)
- traffic cones (no 20)
- red stop flags (no 2)
- road signs (no 10)
- generator for lights (no 1)
- 200 litre drum for petrol
- electrical lamps (no 2) incl. cables
- torches incl. spare batteries (no 2)
- axle survey forms

- pens and other stationary
- spade (no1)
- pick (no 1)
- broom (no 1)
- camera (no 1)

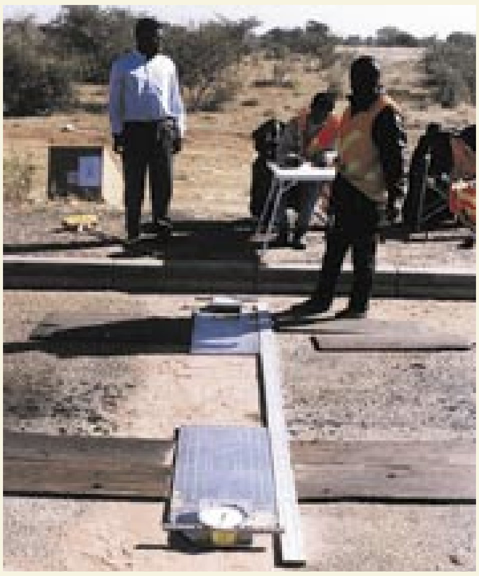
In case were the mobile weigh bridges are used the following additional equipment will be required:

- weigh pads and peripheries
- generator for lights (no 1)
- 2 metre long straight edge (no 1)
- spirit level (no 1)
- bags of fine sand to level mobile weigh bridge (no 5)
- ramps (no 4)
- chairs (no 2)
- table (no 1)
- large umbrella (no 1)

Axle load survey a stationary weigh bridge location.

A correctly selected site location is necessary for a successful axle load survey.

Correct cross wise gradient is a must for collecting data. The use of a sprit level and a straight edge.



Fine dry sand shall be used to even out irregularities under the platform for the mobile weigh bridges. This will prevent sharp stones to punch into the platform.

4. Condition of Survey Sites

4.1 General

The success of an axle load survey and the ease with which it can be carried out will depend largely on the choice of site. In general the site must be selected to make it possible to weigh the vehicles easily and safely.

Ideally, the survey location should be on a road stretch with good visibility so the traffic will be aware of the survey well in advance and provide ample time to slow down and stop.

4.2 Stationary weigh bridges

Obviously the site location for the stationary weigh bridges are already pre-determined and these locations have been carefully selected in order to capture the main stream of loaded vehicles that are using the road network. The site conditions for the stationary weigh bridges have been carefully designed to cater for the activities normally taking place at these locations and are therefore ideal for axle load survey activities.

4.3 Site location for mobile weigh bridges

The site location for axle load surveys using the mobile weigh bridges must be carefully selected and in accordance with the objective of the axle load survey. It is important to ensure that:

- the correct road section is surveyed;
- traffic in both directions can be surveyed;
- the traffic safety aspects have been considered;
- there are no access to easy detours to avoid the survey site;
- the local police are informed of the survey location and duration.

The items listed above should be carefully addressed prior to conducting the axle load survey.

Ideally, the survey location should be sited on a clear stretch of road with good visibility as it is important to inform the road users that a survey is being conducted ahead. This will give them ample time to slow down and stop.

There are many different types of mobile weigh bridges available, however the requirements on the measuring position is, in general, similar for all the types.

The weighing surface gradient/slope should not exceed 2% in order to comply with the weigh bridge requirements. In addition to this more general requirement, there are several other sources that might give measuring errors. Such sources are listed in the figures below and should be studied:

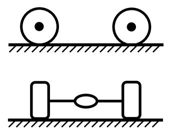
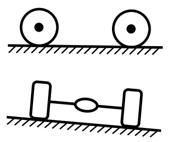
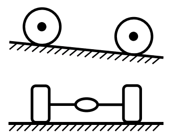
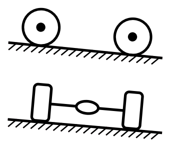
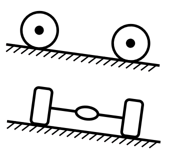
Gradient \ Measurement		Total weight	Wheel load	Axle load
	lengthw. 0 % crossw. 0 %	correct	correct	correct
	lengthw. 0 % crossw. 5 %	correct	correct	incorrect
	lengthw. 5 % crossw. 0 %	correct	incorrect	incorrect
	total 5 %	correct	incorrect	incorrect
	total > 5 %	incorrect	incorrect	incorrect

Figure 4.1 Sources of errors at the weighing place; weighing site gradients.

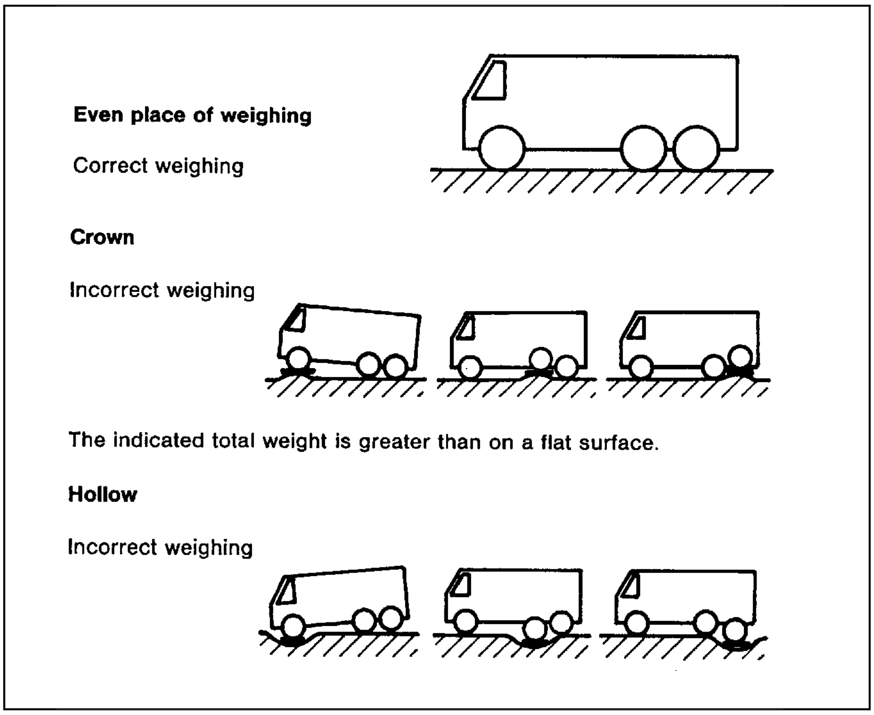
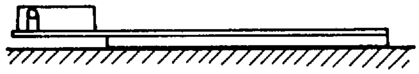


Figure 4.2 Sources of errors at the weighing place, uneven place of weighing.

The mobile weigh bridges must be repositioned regulary to maintain correct readings.

Even place of weighing

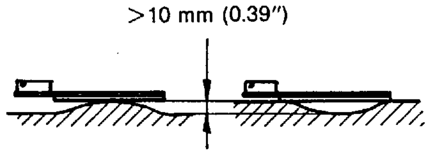
Correct weighing



The scale is correctly placed. The space between the scale and the ground is nowhere more than 10 mm (0.39″).

Uneven place of weighing

Incorrect weighing



The space between the scale and the ground is greater than 10 mm (0.39″). The scale could be deformed too strongly.

Figure 4.3 Sources of errors at the weighing place, even and uneven place of weighing.

A correct selected weighing place with the scales correctly positioned.

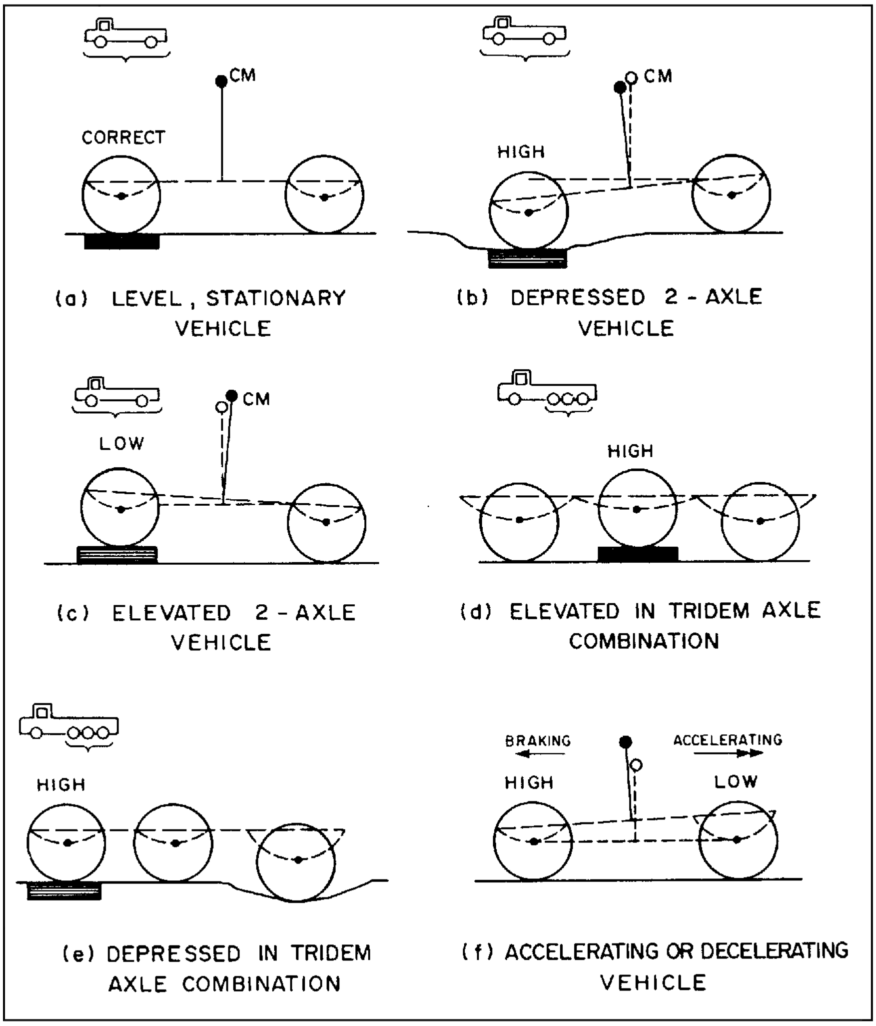


Figure 4.4 Illustration of correct and incorrect vehicle and axle placement when weighing.

5. Traffic Safety

5.1 General

In order to conduct a successful axle load survey the traffic safety aspect must be dealt with in an efficient and proper manner. The first essential requirement is to select an appropriate site location for the axle load survey where the traffic safety can be dealt with properly. This means that site locations immediately before or after horizontal and vertical curves should be avoided. Ideally, the site location should be on clear and straight stretch with good visibility, so that traffic can slow down to a reasonable speed and stop whenever required.

5.2 Traffic warning

The traffic warning must be properly arranged with traffic signs on stands in an appropriate sequence.

The following traffic signs should be used, one in each direction:

2 x Slow down
2 x Men at work
2 x Weigh bridge ahead
2 x Speed limit 60 or 50 km/hour
2 x Speed limit 30 km/hour
2 x Prepare to stop
2 x Stop sign
2 x Arrow sign

All the road signs should be reflective.

In addition, a minimum of 20 traffic cones shall be used to direct the traffic in a safety manner.

All personnel must wear reflecting vests, not only for traffic safety reason, but also to promote authority on site. Figure 5.1 shows the standard layout of placing the traffic warning signs.

Road warning signs MUST always be placed to warn the roads users.

