TMH 8

Traffic and Axle Load Monitoring Procedures

Version 1.0
Oct 2014

Committee of Transport Officials
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Committee of Transport Officials
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**Synopsis:**

Traffic monitoring is aimed at the measurement and collection of traffic and vehicle characteristics such as traffic counts, operating speeds and wheel loads. These characteristics are mainly intended for use in the management, planning and design of road networks.

This document describes a range of aspects associated with traffic monitoring, such as the establishment of traffic monitoring programmes, methods for collecting traffic data, processing of the data, as well as typical applications of the data.

**Withdrawal of previous publication:**

This publication replaces the previous “TMH8 Verkeerstelling procedures vir Buitestedelike Paaie” which was published in 1987. This previous publication is effectively withdrawn with the publication of this document.
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Appendix A: Estimation of static load distributions
Appendix B: Traffic pattern tests
Definitions

Traffic volume

**ADT**: Average Daily Traffic (veh/day). The average volume of traffic per day passing a point along a road over a period other than one year.

**AADT**: Annual Average Daily Traffic (veh/day). The average volume of traffic per day passing a point along a road over period of one calendar year. The AADT can either be obtained from an annual traffic count or estimated from a short-term count.

**15th Highest hour flow on normal days**: The flow rate which is only exceeded during 14 hours on normal days of the year.

**30th Highest hour flow (all days)**: The flow rate which is only exceeded during 29 hours on all days of the year.

Normal, abnormal and exceptional days

**Normal traffic days**: These are days of the year that are not public and school holidays (or other days on which traffic is influenced by such holidays).

**Abnormal days**: These are days of the year that are public or school holidays (as well as other days on which traffic is influenced by such holidays).

**Exceptional days**: These are days of the year on which traffic patterns differ significantly from those on other days. Exceptional days may include both normal and abnormal days.

Traffic and axle load monitoring

**Traffic monitoring**: The process of monitoring traffic-flow (count) characteristics (but not axle loads).

**Traffic and axle load monitoring**: The process of monitoring traffic-flow characteristics, as well as axle loads by means of a Weigh-in-Motion (WIM) device.

**Axle load monitoring**: The process of monitoring vehicle loads by means of a Weigh-in-Motion (WIM) device.

**Short-term monitoring**: Monitoring over a period shorter than one year.

**Long-term monitoring**: Monitoring over a period of one year or longer (normally calendar years). Also known as continuous monitoring.

**Permanent counting stations**: Counting stations used as part of a system-level monitoring programme.

**Secondary counting stations**: Counting stations used as part of a network-level monitoring programme. Also known as coverage counting stations.
Monitoring levels

**System-level monitoring**: Monitoring that is undertaken with the purpose of collecting traffic data for the determination of expansion factors. Such factors are used for expanding short-term traffic observations to equivalent annual traffic characteristics.

**Network-level monitoring**: Monitoring that is undertaken with the purpose of identifying and prioritising road maintenance, rehabilitation and improvement projects.

**Project-level monitoring**: Monitoring is undertaken to collect data required for the planning and design of a road and associated facilities.

Axle load monitoring

**Weigh-In-Motion (WIM)**: Process of measuring the loads of a moving vehicle.

**High-speed WIM (HS WIM)**: The process of measuring loads of vehicles that are travelling at normal speeds on a road. The loads include dynamic forces resulting from the vehicle motion.

**Low-speed WIM (LS WIM)**: The process of measuring static loads of vehicles that are travelling at low speed (typically lower than 15 km/h), usually outside the normal traffic flow. The speeds are so low that the dynamic forces are considered to be negligible.

**Axle sensor or detector**: A device that measures the presence of a wheel and/or axle.

**Single/dual tyre sensor or detector**: A device that determines whether a wheel is fitted with a single tyre or with dual tyres.

**Wheel load sensor**: A device which measures the wheel load of a vehicle.

**Axle load sensor**: A device which simultaneously measures the combined wheel load for all wheels and tyres on an axle.

**Weighbridge**: A weighing device which measures the weight or static load of stationary vehicles with a very high level of accuracy suitable for legal purposes.

Mass and load

According to the International System of Units (SI), forces and weights should be expressed in N or kN while masses must be expressed in kg and Mg (ton). In terms of these specifications, however, all loads and forces must be converted and expressed in terms of equivalent mass units (kg). The conversion must be undertaken with the standard value for gravitational acceleration.

**Gravitational acceleration**: The acceleration caused by gravity. For the purposes of these specifications, the standard value of 9.80665 m/s² must be used.

**Mass**: Mass is a measure of the amount of material in an object measured in units of kg (kilogram). Can be estimated by dividing the weight or static load (in units of N) of the object by the gravitational acceleration (in units of m/s²).

**Load**: The load exercised by a moving or stationary vehicle. Consists of static and dynamic load components. Converted to equivalent mass units of kg by dividing the load measured in units of N by the gravitational acceleration (in units of m/s²). 

**Weight**: The gravitational force acting on a body mass. Equivalent to the static load exercised by a stationary vehicle.

**Static load**: Load exercised by a stationary vehicle. Equivalent to the weight of a vehicle.

**Static load component**: The static load component of the total load exercised by a moving vehicle.

**Dynamic load component**: The non-static component of the total load exercised by a moving vehicle.

**Statistics**

**Mean (arithmetic), average**: First moment of a probability distribution (for the population or a sample).

**Standard deviation**: Positive square root of the variance.

**Variance**: Second central moment of a probability distribution (for the population or a sample).

**Confidence Interval**: A \( \alpha \)th percentile confidence interval is defined as an interval that will include the true population parameters in a proportion \( \alpha \) of samples if a very large number of samples would repeatedly be taken. The level of confidence \( \alpha \) is usually taken as 95%.
Traffic monitoring and axle load is the process of measuring and collecting various traffic and vehicle characteristics such as traffic counts and axle loads. These characteristics are mainly intended for use in the engineering management, planning and design of road networks and infrastructure.

This document describes various aspects of traffic monitoring, such as the establishment of traffic monitoring programmes, methods for collecting traffic data, processing of the data, as well as typical applications of the data.
1 INTRODUCTION

Traffic and axle load monitoring is the process of measuring and collecting traffic characteristics such as counts, speeds and axle loads. All types of traffic may be monitored, including motorised as well as non-motorised traffic.

This document serves as a uniform reference for road authorities and engineers involved with the management, planning and design of roads in South Africa. Guidance is provided for a wide range of aspects, including the establishment of traffic monitoring programmes, methods for collecting traffic data, processing of the data, as well as typical applications of the data.

The scope of the document is limited to the monitoring that is generally undertaken for the purposes of obtaining traffic counts and axle load distributions. The scope excludes other types of data, such as operating speeds, origin-destination studies, home or roadside interviews and vehicle occupancy studies. Specialised guidelines must be consulted for guidance on such studies.

1.1 Background

Traffic and axle load monitoring is the process of measuring and collecting various traffic characteristics such as traffic counts and axle loads. All types of traffic may be monitored, including motorised traffic as well as non-motorised traffic. Motorised traffic consists of both light and heavy vehicles as well as public transport vehicles, while non-motorised traffic typically consists of pedestrians, cyclists and animal-drawn vehicles.

The traffic and axle load characteristics are mainly intended for use in the engineering management, planning and design of road networks and infrastructure. Road authorities and engineers involved with road networks have long recognised the critical importance of traffic data as part of their decision-making processes. Without such data, it is not possible to make objective decisions, and this could lead to erroneous conclusions with significant cost implications.

This document serves as a uniform reference for road authorities and engineers involved with the management, planning and design of roads in South Africa. Guidance is provided for a wide range of aspects, including the establishment of traffic monitoring programmes, methods for collecting traffic data, processing of the data, as well as typical applications of the data.
1.2 **Uses of traffic data**

Traffic data are essential for the programming, planning and design of a road system. Specific uses for traffic data include, inter alia, the following:

a) **Management and programming.** Traffic data are required for the identification and prioritisation of road maintenance, rehabilitation and upgrading projects, including the allocation of funding to such projects. Such projects may be required for purposes such as the rehabilitation of road pavements, improvements to the capacity of a road and to address road safety issues.

b) **Traffic engineering** applications, such as traffic impact assessments of proposed land development on the road and transportation network, traffic signal design (traffic signal plans, phasing and timings) and capacity (congestion) analysis.

c) **Safety** analysis and modelling of roads, including the identification of hazardous locations.

d) **Noise and vehicle emission** analysis and modelling, as well as the evaluation of alternative mitigating measures.

e) **Geometric design** of roads, including the road alignment, road width and the provision of passing and climbing lanes.

f) **Pavement** analysis and design, including strength requirements.

g) **Economic analysis** (project evaluation) of alternatives and proposed road improvements.

1.3 **Scope of document**

The scope of this document is limited to the monitoring that is generally undertaken for the engineering management, planning and design of a road network. The data covered by the document includes the following:

- Traffic-flow data including data such as traffic volumes, vehicle composition, etc.
- Axle load data monitored by means of Weigh-in-Motion (WIM) systems.

The scope excludes other types of data, such as operating speeds, origin-destination studies, home or road-side interviews, vehicle-occupancy studies. Specialised guidelines must be consulted for guidance on such studies.

The document covers rural as well as urban roads. Most of the procedures described in this document can be applied to both types of roads, but information is provided where it is necessary to differentiate between the two types of roads.
1.4 Terminology

Some of the terminology used in this document may not be familiar to users of the document and a list of definitions is therefore provided at the start of the document. Brief explanations of the meaning and use of the different terms within a traffic monitoring programme are provided.

The terms “traffic monitoring” and “axle load monitoring” are particularly important. Traffic monitoring is the process of monitoring traffic-flow (count) characteristics (but not axle loads) while axle load monitoring is the process of monitoring axle loads by means of Weigh-in-Motion (WIM) devices.
2 OVERVIEW OF A MONITORING PROGRAMME

The intention of this chapter is to provide an overview of the different elements that are involved in the development of a traffic monitoring programme. A summarised overview of the different chapters of the document is provided.

2.1 Introduction

An overview is provided in this chapter of the different elements that are involved in the development of a traffic monitoring programme. The purpose of the chapter is to provide a summarised overview of the document and to highlight the more important aspects involved in the development of a traffic monitoring programme. Reference is provided to the different chapters in this document.

2.2 Traffic monitoring levels

One of the first aspects that must be addressed when a traffic monitoring programme is development is to establish the purpose for which the traffic monitoring is required. This involves developing a list of applications of traffic data that are required by a road authority, as well as a list of data items required by such applications.

The applications and purpose for which traffic data are typically collected in South Africa are discussed in Chapter 3 of this document. There are generally three main levels at which traffic data are collected:

- Monitoring system-level data.
- Network-level data.
- Project-level data.

Monitoring system-level data are required to establish expansion factors that are used to expand short-term traffic counts to equivalent annual traffic volumes. An example of such expansion is to expand a short 12-hour or 7-day count to an AADT (Annual Average Daily Traffic). System-level monitoring is undertaken at locations that are representative of the different traffic patterns on a road network.

Network-level data are collected by road authorities for the purpose of identifying and prioritising road projects (including funding allocation to projects). Such projects may involve the maintenance and rehabilitation of the road pavement or road geometry improvement. A lower level of accuracy is usually required at the network level.

Project-level data are collected for use in specific planning and design projects for roads and related infrastructure. This data are collected at a higher level of accuracy than required for network-level data.
2.3 Traffic monitoring technologies

Various technologies that are available for use in traffic observations are described in Chapter 4. All monitoring technologies have certain limitations that must be taken into account in the development of a traffic monitoring programme.

In South Africa, the TMH 3 Specifications for the Provision of Traffic and Weigh-in-Motion Monitoring Service (COTO 2014) document is available that can be used for the specification of traffic and WIM monitoring services by service providers. These specifications allow the use of any technology or system, provided that the system complies with the minimum functional requirements of the specifications. It is therefore only necessary to specify the type of monitoring that is required as well as the required accuracy, but not the specific technology when undertaking traffic monitoring.

2.4 Traffic variability

It is not cost effective to undertake permanent 24-hour, 365 day monitoring on all roads in the country, and use must therefore be made of short-term monitoring. Such short-term monitoring is usually undertaken over a period of between 12 hours and 7 days. Monitoring over such short durations, however, is subject to significant traffic variability which could affect the accuracy of the monitoring. This could result in a serious under- or overestimate of the actual traffic volumes on a road (unless provision is made for such variation).

The variation in traffic must therefore be taken into account when developing a short-term traffic monitoring programme. A discussion of the impact of traffic variability on accuracy is provided in Chapter 5, and methods are discussed that are aimed at minimising the impact of such variation.

2.5 Normal, abnormal and exceptional days

Short-term traffic counts in South Africa are mostly undertaken on so-called “normal days”. Traffic patterns in the country are significantly affected by school and public holidays which increase the variability of traffic when counts are undertaken on such days. Undertaking traffic counts on normal days can significantly reduce such variability, and thus the period over which counts must be taken (e.g. sample size requirements).

Definitions of normal, abnormal and exceptional days are provided in Chapter 6 of this document. Short-term observations undertaken on abnormal and exceptional days should be excluded from traffic expansion calculations.
2.6 System-level traffic monitoring

Guidelines are provided in Chapter 7 for establishing a system-level traffic monitoring programme by a road authority. This programme is required when it is necessarily to determine expansion factors for the expansion of short-term counts. Various stratification systems that can be used for deriving such expansion factors are discussed in the chapter.

2.7 Network-level traffic monitoring

In Chapter 8, guidelines are provided for road authorities for the establishment of network-level traffic monitoring programmes. Network-level data are collected for the purposes of identifying and prioritising road maintenance, rehabilitation and improvement projects. This application of traffic data requires access to some methodology or software that can be used for the identification and prioritisation. The data should only be collected when it will be actively used by a road authority for the purposes of project identification and prioritisation.

2.8 Project-level traffic monitoring

Guidelines are provided in Chapter 9 for the undertaking of project-level traffic monitoring. Such monitoring is undertaken when traffic data are required for use in specific engineering projects. The data are collected on an ad-hoc basis as and when required. Short-term observations made for this purpose may be expanded using expansion factors obtained from the system-level monitoring.