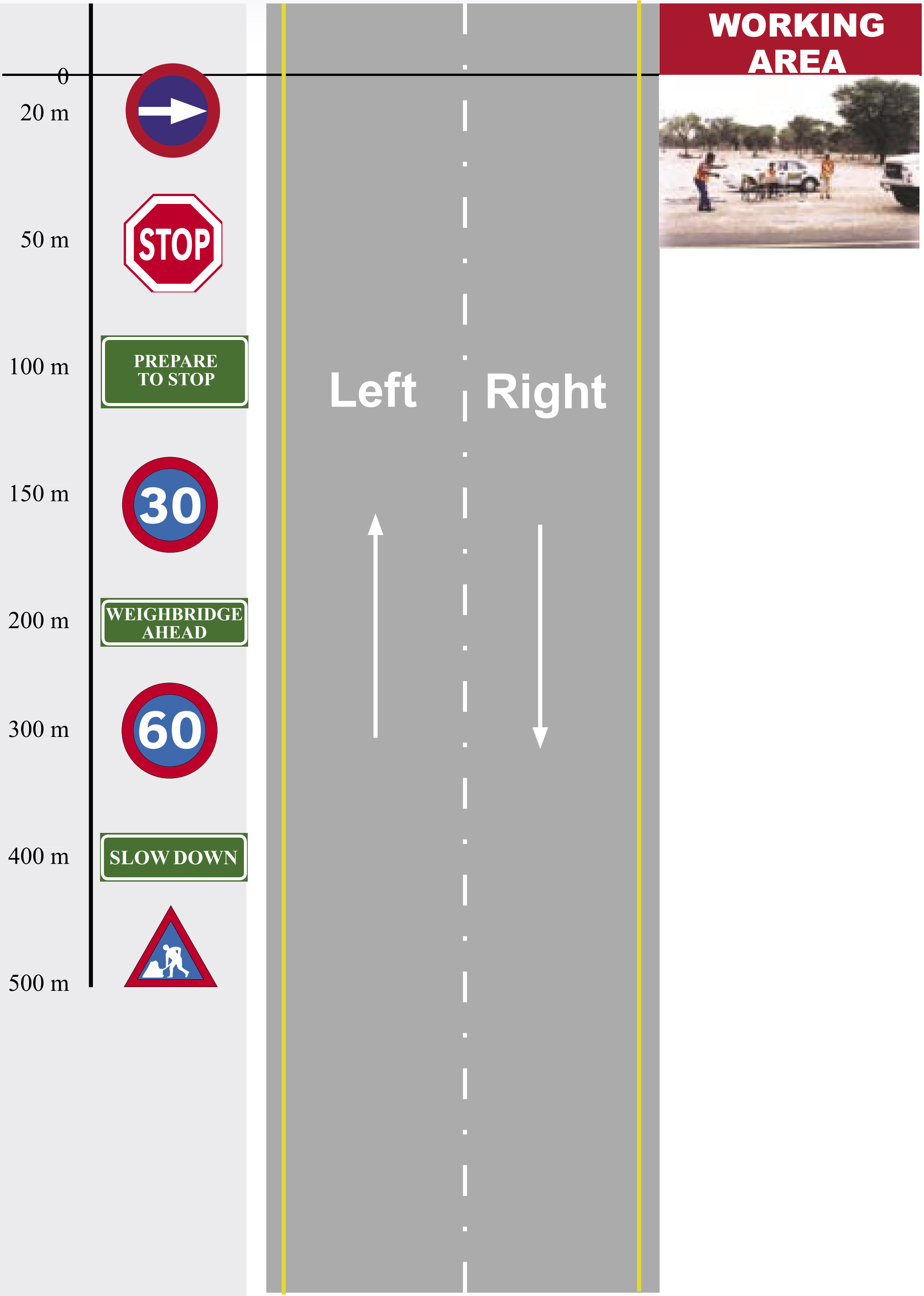


Figure 5.1 Standard layout for placing of traffic warning signs.

6. Axle Weighing

6.1 General

Light vehicles (gross weight less than 5,0 tonnes) cause minimal structural damage to road pavements, and therefore such vehicles are not included in axle load surveys and should therefore not be weighed. Buses with seating capacity of more than 40 seats have, very often large axle loads and such buses must always be included in the survey.

The axle load survey should consider the two traffic directions separately, as it is very rare that the traffic loading are similar for the two directions of traffic. Very often there is a significant difference in loading between the two directions of traffic.

An axle load survey will among other things give the average vehicle equivalent factors (VEF) for a particular vehicle category and cumulative axle load distribution. It is, therefore, important to also include all the empty vehicles.

The axle load weighing described in this Guideline deals only with static weighing and does not deal with the weight of moving vehicles commonly termed Weigh - in - motion (WIM).

Vehicles with gross weight less than 5,0 tones shall NOT be included in the axle load survey.

Empty trucks shall always be included in the axle load surveys, otherwise the VEF figures will be wrong and inaccurate.

Specialised plant equipment i.e. a grader shall NOT be included in the axle load survey.

6.2 Factors affecting the vehicle weighing

When conducting an axle load survey the validity of the two following assumptions are made:

- The load on the wheels of an axle remains constant at all times, ie. remains the same as it was when the vehicle was originally loaded;
- The load exerted on the road by any wheel of any vehicle, whether at rest or in motion, is constant and determined by the initial load distribution of the vehicle.

These assumptions disregard the fact that the load concentration on a wheel or an axle changes continuously when the vehicle is in motion.

6.3 Distribution of vehicle load

A basic misconception concerning vehicle weighing relates to the fact that the load concentration or distribution is not constant. The mass on two adjacent truck wheels is the same only if the tyres and tyre pressure are similar. It has been found that if the tyre pressure in one of the adjacent wheels of a dual-wheeled axle is decreased from 400 kPa to 200 kPa, then it is possible that 25% of the load is transferred to the 400 kPa wheel.

For similar reasons, it is important to weigh the vehicles on as level a site as possible. Every effort should be made to have all the wheel of a vehicle to rest on an equally level plane. If the weighing plane raises the level of the wheels to be weighted above the plane of the remaining wheels of a vehicle of two axles, the measured weight will be less than the actual. Similarly, if the level of the weighted wheel or axle is lowered, the weight will be more than the actual.

The axle load for a loaded truck in motion will be affected by the design, construction and mechanical condition of the vehicle. The road gradient and surface roughness will also influence the axle load. The weather also has some influence because springs and suspensions behave differently in dry, wet, warm or cold weather conditions. However, these effects are not normally considered because their influence are only relatively small.

A wheelbarrow, the simplest of all vehicles, can be used to illustrate this point. As the handles of the wheelbarrow are either raised or lowered, the centre of mass moves in relation to the wheel and thus the load on the wheel changes, both vertically and horizontally.

The gradient of the slope or plane has less influence on the accuracy of weighing for a large wheel base vehicle than for a short wheel base vehicle.

The accuracy of the weighing procedure will basically depend on the following:

- the gradient of slope or plane of the weighed axle;
- the wheel base, spacing between the dual wheels and the equality in tyre pressure and the wear and tear of the tyres;
- the height of the load above the centre of the axle.

6.4 Measuring accuracy

If the preparatory works has not been executed satisfactory wrong axle load reading will prevail.

The accuracy of weighted individual axles depends greatly on what has been discussed above. In addition, it is important to ensure that the weigh bridge to be used, whether it is a stationary or a mobile, has been properly calibrated according to specifications. Normally, calibration of weigh bridges are carried out by the manufacturers or specialised firms. It is, therefore, important to ensure that the weigh bridges to be used in the survey are in such a condition that the data obtained is reliable.

During axle load surveys, it is common to consider all axles are regarded as a single axle in the calculations, even though they are tandem or multiple axle combinations. Also no distinction is made between a dual wheel mounted tyre and a single mounted tyre.

6.5 Duration of the survey

It is important to observe any seasonal events or activities which might give rise to variations in traffic volume that are not normal.

Axle load surveys should be carried out for seven consecutive days and for 24 hours a day. This is done to ensure a representative sample of the traffic loading over the seven week days. For this reason, axle load surveys less than seven days duration are not recommended.

If the axle load survey is carried out in conjunction with a border gate station, the hours of the survey should be in accordance with the opening hours of the border gate.

6.6 Origin and Destination (O/D) survey

The field working sheet for the axle load survey should be filed for possible later use.

As axle load survey is a costly exercise all information that can be easily captured should be recorded. Conducting an O/D (origin and destination) survey in parallel with an axle load survey will not involve extra resources as one only questions the driver from where he started the journey and where it is going to end. The type of load the vehicle is carrying could also be recorded. Normally the O/D information is not reported in the axle load survey report, however the information remains on the field worksheets and can be very useful for future feasibility studies or for other purposes. It is partly for this reason the field work sheets from the axle load survey should be properly filed for future access and use.

6.7 Procedures for weighing

The axle load survey shift team consists normally of four people for surveys on permanent weigh bridges. Normally five people are required for surveys using mobile weigh bridges, depending on whether the scale reading is recorded on the scale itself or from an electronic display placed in front of the recording officer, similar to those for the stationary weigh bridges.

The two flag men (traffic controllers) should stand on the road where they are clearly visible to the oncoming traffic. They must wear reflective traffic safety vests and during the night they should be equipped with a flash torch showing a red light. The flag men are stationed at a distance of 30 meter on either side of the weigh bridge. They should force the vehicles to be weighed to a complete stop for weighing. The traffic controller instructs the truck driver on how to approach the weigh bridge at slow walking speed.

During an axle load survey it is important that all vehicles above a gross weight of 5,0 tonnes are weighed, this applies whether they are empty, partly or fully loaded.

The flag man have the important job of stopping the vehicles for weighing. Experience has shown this to be a difficult task, and assistance from the police should be sought.

6.8 Vehicle categories

During the axle load survey, heavy vehicles are divided into four categories as shown in Table 6.1.

Table 6.1 Heavy vehicle categories and definitions.

Heavy vehicle category	Definitions
Buses BUSES	Seating capacity of 40, or more
Medium Goods vehicle MGV	- 2 axles, incl. steering axle, and - 3 tonnes empty weigh, or more
Heavy Goods Vehicle HGV	- 3 axles, incl. steering axle and - 3 tonnes empty weigh, or more
Very Heavy Goods Vehicle VHGV	- 4 or more axles, incl. steering axle and - 3 tonnes empty weigh, or more

The BUSES category also includes buses with 3 axles. The VHGV's category includes both semi-trailers, trailers and combinations of both.

The data processing deals with these combinations separately, but they are combined into a summary of the three VHGV's categorie during the data analysis stage.

6.9 Axle configuration

Each vehicle is given an axle configuration code for ease of defining and processing the axle load data. This code is simple and each axle is represented by a digit, '1' and '2' depending on how many wheels are on the end of the axle. Tandem axles are indicated by recording the digits directly after each other. A decimal point '.' is placed between code digits for a vehicle's front and back wheels. The code for semi-trailers and articulated trailer are recorded in the same way as for trucks but is separated from the truck code by a minus '-' sign. For the trailers a plus '+' sign is used. Examples of common axle configurations in this country is given in Figure 6.1.