2.9 Expansion factors for traffic counts

Chapter 10 provides information on the application and derivation of expansion factors for traffic counts. Various formulae are provided for purposes such as estimating the AADT, vehicle composition and design hour traffic.

2.10 Annual Average Daily Traffic

Traffic volume is one of the most fundamental parameters required in the analysis and design of roads. Chapter 11 provides a discussion of the annual average daily traffic (AADT) and other related characteristics. Methods are provided for the derivation of the characteristics from traffic observations.
2.11 Annual hourly flow distributions

The distribution of hourly traffic flows is also an important parameter in the design of roads and other transportation facilities. For this purpose, it is necessary to identify hours of the year for which a road must be designed and then to obtain traffic characteristics for these hours. The design hours that are typically used in South Africa are discussed in Chapter 12 and methods are provided for estimating the traffic characteristics for these hours from traffic observations.

2.12 Axle load observations

Axle loading is an important parameter in various road planning and design applications. Such applications are not only limited to the design of road pavements, but may also include economic analysis and the development of road safety programmes.

Axle load monitoring is discussed in Chapter 13 of this document. Although this monitoring is described as a separate topic in the chapter, it is important to recognise that axle load monitoring must be integrated with other types of traffic monitoring. Axle load data cannot be used in isolation and must be combined with other data, such as traffic volumes, vehicle composition, etc.

2.13 Vehicle classification

Vehicle classification is an important consideration in traffic monitoring. Many applications require estimates of traffic volumes for different vehicle classes. For example, heavy vehicle volume is a particularly important traffic characteristic in the design of road pavements. Other important classifications include public transport vehicles (e.g. buses) and non-motorised transport. Various classification systems are described in Chapter 14.

2.14 Non-motorised traffic

Non-motorised traffic typically includes pedestrians, cyclists and animal-drawn vehicles. This type of traffic is usually monitored by means of manual observations, although automatic equipment is available that can be used for this purpose.

Some basic guidance on the monitoring of non-motorised traffic is provided in Chapter 15. One of the major issues with non-motorised monitoring is that such monitoring is mostly undertaken by means of short-term counts because of the difficulty and cost involved in undertaking long-term counts. It is therefore not always possible to develop expansion factors for the estimation of annual non-motorised traffic volumes from short-term counts. Currently, no methods are available for the establishment of such expansion factors.
2.15 Data verification

The verification of traffic data is a very important element of a traffic monitoring programme. Data that contain major errors could have serious consequences in the planning and design of roads. Road authorities should therefore ensure that data verification should form an important part of a traffic monitoring programme. Details of data verification tests that can be undertaken are provided in Chapter 16 of this document.

2.16 RSA Data format

Chapter 17 provides an overview of the data format that should be used in South Africa for the transfer of data between different road authorities and other organisations. This is particularly important when automatic monitoring is undertaken due to the large volumes of data that can be collected.

2.17 Traffic data summaries

A very important element of a traffic monitoring programme is the production of data summaries after the collection of data. Recommendations are provided in Chapter 18 for the summaries that should be made available. The summaries may be produced in the form of a traffic monitoring data book that is published annually by a road authority, or can be made available electronically in a suitable format.
3 TRAFFIC MONITORING LEVELS

One of the first aspects that must be investigated during the development of a traffic monitoring programme is the purpose for which the monitoring is required. This involves developing a list of applications for which traffic data are required, as well as the data items that must be collected during the programme.

The applications and purpose for which traffic data are typically collected in South Africa are discussed in this chapter. There are generally three main levels at which traffic data are required:

- Monitoring system-level data.
- Network-level data.
- Project-level data.

Monitoring system-level data are collected with the purpose of establishing expansion factors that are used for expanding traffic counts undertaken at short-term counting stations.

Network-level data are collected by a road authority with the purpose of identifying and prioritising road maintenance, rehabilitation and improvement (upgrading) projects. Such data are usually collected at a lower level of accuracy than data required at a project level.

Project-level data are collected for the planning and design of specific road projects. Data are collected at a relatively high level of accuracy.

3.1 Introduction

One of the first aspects that must be investigated during the development of a traffic monitoring programme for a road authority is the purpose for which the traffic monitoring is required. This involves developing a list of applications of traffic data that are required by the road authority, as well as a list of data items that must be collected as part of the traffic monitoring programme.

The applications and purpose for which traffic data are typically collected in South Africa are discussed in this chapter. There are generally three main levels at which traffic data are required:

- Monitoring system-level data.
- Network-level data.
- Project-level data.

More detail about these three levels is provided in the following sections.
3.2 Monitoring system-level data

Most traffic data that are required on network and project levels are collected by means of short-term monitoring. It is not cost effective to undertake permanent or continuous monitoring on all the roads of a network, and short-term monitoring must therefore be used. Data collected during the short-term monitoring is expanded by means of expansion factors derived from system-level monitoring.

Monitoring system-level data are thus collected at a relatively small number of permanent counting stations for the derivation of the expansion factors. These factors are then applied to traffic counts collected by means of short-term monitoring at other counting stations. The expansion factors are used to convert a short-term traffic count to an equivalent annual traffic characteristic.

It is important to note that monitoring system-level data are only collected with the purpose of establishing expansion factors. The data could also coincidently be used for network- and project-level applications, but such use should not be taken into account when planning a system-level monitoring programme.

3.3 Network-level data

Network-level data are collected by road authorities for the purpose of identifying and prioritising road projects. Such data are firstly used to identify roads that may require maintenance or rehabilitation or some form of improvement or upgrading, and secondly to prioritise identified road projects. Once such road projects have been identified and prioritised, additional data that are required for project-level investigations may be collected.

The collection of network-level data implies that a road authority has access to some methodology (or software) that can be used for the identification and prioritisation of road projects. It would serve no purpose to collect network-level data if such methodology is not available. Road authorities should therefore only collect data at this level if such a methodology is available and is actively being used by the authority for identification and prioritisation purposes.

Network-level data may also be collected for purposes of obtaining general travel statistics, such as annual vehicle-kilometres of travel. However, the collection of network-level data for the sole purpose of producing such statistics is not cost effective and can therefore not be recommended. Statistics may, however, be produced as a by-product of the data collected for project identification and prioritisation purposes.

The collection of network-level data can be a costly exercise and it is therefore important that the traffic monitoring should only be undertaken at the minimum level of accuracy required by the application methodologies or software. A sensitivity analysis can be undertaken to determine whether any decisions would be affected by the level of accuracy at which data are collected. Where roads could be excluded from the priority list due to inaccuracies introduced by the duration of the observations, observations should be undertaken over longer periods in order to increase the accuracy of the observations.
Network-level data are normally collected for all roads (homogeneous traffic segments) under the jurisdiction of the authority. Such monitoring is normally undertaken by means of short-term observations of a limited duration of either 12 hours (on one day) or 7 days. This monitoring is also regularly repeated (typically every 3 to 5 years) to ensure that the latest traffic information is available for a road. More information on these requirements is provided in Chapter 8 of this document.

3.4 Project-level data

Project-level data are data that are collected for the purposes of the planning and design of specific road projects. This data are collected at a higher level of accuracy than required for network-level data, while additional data may be collected as required by specific planning and design applications.

Data collected on a project-level can be used for several purposes, such as traffic engineering applications, safety analysis and modelling, noise and vehicle emission analysis and modelling, the geometric design of roads, pavement analysis and design, as well as the economic analysis of alternatives.

The data required by the different applications on a project level may vary significantly and are determined by the specific requirements of each application. Project-level data are therefore collected on an ad hoc basis as and when required.

Project-level monitoring is normally undertaken by means of short-term observations. It is, however, important that relatively recent data should be used on a project level. More information on these aspects is provided in Chapter 9 of this document.
4 TRAFFIC MONITORING TECHNOLOGIES

This chapter provides an overview of the technologies that can be used for the monitoring of traffic. The intention is not to provide detailed descriptions of the technologies but to provide some background information on systems that are typically used in South Africa for traffic monitoring purposes.

An important consideration in the evaluation of alternative technologies is that all technologies have certain limitations that must be taken into account when developing a traffic monitoring programme. It is not possible to monitor all possible traffic characteristics, and traffic monitoring programmes are therefore limited to those characteristics that can be readily observed by means of available technologies.

In South Africa, the TMH 3 Specifications for the Provision of Traffic and Weigh-in-Motion Monitoring Service (COTO 2014) is available that can be used for the specification of traffic and WIM monitoring services by service providers. These specifications are of a functional nature and no differentiation is made between specific technologies. Any technology can therefore be used, provided that it complies with the functional requirements of the specifications.

4.1 Introduction

An overview of traffic monitoring technologies is provided in this chapter. The intention of this overview is not to provide detailed descriptions of the available technologies that can be used for traffic monitoring but only to provide some background information on the systems that are typically used in South Africa for traffic monitoring purposes.

An important consideration in the evaluation of alternative technologies is that all technologies have certain limitations that must be taken into account when developing a traffic monitoring programme. It is not possible to monitor all possible traffic characteristics, and traffic monitoring programmes are therefore limited to those characteristics that can be readily observed by means of available technologies.

4.2 Automatic monitoring

This section provides an overview of a number of technologies that are available for traffic monitoring. These technologies have evolved very quickly in the recent past due to the availability of low-cost computing and communication technology.

It is important to recognise that different monitoring systems are not necessarily of equal quality. Even within the same technology, equipment performance can vary widely between different monitoring systems, depending on factors such as the components and internal software that are used in the systems. It is therefore important that equipment
must be tested and certified to ensure that the equipment complies with the functional requirements of TMH 3 (COTO 2014) as discussed in the next section of this chapter.

Automatic monitoring equipment includes technologies such as the following (FHWA, 2013):

- Inductive Loop Detectors. These detectors are capable of detecting the presence and passage of vehicles. The loops consist of one or more turns of wire embedded in or placed on the surface of the pavement.
- Magnetic Sensors or Detectors. These sensors detect the presence of ferrous metal objects through the perturbation it causes in the Earth's magnetic field.
- Laser Radar Sensors. These sensors transmit energy in the near infrared spectrum.
- Microwave Radar Sensors. These sensors transmit electromagnetic energy from an antenna towards vehicles. The traffic reflects a portion of the transmitted energy back towards the antenna. This reflected energy is used to derive traffic data.
- Microwave Doppler. This equipment allows vehicle speeds to be measured using the Doppler principle. The frequency of the received signal increases as a vehicle moves towards the equipment and decreases when moving away. Only moving vehicles are detected.
- Ultrasonic Sensors. These sensors transmit pressure waves of sound energy at a frequency above the human audible range.
- Passive Infrared Sensors. These sensors transmit no energy of their own and detect energy from two sources: a) energy emitted from vehicles, road surfaces, and other objects in their field of view, and b) energy emitted by the atmosphere and reflected by vehicles, road surfaces, or other objects into the sensor aperture.
- Passive Acoustic Array Sensors. These sensors measure vehicle passage, presence, and speed by detecting the acoustic energy or audible sounds produced by vehicular traffic.
- Video Detection Systems. These systems use video technology and software that is able to interpret the recorded images of vehicles.

Automatic systems are classified as intrusive and non-intrusive. Intrusive detectors are those that must be embedded or placed on the road pavement, while non-intrusive detectors are those that are placed outside the traffic stream. The main disadvantage of intrusive detectors is the disruption of traffic that is required for the installation or maintenance of the equipment. This is particularly an issue on roads that carry large volumes of traffic at high speeds (e.g. freeways). On such roads, it may be preferable to use non-intrusive detectors, provided that they can provide the required data at the prescribed accuracies. At the time of writing of this document, such detectors were, however, either not readily available, or very costly compared to other detectors.
4.3 TMH 3 Specifications

In South Africa, the following document is available that provides a functional specification for the provision of traffic and WIM monitoring services by service providers.


The specifications provided in the document are of a generic nature and no differentiation is made between specific technologies. Any technology can therefore be used, provided that it complies with the functional requirements of the specifications. These include, inter alia, requirements such as detection capabilities (capabilities of detecting certain traffic characteristics) and accuracy requirements.

The above specifications also provide for the certification of monitoring systems (as well as service providers) by an independent certification organisation. Provided that a monitoring system is certified by such an organisation, any technology can be used for the collection of traffic data.

4.4 Monitoring system types and accuracy classes

The TMH 3 specifications for traffic monitoring systems differentiate between four types of automatic monitoring systems (types A to D) and between two accuracy levels (1 and 2). The following systems can be specified:

a) **Type A** traffic monitoring systems provide for vehicle, axle, single/dual tyre and speed detection. These systems allow for measurements of characteristics such as traffic volumes, number of axles, axle spacing, tyre configuration (single or dual) and speeds. Differentiation is made between the following two accuracy classes:

   i) **Type A1** systems with the highest levels of detection and vehicle classification accuracy.

   ii) **Type A2** systems with relatively high levels of detection and vehicle classification (categorisation) accuracy.

   The main difference between Type A and the other systems is the provision for **single/dual tyre detection**. This information can be used to differentiate between light and heavy vehicles which significantly improves the vehicle classification accuracy of these systems. The cost of the systems, however, is relatively high and the systems are therefore only used when a high level of vehicle classification is required (e.g. for research purposes or for critical projects where a high level of accuracy is required).

b) **Type B** traffic monitoring systems with vehicle, axle and speed detection but without single/dual tyre detection. This system allows for the measurement of characteristics such as traffic volumes, number of axles, axle spacing and speeds, but not tyre configuration. Differentiation is made between the following two accuracy classes:

   i) **Type B1** systems with the highest level of detection and a relatively high level of vehicle classification accuracy.
ii) Type B2 systems with a relatively high level of detection and a medium to high level of vehicle classification accuracy.