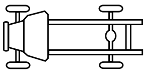
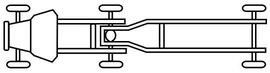
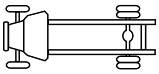
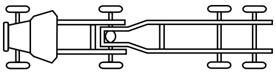
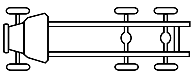
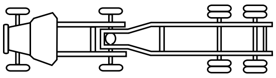
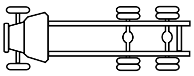
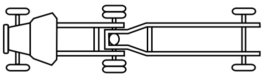
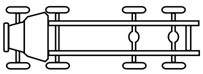
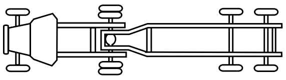
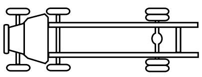
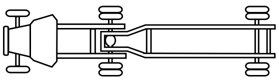
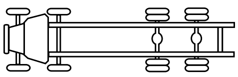
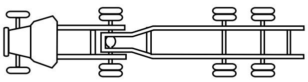
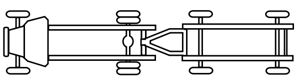
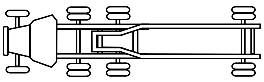
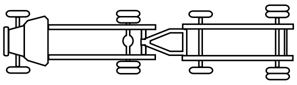
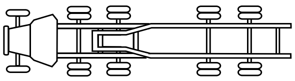
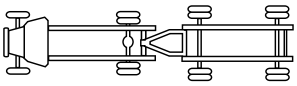
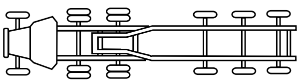
RIGID - CHASSIS COMMERCIAL VEHICLES			ARTICULATED COMMERCIAL VEHICLES		
	11	Single tyres on front and rear axles		1.1 - 1	Single tyres both axles of tractor Single tyres axle of trailer
	12	Single tyres on front axle Twin tyres on rear axle		1.1 - 11	Single tyres on both axles of tractor Single tyres on both axles of trailer
	1.11	Single tyres on front axle Twin tyres on rear axles Two rear axles		1.1 - 22	Single tyres on both axles of tractor Twin tyres on both axles of trailer
	1.22	Single tyres on front axle Twin tyres on rear pair of axles Two rear axles		1.2 - 1	Single tyres on front axle of tractor Twin tyres on rear axle of tractor Single tyres on axle of trailer
	11.11	Single tyres on front pair of axles Single tyres on rear pair of axles		1.2 - 11	Single tyres on front axle of tractor Twin tyres on rear axle of tractor Single tyres on both axleS of trailer
	11.2	Single tyres on front pair of axles Twin tyres on rear axle		1.2 - 2	Single tyres on front axle of tractor Twin tyres on rear axle of tractor Twin tyres on axle of trailer
	11.22	Single tyres on front pair axles Twin tyres on rear pair of axles		1.2 - 22	Single tyres on front axle of tractor Twin tyres on rear axle of tractor Twin tyres on both axle of trailer
	1.2 + 1.1	TRAILERS Single tyres on both axles		1.22 - 2	Single tyres on front axle of tractor Twin tyres on both rear axles of tractor Twin tyres on rear axleS of trailer
	1.2 + 1.2	Single tyres on front axle Twin tyres on rear axle		1.22 - 22	Single tyres on front axle of tractor Twin tyres on both rear axles of tractor Twin tyres on both rear axles of trailer
	1.2 + 2.2	Twin tyres on both axles		1.22 - 111 1.22 - 222	Single tyres on front axle of tractor Twin tyres on both rear axles of tractor Single/twin tyres on axles of tractor

Figure 6.1 Common axle configurations in the country.

Stationary weigh bridge.

Experience has shown that the truck drivers have little or no understanding of why they have to weigh an empty truck. The flag men should therefore be able to explain why this aspect is important in carrying out an axle load survey.

6.10 Surveying procedure

6.10.1 Stationary weigh bridges

The stationary weigh bridges are normally well signed by the use of traffic sign boards so the road users and most of the heavy vehicles drivers know that they must report at the weigh bridge. However, this only applies when the vehicle is loaded. Empty trucks are free to pass the weigh bridge station. For axle load surveys empty truks must also be weighted, therefore, it is important to position the flag men on either side of the turn off access roads to the weigh bridge.

The weigh bridge officer stands in front of the weigh bridge to direct the vehicle onto the weigh bridge platform ensuring that the axle are accurately placed on the platform.

Each axle is dealt with separately, hence each axle is recorded separately on the pre-made survey form.

Appendix 7 A-B shows the field work sheets (a blank and filled).

After the front axle of the vehicle has been positioned accurately on the platform and come to a complete stop, the weigh bridge officer asks the questions that applies for the O/D survey, and passes the answers to the recording officer. The recording officer shall not interfere with the maintenance officer assigned to the weigh bridge in taking axle load records, but shall take his own recordings from the scale showing the axle load figure.

When the weight of the last axle load has been recorded, the driver must be told to drive off the platform slowly. An accelerated departure from the platform may cause damage to the platform.

Traffic travelling in opposite directions shall be recorded on separate sheets.

6.10.2 Mobile weigh bridges

Unlike from the stationary weigh bridges, the mobile weigh bridges are normally put up where the road users are not used to observe them. Pre-warning according to Chapter 5 is necessary. The flag men, even more important than for a stationary weigh bridge. All vehicles categories shown in table 6.1 shall be directed towards the mobile weigh bridge where the weigh bridge officer stands in front of the weigh bridge to direct the vehicle onto the weigh bridge platform The axle load weighing described in this Guideline deals only with static weighing and does not deal with the weight of moving vehicles commonly termed Weigh - in - motion (WIM).ensuring that the wheels are accurately placed on the platform.

Each axle is dealt with separately in the axle load survey, hence each axle is recorded separately on the pre-made survey form. Appendix 7 A-B shows a blank and filled in, field work sheets.

After the front axle of the vehicle has been positioned accurately on the platform and has come to a complete stop, the weigh bridge officer ask the questions regarding the O/D survey, and pass the answers to the recording officer. Traffic travelling in opposite directions shall be recorded on separate sheets.

After weighing the front axle of the vehicle, the weigh bridge officer directs the driver of the vehicle to position the next wheel (axle) on the platform. This procedure continues until all the wheels (axles) of the vehicle have being weighed and the truck driver is allowed to leave the platform. As for the stationary weigh bridges it is even more important that the driver is told to drive off the platform slowly. An accelerated departure from the mobile weigh bridge platform may cause serious defects to the weigh bridge.

It is important that the axle load survey is as much as possible uninterrupted by weather. A shelter, umbrella or similar should be made available to the survey team so rain or excessive sun does not affect the survey to the extent that the sampled data does not give the required level of confidence.

Mobile weigh bridge team in operation.

Normally only one functional platform is used when using the mobile weigh bridges, the other platform is only a dummy. Hence, the recorded weight is the wheel load and this load has to be multiplied with two to know the actual axle load, assuming that the wheel loads are distributed evenly on the axle wheels.

Applying correct weighting procedures is vital to ensure an effective axle load survey.

A shelter for the recording officer should be provided so rain or inclement sun does not affect the survey.

7. Computer Analysis of Axle Weighing Data

7.1 General

One of the main outputs from an axle load survey is the VEF for each vehicle category and a cumulative axle distribution curve for each of the vehicle categories. Information about various axle configurations within each of the vehicle categories is also frequently required. The computer programme that accompanies this Guideline can be used to generate a variety of useful information from the survey data.

The computer program has been developed using a spreadsheet programme based on lotus 1.2.3 Release 5 and is compatible with the latest version of lotus i.e. lotus 1.2.3 Smart Suite 97. The program can also be converted to Microsoft Excel and used with this software.

An exponent of 4,5 has been incorporated in the Power Law formula used in the data analysis programme.

A digit too much i.e. entering a 100 000 kg axle load instead of 10 000 kg will have significant impact on the results as the VEF will increase from 2,5 to 8949. Such figures indicate that something is completely wrong.

For an axle load survey that includes about 10 000 axles in both directions, it will take about 3 days work for two people to complete the "tick off" axle grouping.

The data analysis program contains both manual and automatic checking features. The grouping of the various axles into axle load groups (1, 2, 3, tonnes etc.) to present the cumulative axle load distribution is done entirely manually by ticking off each axle load. This exercise is done as a quality assurance, as each entered axle load is then checked manually. A digit too little or one too much will easily be discovered during this exercise and can be corrected promptly.

This manual "tick off" work is somewhat time consuming although important as this is the only quality assurance that limits errors which can have a significant impact on the results from the axle load survey.

7.2 Layout of the computer analysis program

The axle load data analysis program contains some important features that are highlighted below in order to ease the understanding of the program.

There are several sheets developed for this program, these include the following:

- Data Entry sheets;
- Vehicle Category Summary Sheets;
- Summary Sheet Axle Load Survey;
- Data Sheet for axle Load Distribution;
- Data sheet to calculate Overloaded Axles;
- Graphical Presentation of VEF and Axle Load Distribution.

Data Entry Sheets: These are basic sheets where the axle loading from a particular vehicle category and axle configuration are entered into the computer. The sheet comprises data from only one traffic direction.

Vehicle Category Summary Sheets: This sheet summarises the axle load information from a particular vehicle category i.e. Medium Goods Vehicle (MGV). The summary sheet contains information for each axle configuration, Average gross weight in tons, VEF and the total number of vehicles. The Average values are weighted figures. The sheet comprises data from only one traffic directions.

Summary Sheet Axle Load Survey: This sheet summarises all the four vehicle categories, but divide the VHGV's category into semitrailers, semitrailer and trailers combinations and trailers. Informations given are Vehicle category, Average gross weight in tonnes, VEF and the total number of vehicles. The sheet comprises data from only one traffic direction.

Data Sheet for Axle Load Distribution: Data from the manual "tick offs" sheets are entered into this data sheet, whereby the cumulative % axle distribution is auto calculated for each vehicle category. Similar for the number of total axles. The sheet comprises data from only one traffic directions.

Data sheet to calculate Overloaded Axles: This sheet presents the quantified percent overload for all axles. The auto calculations give the percentage overloaded axles above 8,2 tonnes and 10,0 tonnes. The sheet comprises data from both traffic directions.

Graphical Presentation of VEF and Axle Load Distribution: This provides a graphical presentation of the cumulative axle load distribution for each vehicle category. It also presents the VEF for each vehicle category.

The data sheets, summary and presentation sheets that are described above are shown in Appendices 7 C-E. The Appendices show the filled forms for the data and results obtained from the axle load surveys conducted at the Mmashoro location on the Serowe - Orapa road, direction Serowe.

The program has no protection of the many formulas, hence caution is required when working on the sheets so not to inadvertently delete formula, rows or columns. Such deletion will result in the entire axle load analysis program being corrupted.

7.3 Data entering and use of spreadsheet components

The entering of the axle load data into the spreadsheet is quite simple, however a certain logical approach has to be adhered to, as this will ease the understanding and use of the data program spreadsheet. Figure 7.1 shows the flow chart for data processing.

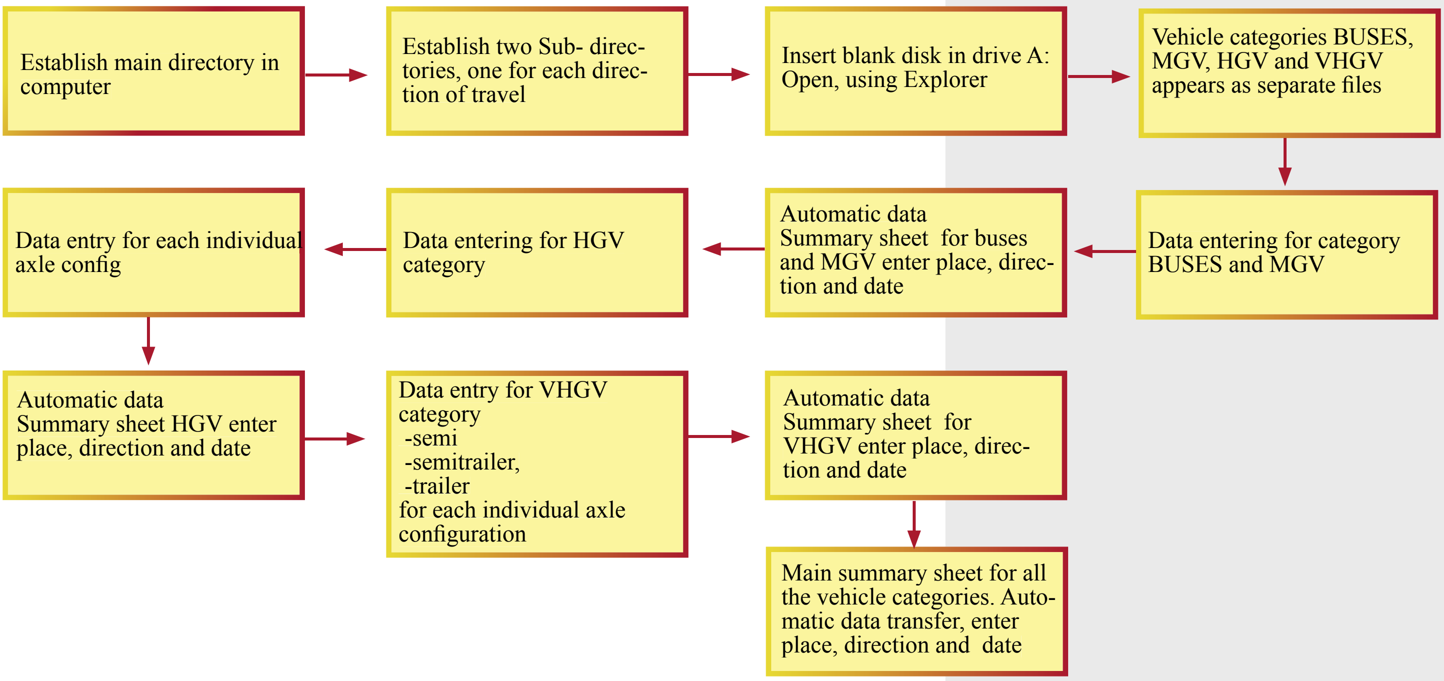
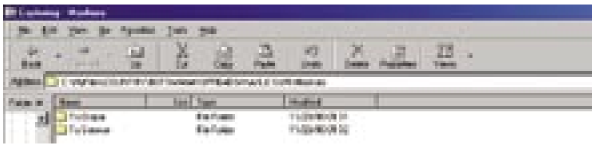


Figure 7.1 Flow chart for data entry and processing.

Step 1 Establishment of directories

- ❑ Establish a main directory, name it with the same name as for the weigh bridge location.

- ❑ Establish two sub-directories, one for each direction of traffic, use known village or town name for ease of identification and to prevent confusion later in identifying the direction of traffic.



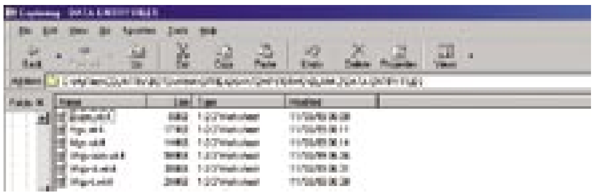
Step 2 Copy disk files into directories

- ❑ Insert the blank program disk in drive A: and copy the files to the newly established two sub- directories on the hard disk by using Window Explorer and the following main files shall be seen:

DATA ENTERING FILES SUMMARY FILES:

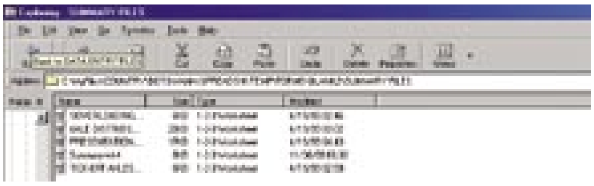
DATA ENTERING FILES CONSITS OF THE FOLLOWING FILES:

BUSES
MGV
HGV
VHGV's (this vehicle category consists of three sub-categories), namely:
- semi (semitrailers)
- st (semitrailers and trailers combinations) and
- t (trailers)



SUMMARY FILES CONSITS OF THE FOLLOWING FILES:

Summary
% overloading
Axle load distrib%
Presentation
Tick-off-axles



Step 3 Data entry

The data entry can now start, preferably in the sequence as follows: BUSES, MGV, HGV and VHGV - semi, - st and - t.

The data entering sheet that appears on the monitor is similar to the working sheet used in the field during the axle load survey, named Field Work Form, refer to Appendix 7A. For the purpose of illustrating how the spread sheet works reference has been made to VHGV's semi-trailers with axle configuration 1.22-22-22.

- Open the file called VHGV and enter the following:
  - Station
  - Direction
  - Axle configuration
- Enter the dates and axle loads for each day.

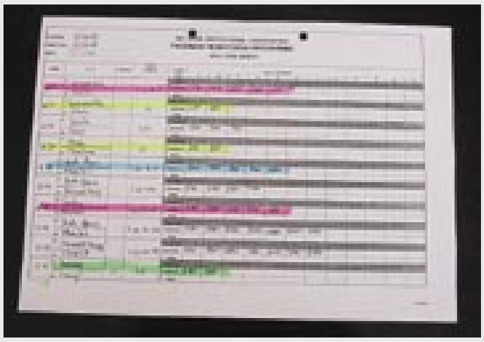
Make sure you enter all of the entered axle loads that appear on the field work sheet.

When the sheets are all full, insert a new one by copying from the blank and remember to change the sheet number in the designated cell. The new sheet that has been added will not automatically show up in the AVERAGE SUMMARY CONFIG (cell R 8) on the right side of the data entering sheet. It must therefore be entered in the designated cell under the previous cell. The formulas (cell S 23 and T 23) must therefore be activated and changed accordingly.

Sometimes, however it occurs that some of the weighed axle configurations do not have a compartment or separate page to the spreadsheet, meaning that the particular axle configuration do not show up in the spreadsheet pages. In this case the particular axle configuration must be entered into the Other Config.

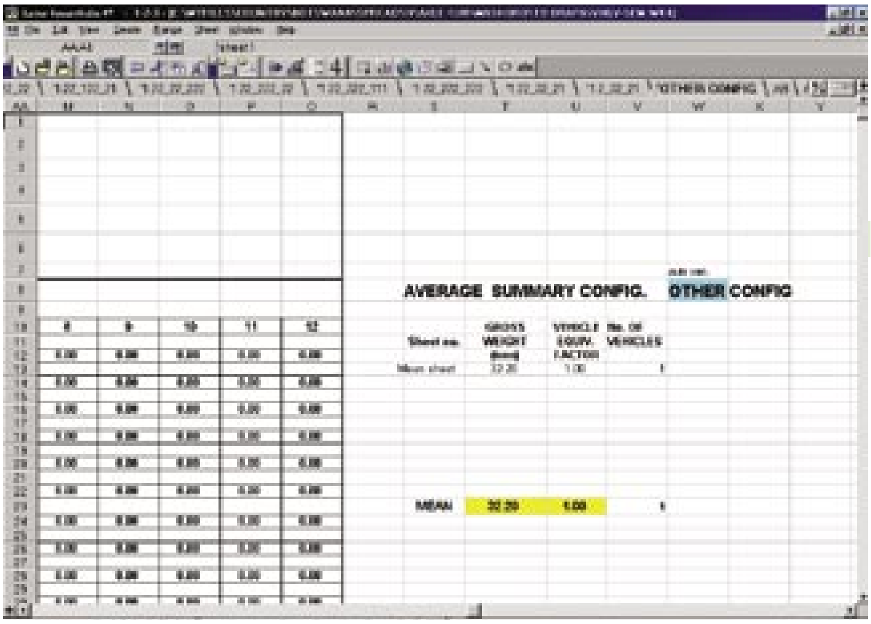
The data entry sheet for each axle configuration have been made for 20 entries, any entries that differ from that must be corrected in the formulas GROSS WEIGHT and CUM ESA. Therefore the yellow column must be checked, because the formulas are only correct when the sheet is full (20 entries). If less numbers are entered, highlight the formula and change the last number (20), to the correct number of the vehicles entered.

Data entery.



After entering that particular axle configuration it is important to mark the entered data with a highlighter. This to ensure that the data that has been entered are not being entered for the second time.

Step 4 Formula corrections



On the right side of the data entry sheet (cell R 8) AVERAGE SUMMARY CONFIG appears, summarising each of the “mean sheets”. Column, for number of vehicles has to be entered according to each number of vehicles in each entry sheet. The values for the cells, the columns for GROSS WEIGHT and VEHICLE EQUIV. FACTOR are automatically calculated. The MEAN values (yellow cells S and T 23) formulas must therefore be according to the number of sheets entered.

Note, that the total number of vehicles are automatically calculated, but the number of vehicles from each sheet must be entered in their respective cells (column U).

The AVERAGE SUMMARY CONFIG as being dealt with is automatically transferred to the SUMMARY SHEET for that particular vehicle category.

Step 5 Summary sheets headings

Data are automatically transferred into the SUMMARY SHEET (from the AVERAGE SUMMARY CONFIG) for each vehicle category, however, the Place, Direction and the Date must be entered manually.

For the remaining vehicle categories follow the same procedure as described in Step 1 to 5.

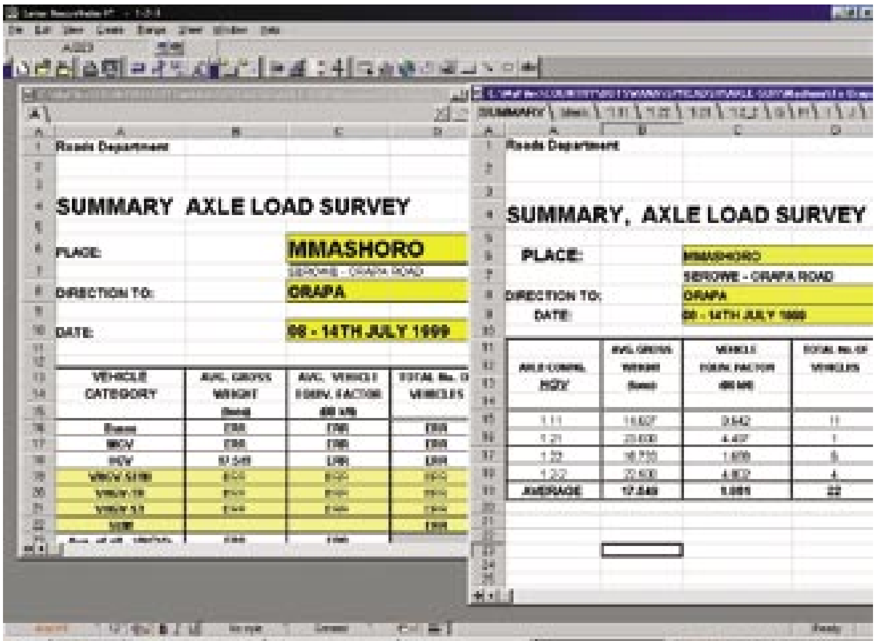
Step 6 File linkage to main summary sheet

After finishing all data entries for each of the vehicle categories and axle configurations, the main summary sheet must be activated in order to extract summary data from each of the vehicle category summary sheets. The following procedures must be adhered to:

- ❑ Open one of the vehicle category files e.g. HGV and then go into SUMMARY. Open the MAIN SUMMARY, and move to Windows toolbar and click tile - left - right. The two summaries will appear on the monitor in tile format.
- ❑ Activate the cell (by entering +) for e.g. HGV in the main summary in AVERAGE. GROSS WEIGHT (tons) column, then go to the summary sheet for HGV in the same column (AVERAGE. GROSS

WEIGHT). Then place your cursor in that cell and press enter. The number will automatically go to the MAIN SUMMARY. Ensure that the correct cell has been extracted.

Follow the same procedure for the remaining vehicle categories



If for some reasons the Main Summary sheet shows ERR, "funny numbers" or are completely blank, it should mean that the linkage procedure between the Vehicle Category Summary sheet and the Main Summary sheet has not been carried out according to the procedure described above.