The main difference between Type B and Type C/D systems is the provision for axle detection in the Type B systems. The information on the number of axles and axle spacing is used to provide a higher level of vehicle classification accuracy compared to the other systems. For example, in Type B systems it is possible to identify vehicle classes such as single-unit and articulated trucks (which is not possible in the Type C or D systems). These systems may be used when there is need for a more detailed vehicle classification.

c) Type C traffic monitoring systems with vehicle and speed detection but without axle and single/dual tyre detection. This system allows for the measurement of characteristics such as traffic volumes, vehicle lengths and speeds but not of number of axles, axle spacing and tyre configuration. Differentiation is made between the following two accuracy classes:

i) Type C1 systems with a relatively high level of vehicle detection and a medium to low level of vehicle classification accuracy, and where axle data are not required.

ii) Type C2 systems with a medium level of vehicle detection and a relatively low level of vehicle classification accuracy, and where axle data are not required.

Type C systems provide for speed measurements which allow vehicle length measurements. These systems can be used to identify light and heavy vehicles and to differentiate between different lengths of heavy vehicles (i.e. short, medium and long). The vehicle classification system is relatively simple, but adequate for many engineering applications. These systems are the most cost-effective available when a lower level of vehicle classification accuracy is acceptable.

d) Type D traffic monitoring systems without speed, axle and single/dual tyre detection. This is the most basic of the traffic monitoring systems. The systems only provide for traffic counts and not for the measurement of characteristics such as speeds, number of axles, axle spacing and tyre configurations. Differentiation is made between the following two accuracy classes:

i) Type D1 systems with a medium level of detection accuracy and either no vehicle classification, or a low level of vehicle classification accuracy.

ii) Type D2 systems with a relative low level of detection accuracy and either no vehicle classification, or a low level of vehicle classification accuracy.

Type D systems provide the most cost-effective method for undertaking traffic counts. The limitation of the systems is that they cannot be used for the classification of vehicles. These systems should therefore only be used when there is only a need for traffic counts but not for vehicle classification.
4.5 Recommended monitoring systems

The following systems are generally recommended for use in traffic, as well as axle load monitoring programmes:

a) **System-level monitoring.** Type C1 systems are generally recommended for system-level monitoring. These systems provide for a relatively high level of vehicle detection and can be used to classify vehicles as light and heavy, differentiating between short, medium and long heavy vehicles. Type B2 systems may, however, be used in critical situations where a higher level of vehicle classification accuracy is required.

b) **Network-level monitoring.** The following systems are generally recommended for network-level monitoring:

i) Medium to high volume roads. Type C1 systems are recommended for medium to high volume roads where a relatively high level of accuracy is required.

ii) Low volume roads. Type C2 systems are recommended for low volume roads where a lower level of accuracy is acceptable (alternatively, manual monitoring may also be undertaken on such roads).

iii) Traffic generators. In situations where traffic monitoring is required for the purpose of identifying homogeneous traffic sections, type D1 systems may be used to identify the locations of major traffic generators on the road network. Such traffic monitoring would typically be undertaken on side roads at intersections or interchanges on the road network.

c) **Project-level monitoring.** Either Type C1 or Type B2 systems may be used for project-level monitoring. Type C1 systems are used when a simpler vehicle classification system is acceptable, while Type B2 systems should be used when a more detailed classification system is required. Type A2 systems may be considered when a high level of vehicle classification accuracy is required.

d) **Axle load monitoring.** Type B2 systems are generally recommended when axle load monitoring is undertaken.

4.6 Manual monitoring

The TMH 3 specifications (COTO 2014) only provide for automatic monitoring of traffic and not for manual monitoring methods. This, however, does not mean that manual methods should not be used. There are applications for which the manual methods are more suitable and cost effective than automatic methods.

Manual counting methods are often used for purposes such as the following:

- Short-term traffic counts for periods shorter than one week (typically 12 hours).
- Vehicle classification counts where automatic equipment is unable to differentiate between specific vehicle classes, such as public transport and non-motorised traffic. This includes cases where equipment is available but the cost of such equipment is very high.
Quality control

A major issue with manual counts is the quality control of counts (particularly intersection counts). It is difficult to introduce quality control measures, with the result that the quality of manual counts is not often controlled. Typical issues that are found with manual counts include the following:

- Wrong recording of turning or travel movements and/or vehicle classes.
- Missing of vehicles, particularly when traffic volumes are high.

Manual counts should only be used where automatic counts are not possible or too costly, and where quality control measures can be introduced. When manual counts are undertaken, it is important that technology should be used which is aimed at improving the quality of such counts.

Manual counting technologies

The following are a number of technologies that can be used in manual counts:

- Mechanical manual counters (clickers) used with clipboards.
- Electronic manual counters in which the passage of each vehicle is recorded.
- Video recorders that are used to record the traffic stream (with time and date stamps). The count is then manually undertaken from the recording but software could also be available for this purpose (when available).

The recommended technology is the use of video recordings. Such recordings have the advantage that a record is available that can be used for quality control purposes.

Where video recordings are not possible, preference should be given to the use of electronic manual counters. Such counters can be used to record data for each passing vehicle, which not only provides additional data but also data which can be used for quality control purposes.

Due to problems with quality control, the use of mechanical counters is generally not recommended and their use should be discouraged by road authorities unless high levels of quality control measures can be introduced. Mechanical counters should only be used when the cost of electronic counters or video recorders are excessive or not practical.

Link and intersection counts

Manual counts can be undertaken on road links between intersections or at intersections, depending on the application. The turning or travel directions should be recorded, while some level of vehicle classification may be required.

The undertaking of link and intersection counts is generally straightforward and relatively simple. Roundabouts, however, impose significant difficulties because of the need to track vehicles through the roundabouts. Roundabout counts can be undertaken using number plate recordings or by means of road-side interviews on the approaches to the roundabout. Such surveys, however, are difficult and costly to undertake. An alternative is to count the total approach volume and to estimate the turning movements by means of sample counts of individual vehicle movements through the roundabout.
Traffic and Axle Load Monitoring Procedures

Traffic counting sheets

Examples of traffic counting sheets are given in Figures 4.1 and 4.2 for link and intersection counts, respectively. These sheets are provided for illustrative purposes only, and they should be adjusted for specific circumstances.

The sheets provide for the capturing of, inter alia, the following information:

- Location of the count.
- Date as well as the day of the week.
- Weather conditions on the day of the count.
- Supervisor and personnel names.
- Layout sketch (with north direction arrow).
- Counts per 15-minute interval per turning movement or travel direction.