Step 7 Quality assurance

All the data are now processed, the various data entry sheets, vehicle category summary sheets and main summary sheet have been linked together and the printing can now begin. However, it is advisable to carry out a thorough check of all the entered data prior to printing. Such errors will influence not only the sheet which was entered into wrongly, but will also influence the summaries. In consequence many, if not all sheets will have to be reprinted.

Errors commonly encountered are as follows:

- Sometimes one digit or more may have been missed or added. Instead of entering 4000 you may have entered 400 or 40000 which makes a significant error in the VEF figure as the formula used is an exponential function.
- Very often correction of the sheet summary MEAN formula in bottom of each entry sheet is forgotten when the sheet is not full. Hence, wrong Mean values are calculated.
- Make sure that the total number of vehicles is entered on top right side of the data entry sheet (Cell R 8).
- The entering of the various sheet headings may easily be forgotten, although this does not affect the mathematical calculations.

Step 8 Printing preparations of Data and Summary sheets

Before printing starts, ensure that margins etc. is set according to the printing set-up as required.

7.4 Presentation of axle load data

The data program offer both tabulated summaries and the graphical presentation for each vehicle category. However, to minimise the occurrence of errors, which in fact may occur rather frequently when dealing with such a large data sample, a manual quality assurance has been enforced. This ensures that all entered axle load data are checked manually.

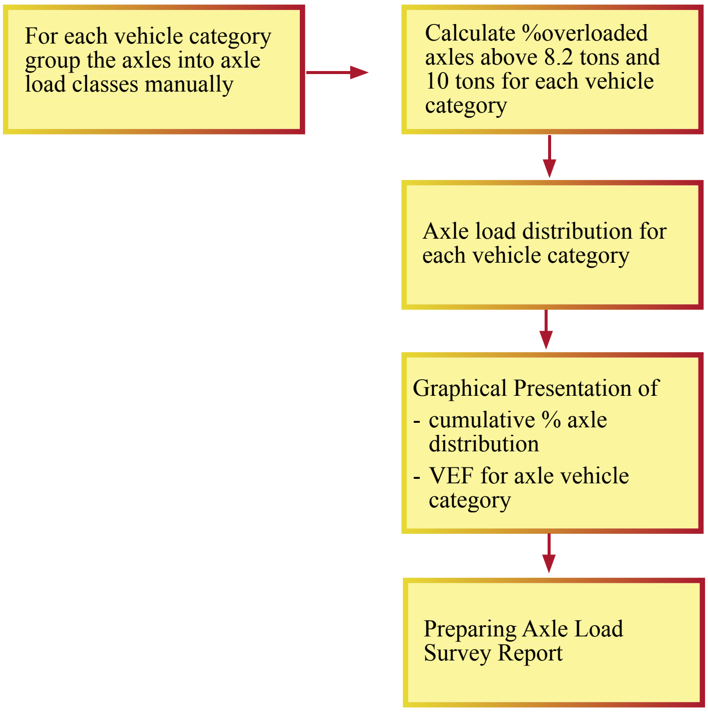


Figure 7.2 shows the flow chart for the data presentation for both traffic directions.

Step 1 Manual input requirements

In order to obtain figures required to establish cumulative axle load distribution and percent overloading a manual needs to be carried out.

From the printed data entry sheets for each of the vehicle categories, all the weighed axles are grouped into axle load classes ranging from 1,0 ton; 2,0 tons; 3,0 tons; and up to the highest axle load obtained in the survey. Normal rounding-off procedure shall apply e.g. 8,4 tons becomes 8,0 tons and 8,5 tons become 9,0 tons.

The grouping of axle loads shall be performed as follows:

- On the Work sheet (tick-off sheet) for manual entering of axle load grouping add manually the Headings, Place, Road link, Direction, Date and Vehicle category.

Appendix H-I shows the work sheet for the tick offs of the axle loads.

- From the printed data entry sheet read off the axle loads and tick-off on the Manual work sheet for axle load grouping.
- After finishing all the tick offs comprising all axles in each of the four vehicle categories, summarise the total number of axles for each axle group.

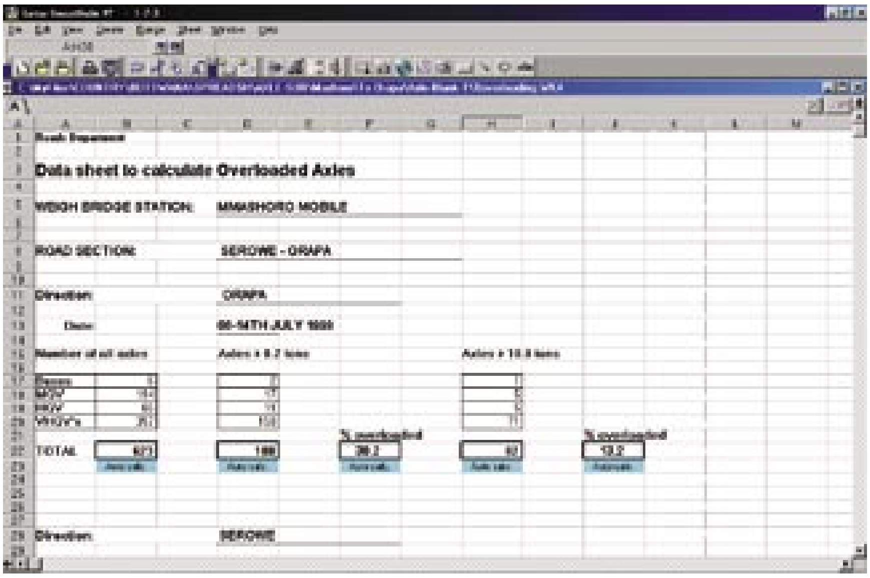
The tick-off exercise will normally requires 2 persons, one reads off the axles whilst the other ticks off the axle load into correct axle load grouping. A total number of 10 000 axles in both directions will normally take two persons about 3 - 4 days.

From the same tick-off sheet it is also necessary to establish the number of axles above 8,2 tons and 10,0 tons for each of the vehicle categories. For the 8,0 tons axle class divide the total number of axles with 2 and add up with the number of axles from 9,0 tons and above and do the same with 10,0 tons.

The manual work is now complete.

During this exercise, very often errors are seen as a result of wrong numbers entered e,g, 40000 instead of 4000 as the weighed axle load. Any such discrepancies must be corrected and reprinted before continuation of the tick-off procedure.

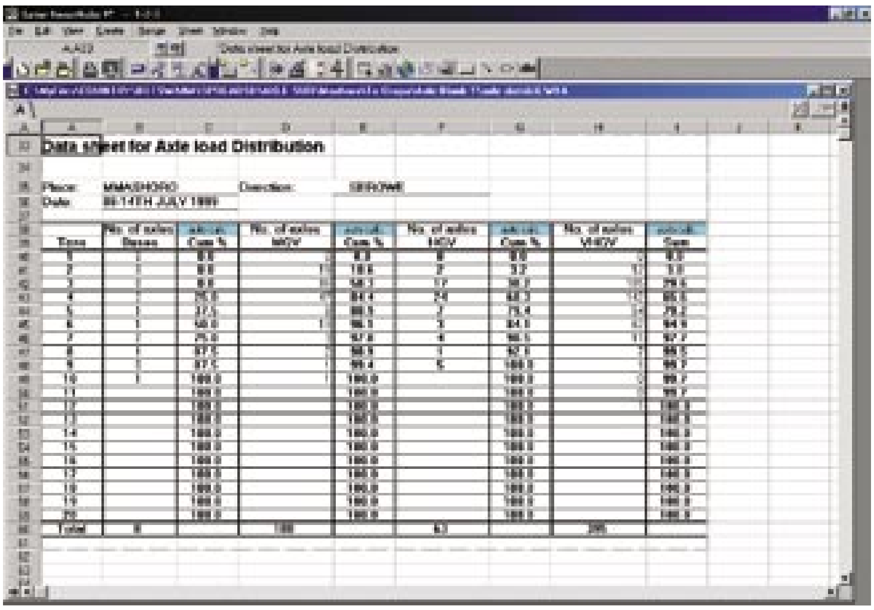
Step 2 Assessment of overloading, tabulated



Open file %overloading. Fill in the Headings, Place, Direction and Date, and enter the total number of axles for each vehicle category in the respective axle load classes. The percentage of overloaded vehicles above 8,2 tons and 10,0 tons will now be automatically calculated. Ref. Appendix 7 G.

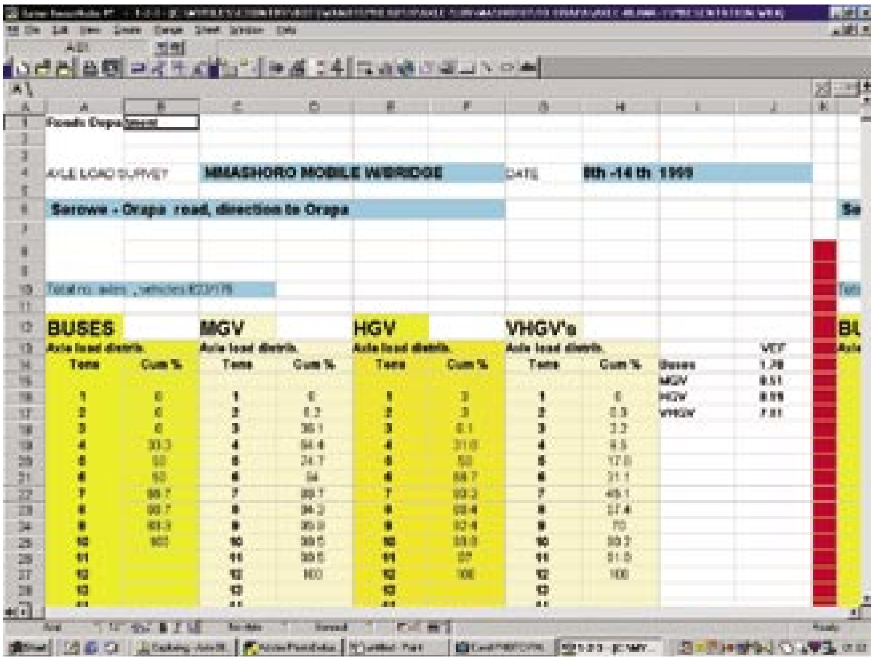
Step 3 Assessment of cumulative axle load distribution, tabulated

Open file axle distrib % and enter the headings for both directions. From the manual tick-off sheets enter for each vehicle category the number of axles for each axle load class. Ref. Appendix F.



The cumulative axles and cumulative axle distribution % are calculated automatically.

Step 4 Graphical presentation



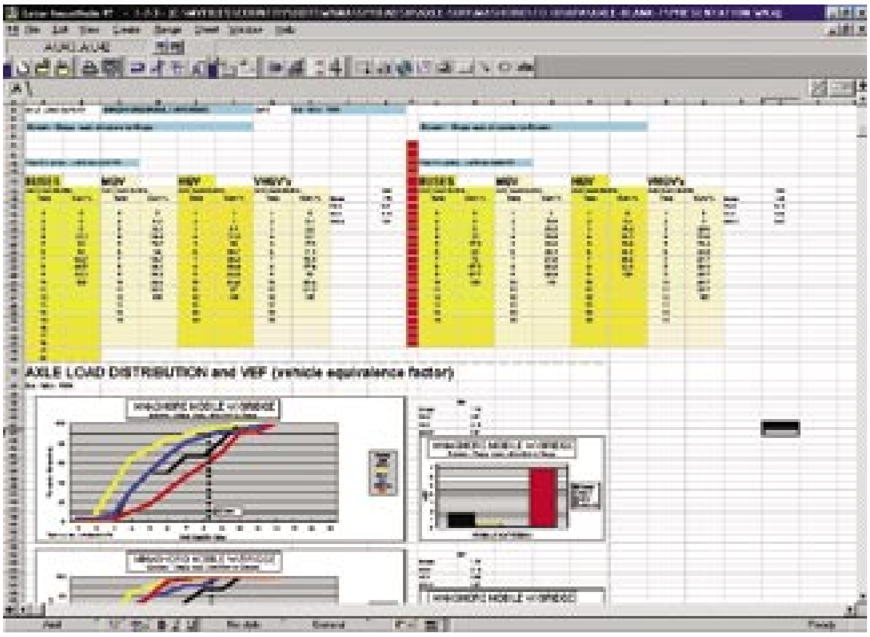
The last step is the graphical presentation of the axle load survey. Open file presentation. The file consists of data entry tables from where the graphs are made automatically. The top of the spreadsheet contains the table entries and the bottom part of the spreadsheet contains the graphs for each direction.

The data entry (cumulative %) is obtained from the file axle distrib. % (Data sheet for Axle load Distribution). The VEF (vehicle equivalence factor) is obtained from the MAIN SUMMARY sheet.

The following procedure shall be followed to activate the automatic graphical presentation of the axle load survey:

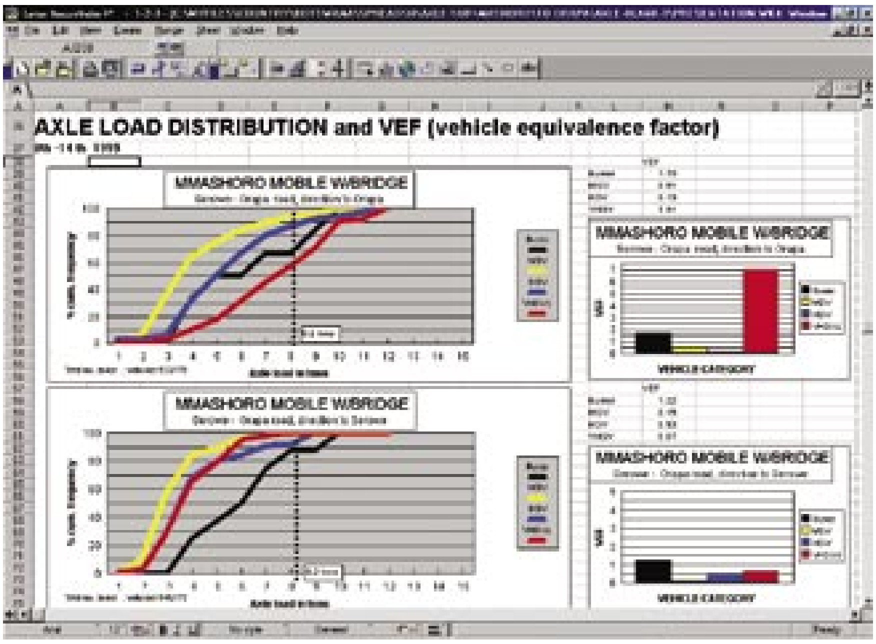
- Enter the headings which consist of: Weigh bridge location (cell C 4), Dates (cell H 4), Road and Directions to (cell A 6 and L 6).
- Enter the total number of axles and vehicles (cell A 10 and L 10).
- On right hand side of each of the data entering tables for cumulative % axle distribution columns (VHGV's) there is a column for VEF (Vehicle Equivalence Factor) which has to be entered (cells J 14..17 and cell U 14..17).
- Enter the cumulative % for the four vehicle axle categories in the following cells:

BUSES	B 16..35 and M 16..35
MGV	D 16..35 and O 16..35
HGV	F 16..35 and Q 16..35
VHGV's	H 16..35 and S 16..35



Step 5 Printing of Graphical presentation

The graphs are now ready for printing. Appendices 7 J-K shows zoom picture of the spread sheet, and Appendix L shows the final graphical presentation print-out.



Step 6 Preparing axle load survey report

The data and findings from axle load surveys plays an important role in road planning, road design and maintenance strategy. Hence, it is important that those data is presented in an appropriate reporting format.

Axle load survey reports should be distributed to all divisions in Roads Department, as its findings may be an important tool in the planning, design and maintance of roads.

REFERENCES.

1. **Ramontsho, S. Keganne, M and Overby, C. 1996.** Axle load Surveys Report, Roads Department, Botswana.

2. **Pinard, M. and Kgoboko, K. 1990.** Issues associated with the choice of vehicle load limits in southern Africa. Proc. TRL - Regional Road Course, Gaborone, Botswana.

3. **Norwegian Road Research Laboratory (NRRL) Publication no 62, March 1992**. Effects of Tire Pressures on Flexible Pavement Structures - A literature survey.

4. **Department of Transport. Roads and Transport Technology, CSIR. South Africa. April 1997.** The damaging effect of overloaded heavy vehicles on roads.

5. **Frank. R. M. 1996.** How overloading destroy our roads. First National Road Conference, Roads Department, Botswana.

6. **Overby, C. Obika, B. and Motswagole, K. 1996.** Improved road network management strategies through pavement performance monitoring. Innovative Engineering in National Development Planning Conference, Gaborone, botswana.

7. **Overby, C and Ramonthso, S. 1997.** "Overloaded vehicles, is that a problem for the durability of the Botswana road network?". Botswana Association of Engineers, Annual Meeting.

8. **Van Wijk, A. J. and Sadzik, E. South Africa 1996.** Use of axle load information in pavement management systems.

9. **Draft TMH 3, June 1988.** South Africa. Traffic axle load surveys for pavement design.

10. **TRL, Road Note 40. UK 1978.** A guide to the measurements of axle loads in developing countries using a portable weigh bridge.

11. **HAENNI Mobile weigh bridge**. Operating instructions. Wheel Load Scale WL 101.

12. **HAENNI Mobile weigh bridge.** Operating instructions. Wheel Load Scale WL 200.

13. **NPRA, Publication nr. 75 November 1994** (in Norwegian). Sluttrapport for erstatningsområdet "Bedre utnyttelse av vegens bæreevne.

APPENDICES

Appendix 7 A

STATION: ______________________

IRECTION: ______________________

RD / NPRA INSTITUTIONAL COOPERATION

PAVEMENT MONITORING PROGRAMME

AXLE LOAD SURVEY

DATE	O / D	BUSES	AXLE CONFIG.	LOAD (tons)	AXLE NUMBER 1	2	3	4	5	6	7	8	9	10	11	12
	O			Wheelload												
				Axleload												
	D			ESAs												
	O			Wheelload												
				Axleload												
	D			ESAs												
	O			Wheelload												
				Axleload												
	D			ESAs												
	O			Wheelload												
				Axleload												
	D			ESAs												
	O			Wheelload												
				Axleload												
	D			ESAs												
	O			Wheelload												
				Axleload												
	D			ESAs												
	O			Wheelload												
				Axleload												
	D			ESAs												
	O			Wheelload												
				Axleload												
	D			ESAs												
	O			Wheelload												
				Axleload												
	D			ESAs												
	O			Wheelload												
				Axleload												
	D			ESAs												

Appendix 7 B

STATION: Mmashoro
DIRECTION: Orapa

RD / NPRA INSTITUTIONAL COOPERATION
PAVEMENT MONITORING PROGRAMME
AXLE LOAD SURVEY

DATE	O / D	BUSES	AXLE CONFIG.	LOAD (tons)	AXLE NUMBER 1	2	3	4	5	6	7	8	9	10	11	12
09/07/99 06:00	O Joburg D Orapa		1.22-22-22	Wheelload												
				Axleload	7000	10000	9000	10000	10000	10000	10000					
				ESAs												
06:03	O Joburg D Orapa		1.22-22-22	Wheelload												
				Axleload	7000	9000	10000	10000	10000	10000	10000					
				ESAs												
06:05	O Gaborone D Orapa		1.22-222-222	Wheelload												
				Axleload	6400	9000	8600	10000	10000	9000	9000	8400	10000			
				ESAs												
06:15	O Joburg D Orapa		1.22-22	Wheelload												
				Axleload	6800	7200	5800	8600	7800							
				ESAs												
06:20	O Joburg D Orapa		1.22-222	Wheelload												
				Axleload	5800	5800	5800	10000	10000	10200						
				ESAs												
06:30	O Gaborone D Letlhakane		1.22-222+22.22	Wheelload												
				Axleload	8600	10000	9800	10000	6000	7000	5000	6000	6000			
				ESAs												
06:45	O Palapye D Orapa	✓	1.2	Wheelload												
				Axleload	7800	6850										
				ESAs												
06:50	O Gaborone D Orapa		1.2-2	Wheelload												
				Axleload	5600	4850	6400									
				ESAs												
09:54	O Serowe D Orapa		1.1	Wheelload												
				Axleload	3200	5800										
				ESAs												
10:30	O Serowe D Letlhakane		1.1	Wheelload												
				Axleload	3000	3800										
				ESAs												

Appendix 7 C

sheet 1

STATION: MMASHORO

Roads Department

DIRECTION TO: ORAPA

AXLE LOAD SURVEY

AXLE CONFIG: 1.22-22-22

DATE	GROSS WEIGHT (tons)	CUM. ESAs (80kN)	LOAD kilograms	AXLE NUMBER 1	2	3	4	5	6	7	8	9	10	11	12
08-07-99	63.80		Axleload	6000	9600	9000	10000	10000	9800	9400					
		13.15	ESAs	0.25	2.09	1.56	2.52	2.52	2.30	1.90	0.00	0.00	0.00	0.00	0.00
09-07-99	66.00		Axleload	7000	10000	9000	10000	10000	10000	10000					
		14.67	ESAs	0.50	2.52	1.56	2.52	2.52	2.52	2.52	0.00	0.00	0.00	0.00	0.00
	66.00		Axleload	7000	9000	10000	10000	10000	10000	10000					
11-07-99		14.67	ESAs	0.50	1.56	2.52	2.52	2.52	2.52	2.52	0.00	0.00	0.00	0.00	0.00
	64.20		Axleload	6800	9400	8000	10000	10000	10000	10000					
		13.34	ESAs	0.44	1.90	0.91	2.52	2.52	2.52	2.52	0.00	0.00	0.00	0.00	0.00
12-07-99	71.00		Axleload	6600	9200	8600	11600	11400	11800	11800					
		23.62	ESAs	0.38	1.73	1.27	4.96	4.58	5.36	5.36	0.00	0.00	0.00	0.00	0.00
	64.40		Axleload	6800	7600	7600	9600	11600	11600	9600					
		15.98	ESAs	0.44	0.72	0.72	2.09	4.96	4.96	2.09	0.00	0.00	0.00	0.00	0.00
	75.20		Axleload	7800	11000	9200	11800	11800	11800	11800					
		27.86	ESAs	0.81	3.89	1.73	5.36	5.36	5.36	5.36	0.00	0.00	0.00	0.00	0.00
	63.70		Axleload	6700	9100	9100	10500	10200	9500	8600					
		12.47	ESAs	0.41	1.64	1.64	3.15	2.76	2.00	1.27	0.00	0.00	0.00	0.00	0.00
	0.00		Axleload												
		0.00	ESAs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	0.00		Axleload												
		0.00	ESAs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	0.00		Axleload												
		0.00	ESAs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	0.00		Axleload												
		0.00	ESAs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	0.00		Axleload												
		0.00	ESAs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	0.00		Axleload												
		0.00	ESAs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	0.00		Axleload												
		0.00	ESAs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	0.00		Axleload												
		0.00	ESAs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	0.00		Axleload												
		0.00	ESAs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	0.00		Axleload												
		0.00	ESAs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	0.00		Axleload												
		0.00	ESAs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	0.00		Axleload												
		0.00	ESAs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MEAN	48.57	12.38													

NOTE, MEAN VALUE ONLY APPLICABLE WHEN ALL COLUMNS FOR MEAN CALC. ARE FILLED IN. OTHERWISE, FORMULA MUST BE CORRECTED.