The link counts can also provide for classified counts. The sheet in Figure 4.1 provides for light vehicles, heavy vehicles, buses and minibuses. At intersections, it is also possible to undertake classified counts, for example, light and heavy vehicles. Classified counts at intersections can be recorded using additional rows on the count sheet.
## Traffic and Axle Load Monitoring Procedures

### 12-Hour Link Count Sheet

<table>
<thead>
<tr>
<th>City/Region:</th>
<th>Suburb/Area:</th>
<th>Road/Street:</th>
<th>Location:</th>
<th>Direction 1:</th>
<th>Direction 2:</th>
<th>Date/Day of week:</th>
<th>Weather:</th>
<th>Count Supervisor:</th>
<th>Count Personnel:</th>
<th>Link layout and travel directions</th>
</tr>
</thead>
</table>

#### Cumulative Counts

<table>
<thead>
<tr>
<th>Start Time</th>
<th>Direction 1</th>
<th>Direction 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Light</td>
<td>Heavy</td>
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<tr>
<td>06:00</td>
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<td></td>
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<td>06:15</td>
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</tbody>
</table>

#### Figure 4.1: Traffic count sheet for links (12 h Counts)
## 12-Hour Intersection Count Sheet

<table>
<thead>
<tr>
<th>Start Time</th>
<th>North Appr</th>
<th>West Appr</th>
<th>South Appr</th>
<th>East Appr</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LT</td>
<td>ST</td>
<td>RT</td>
<td>LT</td>
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Figure 4.2: Traffic count sheet for intersections (12 h Counts)
5 TRAFFIC VARIABILITY

Variability in traffic is an important consideration in the development of traffic monitoring. It is not cost effective to undertake all traffic monitoring by means of long-term monitoring and use must therefore be made of a combination of long-term and short-term monitoring. Short-term monitoring, however, is subject to significant variability which will reduce the accuracy of such monitoring. This chapter describes methods aimed at reducing the impact of traffic variability on the accuracy of traffic counts.

5.1 Introduction

Variability of traffic is an important consideration in the development of traffic monitoring programmes. It is not cost effective to undertake all traffic monitoring by means of long-term monitoring and use must therefore made of a combination of long-term monitoring (at permanent counting stations) and short-term monitoring (at secondary counting stations). Short-term monitoring, however, is subject to significant traffic variability which will reduce the accuracy of such monitoring. Although the accuracy is reduced, methods can be used that are aimed at reducing the impact of traffic variability and increasing the accuracy of traffic counts.

5.2 Short-term traffic variability

Short-term traffic counts are undertaken over periods of much shorter than one year, and typically over one to seven days of the year. Use is then made of expansion factors to estimate annual traffic characteristics. Because these annual traffic characteristics are estimated from a short-term count, the characteristics are not expected to be perfectly accurate.

The loss of accuracy resulting from short-term monitoring is caused by the variability in traffic over time. For example, short-term monitoring could result in either an under- or overestimation of traffic volumes on a road, depending on whether the traffic flow was low or high during the period the traffic was counted. Expansion factors are used to account for some, but not all of this under- or overestimation.

Research in South Africa (Papenfus and Van As, 2014) has indicated that while some of the variation is random in nature, some of the variations can be explained by a number of factors. These factors are the following:

• Variation over different hours of the day. Such variation must be taken into account when monitoring for a period shorter than the 24 hours of a day.
• Variation over different days of the week. This variation must be taken into account when monitoring is undertaken over a period shorter than seven days.
• Variation resulting from public and school holidays. This is a major cause of variation in traffic volumes in the country. Traffic volumes during holidays can be significantly lower or higher than during days other than holidays.
• Traffic growth over the year resulting in a monthly increase (or decrease) in traffic.
• Seasonal variation over the year resulting in variation in traffic over the different months of the year.

The impact of public and school holidays is one of the most important considerations in South Africa. The concepts of normal and abnormal days have therefore been developed in order to account for this impact. Abnormal days include holidays as well as other days of the year which are affected by holidays. Normal days exclude such days. Short-term counts in the country are normally only undertaken on normal days.

5.3 Time-of-day variability

Time-of-day variability is the variability in traffic that occurs over the different hours of a day. When traffic monitoring is undertaken over durations shorter than 24 hours of the day (e.g. 12 hours between 06:00 and 18:00), expansion factors must be applied if the observations must be expanded to a 24-hour (daily) flow.

Figures 5.1(a) and 5.1(b) show the variability in the 12/24-hour count ratio (12-hour count expressed as a proportion of the daily 24-hour count) for the total traffic stream, and for heavy vehicles, respectively, at a specific counting station. This variation is shown in the figures by means of cumulative frequency distributions. Only normal day traffic counts were used for the derivation of the distributions. The figures also differentiate between the five days of the week (Mondays to Fridays).

The figures are typical of the variability found at most counting stations. Generally, it is found that there is some variability in the 12/24-hour count ratio at a counting station, but that this variation is generally relatively small.

There is also variation in the 12/24 hour count ratios between different counting stations as shown in Figures 5.2(a) and 5.2(b). These figures show the distribution of average 12/24 hour count ratios (for normal days) for a large range of counting stations. For the total stream, generally 0.8 of the total traffic stream travels during the 12-hour period, but there are some roads on which this proportion is either lower or higher. Generally, however, the 24-hour total traffic can be estimated with a relatively high level of accuracy from a 12-hour count.

The variation for heavy vehicles between different roads shown in Figure 5.2(b), however, is particularly high. The accuracy of estimating 24-hour daily heavy vehicles traffic volumes from a 12-hour count can therefore not be expected to be high.

Expansion factors that are required for addressing time-of-the-day variation are only required when short-term counts shorter than 24-hours undertaken. Such factors are not required for the expansion of 24-hour counts.
Figure 5.1(a): Example of variation in 12-Hour/24-Hour count ratios – Total traffic

Figure 5.1(b): Example of variation in 12/24-Hour count ratios – Heavy vehicles
Figure 5.2(a): Variation in average 12/24-Hour count ratios – Total traffic

Figure 5.2(b): Variation in average 12/24-Hour count ratios – Heavy vehicles
5.4 Day-of-the-week variability

Day-of-the-week variability is the variation in traffic over the different days of the week. An example of such variation at a particular counting station is shown in Figures 5.3(a) and 5.3(b). These figures show the cumulative frequency distributions of daily flows (expressed as a ratio of the AADT). Figure 5.3(a) is applicable to normal days and 5.3(b) to abnormal days.

The figures show that there can be significant differences in traffic counts between the different days of the week. Traffic volumes on some (but not all) roads tend to be higher on Fridays than on other days of the week. Weekday variation is therefore a significant factor that must be accounted for by means of expansion factors.

Expansion factors that are required for addressing day-of-the-week variation are only required when counts shorter than one week are undertaken. Such expansion is not required for 7-day counts.

5.5 Normal and abnormal day variation

Daily (24-hour) flows can vary over the different days of the year. Examples of such variation are shown in Figures 5.3(a) and 5.3(b) for normal and abnormal days, respectively. The figures show the cumulative frequency distributions of daily flows (expressed as a ratio of the AADT) at a specific counting station.

Figure 5.3(a) shows that the variation in daily flows is relatively small on normal days. This is typical for most roads in South Africa. Figure 5.3(b), however, shows that the variation is relatively large for abnormal days. The figure does show that there are abnormal days on which the traffic is similar to that of normal days, but no methodology is available for identifying such days. The methodology that is used for the identification of normal days (refer to Chapter 6 of this document) is conservative to ensure that most abnormal days are identified.

The examples provided in Figures 5.3(a) and 5.3(b) are from a road which tends to experience an increase in total traffic volumes on abnormal days. There are, however, also many roads where the opposite is experienced.

An investigation by Van As (2014) into the variation of heavy vehicle flows indicated that heavy vehicle volumes on normal days are in most cases slightly higher than on abnormal days (typically less than 7.5% higher). A few roads have, however, been identified where the heavy vehicle flows are slightly lower.