Appendix 7 D

Roads Department

SUMMARY, AXLE LOAD SURVEY

PLACE:	MMASHORO
	SEROWE - ORAPA ROAD
DIRECTION TO:	ORAPA
DATE:	08 - 14TH JULY 1999

AXLE CONFIG. *VHGV-SEM*	AVG. GROSS WEIGHT (tons)	VEHICLE EQUIV. FACTOR (80 kN) VHGV's	TOTAL No. OF VEHICLES
1.2-11	0.000	0.000	0
1.2-222-111	0.000	0.000	0
1.2-22	24.267	1.622	3
1.2-222	0.000	0.000	0
1.2-11-2	0.000	0.000	0
1.2-2-2	0.000	0.000	0
1.12-222	0.000	0.000	0
1.2_22_21	0.000	0.000	0
PART AVERAGE	**24.267**	**1.622**	**3**

1.2-22-22	0.000	0.000	0
1.22-1.2	0.000	0.000	0
1.22-111	0.000	0.000	0
1.22-22	34.578	3.719	9
1.22-222	45.200	6.677	15
1.2-111-111	0.000	0.000	0
1.2-222-111	0.000	0.000	0
1.22-111-111	0.000	0.000	0
PART AVERAGE	**41.217**	**5.568**	**24**

1.22-22-21	0.000	0.000	0
1.22-22-22	48.573	12.379	11
1.22-122-21	0.000	0.000	0
122-22-222	0.000	0.000	0
1.22-222-22	0.000	0.000	0
1.22-222-111	0.000	0.000	0
1.22-222-222	83.667	19.115	3
Other config.	32.200	0.997	1
PART AVERAGE	**54.500**	**12.968**	**15**

AVERAGE	**44.75**	**7.93**	**42**

Appendix 7 E

Roads Department

SUMMARY AXLE LOAD SURVEY

PLACE: **MMASHORO**

SEROWE - ORAPA ROAD

DIRECTION TO: **ORAPA**

DATE: **08 - 14TH JULY 1999**

VEHICLE CATEGORY	AVG. GROSS WEIGHT (tons)	AVG. VEHICLE EQUIV. FACTOR (80 kN)	TOTAL No. OF VEHICLES
Buses	13.133	1.701	3
MGV	9.088	0.512	99
HGV	17.549	1.861	22
VHGV-SEMI	44.750	7.929	42
VHGV-TR	6.900	0.058	2
VHGV-ST	31.345	4.739	11
SUM			55
Avg. of all VHGV's	40.693	7.005	
		TOTAL	179

Appendix 7 F

Roads Department

Data sheet for Axle load Distribution

Place: MMASHORO Direction: ORAPA
Date: 08-14TH JULY 1999

Tons	No. of axles Buses	auto calc. Cum %	No. of axles MGV	auto calc. Cum %	No. of axles HGV	auto calc. Cum %	No. of axles VHGV	auto calc. Sum
1	0	0.0	0	0.0	2	3.0	0	0.0
2	0	0.0	12	6.2	0	3.0	1	0.3
3	0	0.0	58	36.1	2	6.1	7	2.2
4	2	33.3	55	64.4	17	31.8	26	9.5
5	1	50.0	20	74.7	12	50.0	29	17.6
6	0	50.0	18	84.0	11	66.7	48	31.1
7	1	66.7	9	88.7	9	80.3	50	45.1
8	0	66.7	11	94.3	4	86.4	44	57.4
9	1	83.3	3	95.9	4	92.4	45	70.0
10	1	100.0	7	99.5	1	93.9	72	90.2
11		100.0	0	99.5	2	97.0	6	91.9
12		100.0	1	100.0	2	100.0	29	100.0
13		100.0		100.0		100.0		100.0
14		100.0		100.0		100.0		100.0
15		100.0		100.0		100.0		100.0
16		100.0		100.0		100.0		100.0
17		100.0		100.0		100.0		100.0
18		100.0		100.0		100.0		100.0
19		100.0		100.0		100.0		100.0
20		100.0		100.0		100.0		100.0
Total	6		194		66		357	

Data sheet for Axle load Distribution

Place: MMASHORO Direction: SEROWE
Date: 08-14TH JULY 1999

Tons	No. of axles Buses	auto calc. Cum %	No. of axles MGV	auto calc. Cum %	No. of axles HGV	auto calc. Cum %	No. of axles VHGV	auto calc. Sum
1	0	0.0	0	0.0	0	0.0	0	0.0
2	0	0.0	19	10.6	2	3.2	12	3.0
3	0	0.0	86	58.3	17	30.2	105	29.6
4	2	25.0	47	84.4	24	68.3	142	65.6
5	1	37.5	8	88.9	7	79.4	54	79.2
6	1	50.0	13	96.1	3	84.1	62	94.9
7	2	75.0	3	97.8	4	90.5	11	97.7
8	1	87.5	2	98.9	1	92.1	7	99.5
9	0	87.5	1	99.4	5	100.0	1	99.7
10	1	100.0	1	100.0		100.0	0	99.7
11		100.0		100.0		100.0	0	99.7
12		100.0		100.0		100.0	1	100.0
13		100.0		100.0		100.0		100.0
14		100.0		100.0		100.0		100.0
15		100.0		100.0		100.0		100.0
16		100.0		100.0		100.0		100.0
17		100.0		100.0		100.0		100.0
18		100.0		100.0		100.0		100.0
19		100.0		100.0		100.0		100.0
20		100.0		100.0		100.0		100.0
Total	8		180		63		395	

Appendix 7 G

Roads Department

Data sheet to calculate Overloaded Axles

WEIGH BRIDGE STATION: MMASHORO MOBILE

ROAD SECTION: SEROWE - ORAPA

Direction: ORAPA

Date: 08-14TH JULY 1999

Number of all axles		Axles > 8.2 tons	% overloaded	Axles > 10.0 tons	% overloaded
Buses	6	2		1	
MGV	194	17		5	
HGV	66	11		5	
VHGV's	357	158		71	
TOTAL	623 (Auto calc.)	188 (Auto calc.)	30,2 (Auto calc.)	82 (Auto calc.)	13,2 (Auto calc.)

Direction: SEROWE

Date: 08-14TH JULY 1999

Number of all axles		Axles > 8.2 tons	% overloaded	Axles > 10.0 tons	% overloaded
Buses	8	2		1	
MGV	180	3		1	
HGV	63	4		0	
VHGV's	395	6		1	
TOTAL	646 (Auto calc.)	15 (Auto calc.)	2,3 (Auto calc.)	3 (Auto calc.)	0,5 (Auto calc.)

Appendix 7 H

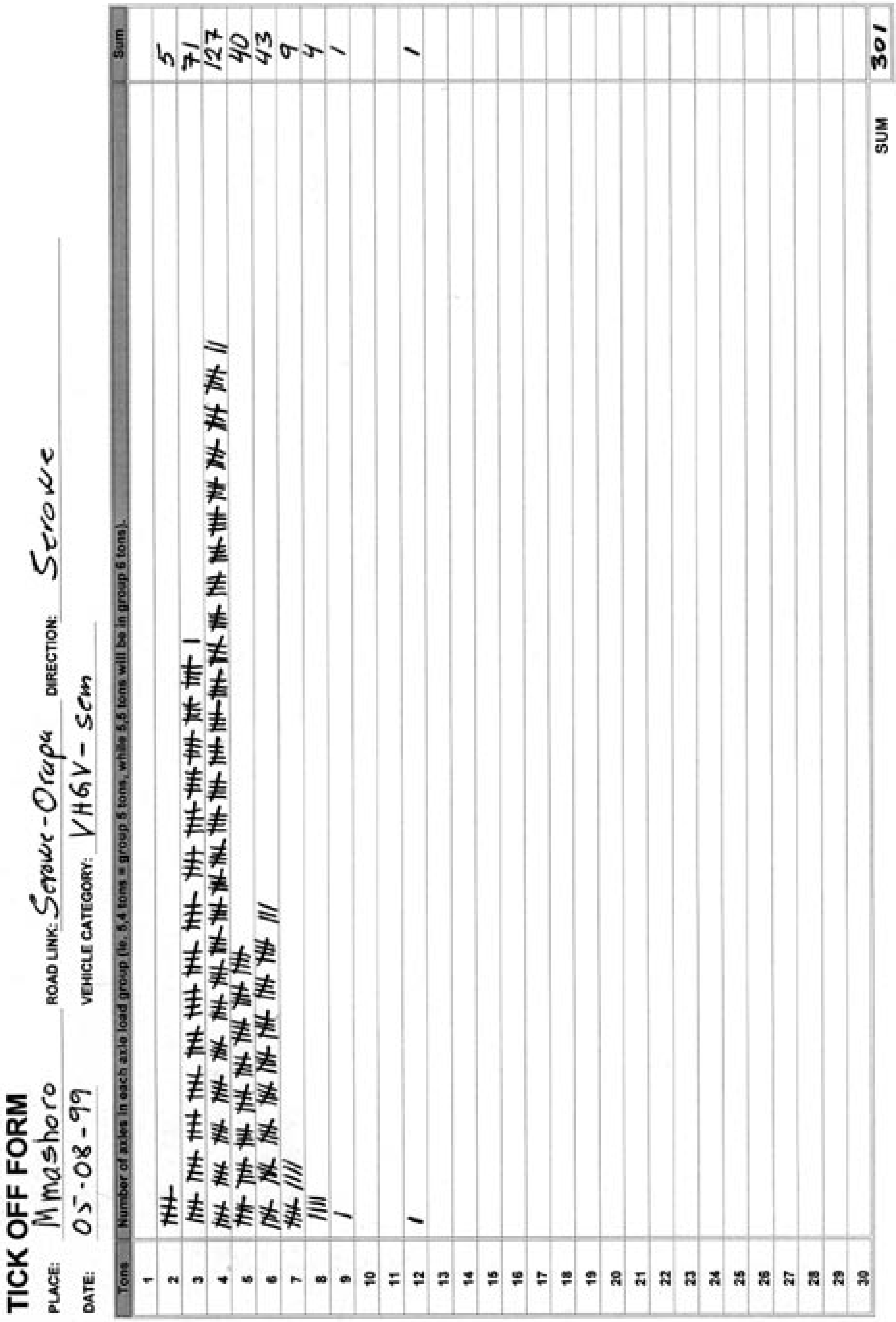
TICK OFF FORM

PLACE: ______________ ROAD LINK: ______________ DIRECTION: ______________

DATE: ______________ VEHICLE CATEGORY: ______________

Tons	Number of axles in each axle load group (ie. 5,4 tons = group 5 tons, while 5,5 tons will be in group 6 tons).	Sum
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
17		
18		
19		
20		
21		
22		
23		
24		
25		
26		
27		
28		
29		
30		
	SUM	

Appendix 7 I



TICK OFF FORM

PLACE: Mmashoro ROAD LINK: Serowe-Orapa DIRECTION: Serowe

DATE: 05-08-99 VEHICLE CATEGORY: VHGV - Scm

Tons	Number of axles in each axle load group (ie. 5,4 tons = group 5 tons, while 5,5 tons will be in group 6 tons).	Sum
1		
2		5
3		71
4		127
5		40
6		43
7		9
8		4
9		1
10		
11		
12		1
13		
14		
15		
16		
17		
18		
19		
20		
21		
22		
23		
24		
25		
26		
27		
28		
29		
30		
	SUM	301

Appendix 7 J

Roads Department

AXLE LOAD SURVEY **MMASHORO MOBILE W/BRIDGE** DATE **8th -14 th 1999**

Serowe - Orapa road, direction to Orapa

Total no. axles , vehicles 623/179

BUSES Axle load distrib. Tons	Cum %	MGV Axle load distrib. Tons	Cum %	HGV Axle load distrib. Tons	Cum %	VHGV's Axle load distrib. Tons	Cum %
1	0	1	0	1	3	1	0
2	0	2	6.2	2	3	2	0.3
3	0	3	36.1	3	6.1	3	2.2
4	33.3	4	64.4	4	31.8	4	9.5
5	50	5	74.7	5	50	5	17.6
6	50	6	84	6	66.7	6	31.1
7	66.7	7	88.7	7	80.3	7	45.1
8	66.7	8	94.3	8	86.4	8	57.4
9	83.3	9	95.9	9	92.4	9	70
10	100	10	99.5	10	93.9	10	90.2
11		11	99.5	11	97	11	91.9
12		12	100	12	100	12	100
13		13		13		13	
14		14		14		14	
15		15		15		15	
16							
17							
18							
19							
20							

	VEF
Buses	1.70
MGV	0.51
HGV	0.19
VHGV	7.01

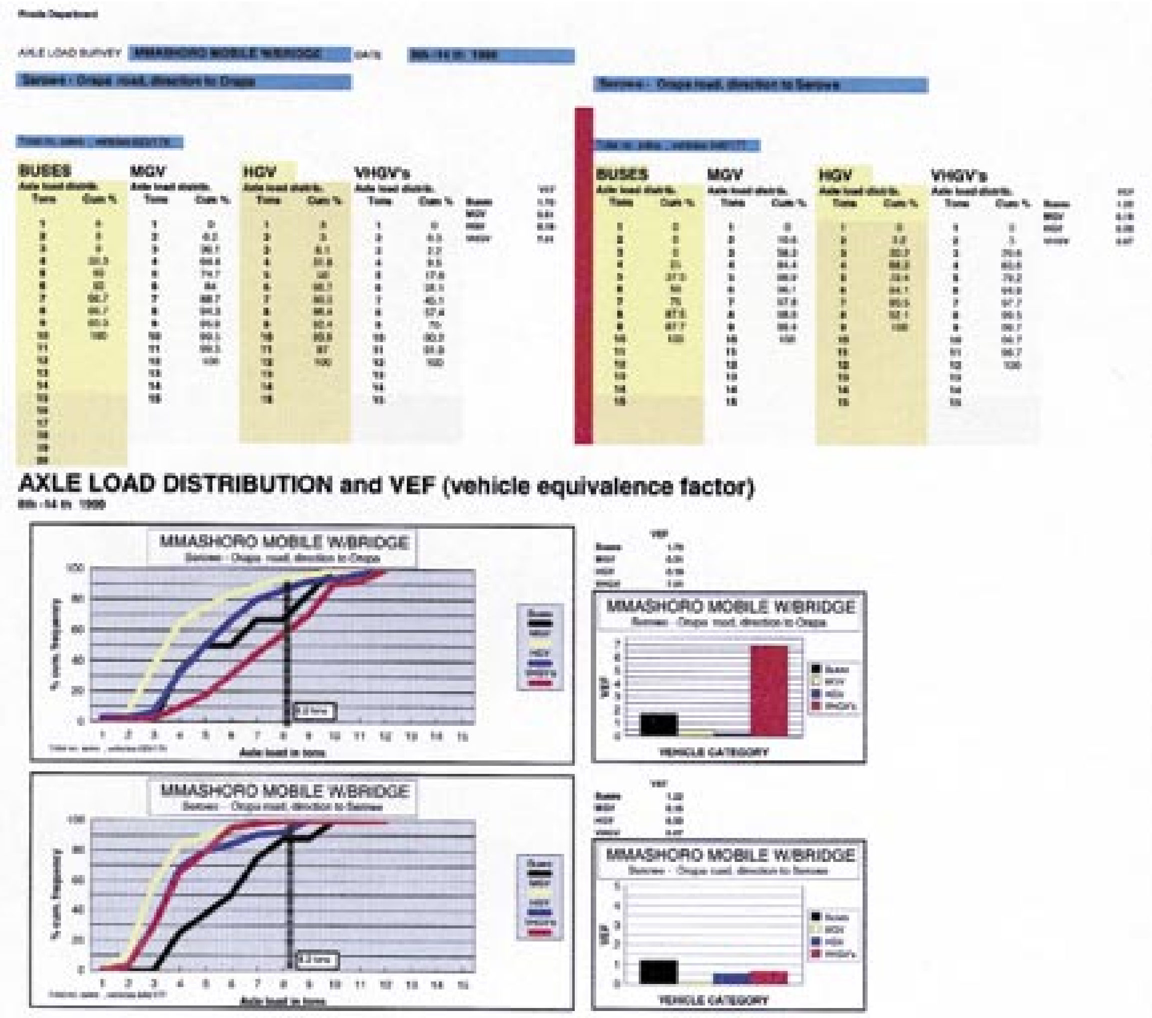
Serowe - Orapa road, direction to Serowe

Total no. axles , vehicles 646/177

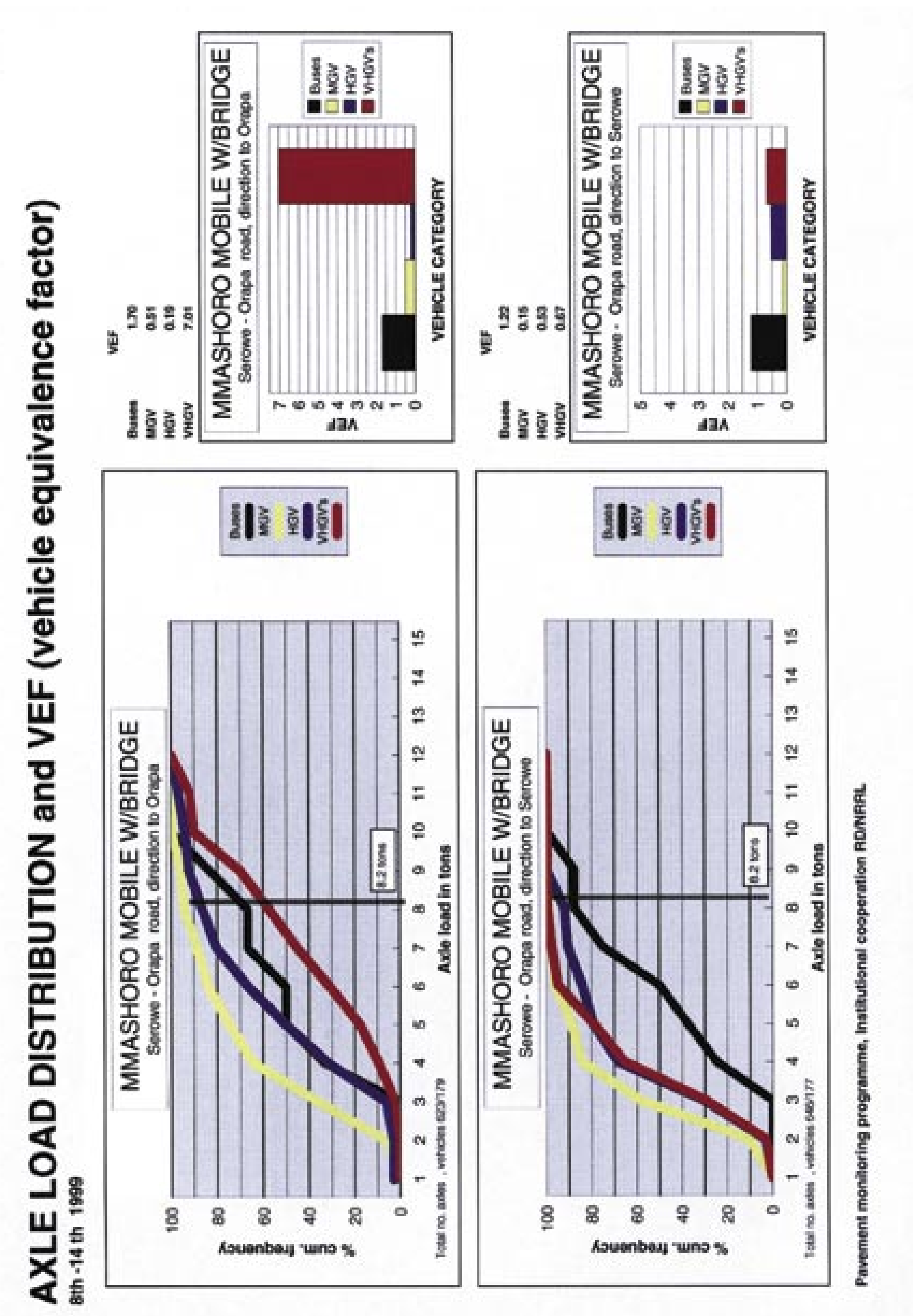
BUSES Axle load distrib. Tons	Cum %	MGV Axle load distrib. Tons	Cum %	HGV Axle load distrib. Tons	Cum %	VHGV's Axle load distrib. Tons	Cum %
1	0	1	0	1	0	1	0
2	0	2	10.6	2	3.2	2	3
3	0	3	58.3	3	30.2	3	29.6
4	25	4	84.4	4	68.3	4	65.6
5	37.5	5	88.9	5	79.4	5	79.2
6	50	6	96.1	6	84.1	6	94.9
7	75	7	97.8	7	90.5	7	97.7
8	87.5	8	98.9	8	92.1	8	99.5
9	87.7	9	99.4	9	100	9	99.7
10	100	10	100	10		10	99.7
11		11		11		11	99.7
12		12		12		12	100
13		13		13		13	
14		14		14		14	
15		15		15		15	

	VEF
Buses	1.22
MGV	0.15
HGV	0.53
VHGV	0.67

Appendix 7 K


AXLE LOAD SURVEY
BUSES
MGV
HGV
VHGV's
AXLE LOAD DISTRIBUTION and VEF (vehicle equivalence factor)
MMASHORO MOBILE W/BRIDGE
Axle load in tons
VEHICLE CATEGORY
MMASHORO MOBILE W/BRIDGE
Axle load in tons
VEHICLE CATEGORY

Appendix 7 L


AXLE LOAD DISTRIBUTION and VEF (vehicle equivalence factor)
8th -14 th 1999
MMASHORO MOBILE W/BRIDGE
Serowe - Orapa road, direction to Orapa
% cum. frequency
8.2 tons
Axle load in tons
Buses
MGV
HGV
VHGV's
MMASHORO MOBILE W/BRIDGE
Serowe - Orapa road, direction to Serowe
% cum. frequency
8.2 tons
Axle load in tons
Buses
MGV
HGV
VHGV's
MMASHORO MOBILE W/BRIDGE
Serowe - Orapa road, direction to Orapa
VEF
VEHICLE CATEGORY
MMASHORO MOBILE W/BRIDGE
Serowe - Orapa road, direction to Serowe
VEF
VEHICLE CATEGORY
Pavement monitoring programme, Institutional cooperation RD/NRRL

Appendix M

ABBREVIATIONS

AADT	Annual Average Daily Traffic
AASHO	Former name of AASHTO (American Association of State Highway and Transportation Officials).
HGV	Heavy Goods Vehicle
kN	Kilo Newton
kPa	kilo Pascal
LEF	Load Equivalence factor
MGV	Medium Goods Vehicle
NORAD	Norwegian Agency for Development Cooperation
NPRA	Norwegian Public Roads Administration
O/D	Origin and Destination survey
PHN	Public Highway Network
TO	Technical officer
VEF	Vehicle Equivalency Factor
VHGV	Very Heavy Goods vehicle
WIM	Weigh-in-Motion