The large variation in traffic volumes during abnormal days means that sample sizes will have to be increased significantly when abnormal days are included in a short-term count. This is the reason why the general practice has been adopted in South Africa to only undertake short-term counts on normal days. It is, however, also important that expansion factors are applied to such normal-day counts in order to account for abnormal days.
Figure 5.3(a): Example of variation in daily traffic – Normal Days

Figure 5.3(b): Example of variation in daily traffic – Abnormal Days
The expansion factors are only needed when it is necessary to convert normal-day counts to equivalent annual flows. The factors are not required when specific peak-hours must be counted (e.g. for purposes such as traffic signal design and traffic impact studies). When such peak-hour counts are required, the following approach is recommended:

• On roads where traffic flows on normal days are higher than abnormal days, the peak-hour counts can be undertaken on normal days. Due to the small variation in traffic volumes on such days, any normal day of the year can be selected but for some land uses it may be preferable to select specific normal days of the year (depending on the trip-generating characteristics of the land uses).

• On roads where traffic flows on abnormal days are higher than normal days (typically roads to holiday destinations), peak-hour counts should be undertaken on abnormal days. Due to the large variation in traffic volumes on such days, specific counting days should be selected during which flows are high. Such a selection must be based on counts obtained from permanent stations.

5.6 Exceptional and extreme variation

Although the variations in traffic volumes are lower during normal days than on abnormal days, it does not mean that "exceptional" variation in traffic cannot also occur on normal days. Such exceptional variation can occur on both normal and abnormal days.

Exceptional variation occurs when there is a very large deviation in traffic volumes from that found on typical normal or abnormal days. Such variation is the result of relatively rare events that may affect traffic counts. The following are examples of such events:

a) Unusual volume increases as a result of activities such as special social gatherings (e.g. music and other festivals), sport games, irregular business activities (e.g. auctions), harvesting, forestry, etc.

b) Unusual volume reductions as a result of incidents such as adverse weather conditions, road closures, road construction, failure of traffic control devices and traffic accidents.

Exceptional variation may also be classified as "extreme" when the variation is due to very rare events. Such events are those that do not occur annually, although they can occur at intervals longer than one year. These events are typically caused by road closures that occur over extended periods of time and where traffic had to be diverted to other roads. Such a diversion can result in either a significant reduction in volumes on the road on which the closure has occurred, or significant increases on roads to which traffic has been diverted. Examples of such events are shown in Figure 5.4.

Traffic observations that are undertaken on days on which such exceptional variation occurs should be excluded from short-term counts, even if such variation occurs on normal days. Such variation must be identified by means of data verification procedures. In situations where exceptional variation is identified, the short-term observations may have to be retaken in order to obtain a complete short-term data set.
Figure 5.4: Examples of exceptional traffic (extreme events)
For long-term observations, days with exceptional variation must also be excluded from the determination of expansion factors. However, for the determination of the annual traffic characteristics such as the AADT, such days must still be taken into account, except when the variation is extreme. Such extreme variation is not typical of the annual variation on a road and must be excluded from the analysis.

5.7 Traffic growth

Traffic growth over a year can result in either an increase or decrease in traffic volumes over the different months of the year. Where such growth occurs, a short-term count at the start of the year could result in an under- or overestimation of the AADT depending on whether the growth is positive or negative.

A limitation of short-term counts is that it is not possible to identify traffic growth over the year. This is only possible if data are available from different periods of the year. Judgement is therefore required to identify roads where such growth occurs. Use must then be made of monthly adjusted factors to account for such growth.

5.8 Seasonal variability

Seasonal variability is the variation in traffic over the different months of a year. Research in South Africa (Papenfus and Van As, 2014) has shown that such variation is not a major factor in the country although there are some roads on which seasonal variation does occur.

The research has shown that the seasonal variation tends to be caused by factors such as the following:

- Light vehicles. Seasonal variation can occur on routes that predominantly carry holiday traffic, and where the holiday traffic is highly seasonal. Examples were found where the traffic during the summer is higher than during the winter but examples were also found where the reverse applies (e.g. due to winter sports or where summer temperatures are very high).

- Heavy vehicles. Seasonal variation may occur on routes on which a large proportion of the freight that is being transported is of a seasonal nature. Examples of such freight include agricultural produce and coal.

A limitation of short-term counts is that it is not possible to identify seasonal variation from short-term counts. The variation can only be identified when data are available from different periods of the year. Judgement is therefore required to identify roads where such seasonal variation occurs. Use must then be made of monthly adjusted factors to account for such variation.
6 NORMAL, ABNORMAL AND EXCEPTIONAL DAYS

6.1 Introduction

Short-term traffic counts in South Africa are mostly undertaken on normal days. The variability of counts on abnormal and exceptional days is very high and undertaking counts on such days would significantly increase sample size requirements. A definition of the different types of days are provided in this chapter.

6.2 Definition of normal and abnormal days

Abnormal days are days on which the traffic patterns are affected by school and public holidays. Normal days are days that are not affected by such holidays. Normal and abnormal days can be predicted from public information on holidays in the county.

Abnormal days are defined as the following days of the year (Papenfus and Van As, 2014):

- Public holidays.
- Days influenced by public holidays, as defined in the table below.
- School holidays in any of the provinces of the country, measured for the full duration of the holiday (i.e. from the first to the last day of the holiday) and including the last and first school days before and following the holiday.
- December recess, measured from the last (seven-day) week in November up to the end of the school holidays in January of the following year in any of the provinces and including the first school day following the holiday.
6.3 Exceptional days

Exceptional days are those on which there are a very large deviation in traffic volumes from those found on typical normal or abnormal days. Short-term observations undertaken during such days should be excluded from a traffic count.

Exceptional days cannot be predicted as in the case of abnormal days and must be identified by means of data verification procedures (described in Chapter 16 of this document). In situations where such days have been identified, the short-term observations may have to be retaken in order to obtain a complete short-term data set.
7 SYSTEM-LEVEL TRAFFIC MONITORING

This chapter provides guidelines for establishing a system-level traffic monitoring programme by a road authority. The main purpose of such a programme is to establish expansion factors for the expansion of network- and project-level data.

7.1 Introduction

Guidelines are provided in this chapter for establishing a system-level traffic monitoring programme by a road authority. Monitoring programmes required for the collection of network and project-level data are described in the following chapters.

The main purpose of the system-level monitoring programme is the establishment of expansion factors for the expansion of network- and project-level data. A further purpose of the system-level monitoring programme is to undertake research aimed at the identification of traffic patterns on a road network. Such research should be undertaken as part of the development of a system-level monitoring programme as well as the maintenance of the programme.

7.2 Long-term monitoring

System-level monitoring requires the use of long-term monitoring at permanent counting stations. Such long-term monitoring is required to derive the annual traffic characteristics for which expansion factors are required.

The long-term monitoring should be undertaken over a 365-day calendar year to allow the derivation of expansion factors for a particular year. For practical reasons, provision is made for a grace period in the TMH 3 Specifications for the Provision of Traffic and Weigh-in-Motion Monitoring Service (COTO 2014) to allow monitoring to be started not earlier than 1 November in the previous year and not later than 1 March in the next year.

7.3 Development of a system-level monitoring programme

The development of a system-level counting programme requires considerable knowledge of traffic patterns on the road network. Where network-level traffic data are available from previous counts, such data can be used for the development of the programme. However, where such data are not available, judgement must be exercised in the development of an initial system.

The system-level traffic monitoring should initially focus on research aimed at verifying the assumptions that were made during the initial development of the programme. Provision should be made for adjustments to the programme as more information becomes available.
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It is also important that the system should be continuously monitored and adjusted to accommodate possible changes in traffic patterns on the road network.

7.4 Traffic stratification method

The purpose of the traffic stratification method is to group counting stations into strata with similar traffic patterns. The expansion factors required by short-term stations are then derived from long-term stations within the same stratum. The stratification is undertaken on the basis of certain observed traffic characteristics.

Short-term stations do not have to be located in the same area as the long-term station, but there is some risk that traffic patterns may not be similar when the stations are located far apart. Use should therefore be made of regions, and a stratification system should be developed for each such region.

Several alternative stratification methods were investigated by Papenfus and Van As (2014) and the accuracies of the methods were found to be similar. Based on practical considerations, the following two methods are recommended:

- 12-hour Counts – Trip-purpose stratification method.
- 7-day Counts – Holiday stratification method.

7.5 Trip-purpose stratification method

The trip-purpose method is used for the stratification of 12-hour traffic observations undertaken on normal days. The method is based on the following three strata:

- Rural stratum with traffic patterns typically found on roads serving rural areas. The traffic patterns on these roads typically do not have a morning (AM) peak period.
- Urban-low stratum with traffic patterns typically found on roads serving urban areas but with relatively low peaking during the morning (AM) peak period.
- Urban-high stratum with traffic patterns typically found on roads also serving urban areas but where the peaking is relatively high.

Peaking factor

The differentiation between the above three strata is based on a traffic characteristic called the “peaking factor”. Only the morning peak is taken into account in the analysis, since peaks tend to be more focused during the mornings. Peaks during the afternoon tend to be more spread out.

In order to determine the peaking factor, the hour in which the traffic volume is the highest must first be selected by means of inspection of the hourly traffic pattern. This hour is selected from the period between 06:00 and 12:00 (the first hour starts at 06:00 and the last hour ends at 12:00). There may be situations in which the peak hour occurs before 06:00, but such hours are ignored.

The Peaking Factor $F_{PE}$ is calculated as follows:

$$F_{PE} = \text{AM Peak Hour count as a } \% \text{ of the 12-hour (06:00 to 18:00) count}$$
The same formula for determining the peaking factor is used at short-term and long-term stations, except that at long-term stations the factor is determined for the average traffic patterns for the different days of the week (observed over a year). Only normal days are used in the determination of these average patterns.

Stratification

The stratification for a short-term count is then determined as follows:

- Rural stratum. This stratum is selected when the peak hour is found to occur later than 09:00 in the morning.
- Urban-low stratum. This stratum is selected when the peaking factor $F_{PE}$ is smaller than or equal to the threshold values given below.
- Urban-high stratum. This stratum is selected when the peaking factor $F_{PE}$ is greater than the threshold values given below.

Examples of traffic patterns for the three strata are shown in Figure 7.1. The example for the rural stratum shows that there is no peaking in the traffic during the morning peak. The examples also show that the peaking for the urban-high stratum is higher than that of the urban-low stratum.

The threshold values for differentiation between Urban-low and Urban-high are as follows:

| Peaking factor threshold values for Urban-low and Urban-high |
|-------------------|---|---|---|---|---|
| Mon | Tue | Wed | Thu | Fri |
| 14% | 12% | 12% | 11% | 10% |

Accuracy of method

The research by Papenfus and Van As (2014) has shown that AADTs estimated from 12-hour counts by means of the trip-purpose stratification method will result in the 90% error intervals provided in the following table. In 90% of cases, the method will result in errors in the AADT smaller than those indicated.

| 90% Error Intervals for estimated AADT |
|-------------------|---|---|---|---|---|
| Traffic | Mon count | Tue count | Wed count | Thu count | Fri count |
| Total traffic | ±28% | ±28% | ±26% | ±23% | ±16% |
| Heavy veh | ±50% | ±37% | ±35% | ±34% | ±37% |

The above evaluation indicates that 12-hour counts do not provide very accurate estimates of the AADT (as can be expected). The estimates of heavy vehicle volumes are particularly poor as a result of the large variation that occurs in the night-day split in heavy vehicle traffic on different roads in the country (as discussed in Chapter 5). Such counts should therefore only be used for network-level applications, and then only on roads that carry relatively low volumes of traffic.

A slight improvement in accuracy can be obtained by counting over a period of 18 or 24 hours. Such counts, however, have been found to be unpractical and not economically viable due to additional costs, labour issues and additional logistics that are involved. If more accurate counts are required, then 7-day counts should be considered.
Figure 7.1: Examples of traffic patterns for rural, urban-low and urban-high strata
7.6 Holiday traffic stratification method

The holiday traffic method is used for the stratification of 7-day traffic observations. The system is based on the relative amount of abnormal day traffic compared to normal day traffic. The term “holiday” is used to indicate that the abnormal days are established from school and public holidays, as well as days influenced by such holidays.

The method is based on the following five strata:

- **High holiday traffic.** Traffic volumes during abnormal days are significantly higher than those on normal days.
- **Medium holiday traffic.** Traffic volumes during abnormal days are somewhat higher than those on normal days.
- **Low holiday traffic.** Traffic volumes during abnormal days are slightly higher than those on normal days.
- **No holiday traffic.** Traffic volumes during abnormal days are similar to those on normal days.
- **Negative holiday traffic.** Traffic volumes during abnormal days are lower than those on normal days.

**Long-term counting stations**

At long-term counting stations, the stratification is based on the following ratio:

\[
\frac{\text{Normal day ADT}}{\text{AADT}}
\]

In which:

- Normal day ADT = Average normal day daily traffic over a calendar year
- AADT = Average annual daily traffic (all days of the year)

The following thresholds are used for the stratification of long-term stations:

<table>
<thead>
<tr>
<th>Stratum</th>
<th>Normal Day ADT/AADT Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>High holiday traffic</td>
<td>&lt; 0.90</td>
</tr>
<tr>
<td>Medium holiday traffic</td>
<td>0.90 – 0.95</td>
</tr>
<tr>
<td>Low holiday traffic</td>
<td>0.95 – 0.98</td>
</tr>
<tr>
<td>No holiday traffic</td>
<td>0.98 – 1.01</td>
</tr>
<tr>
<td>Negative holiday traffic</td>
<td>&gt; 1.01</td>
</tr>
</tbody>
</table>

**Stratification of 7-day counts at short-term counting stations**

The stratification of 7-day short-term counts is based on the peaking factor \( F_{PE} \), defined previously, as well as the following weekend factor \( F_{WE} \):

\[ F_{WE} = \text{Count from 18:00 on Friday to 06:00 on Monday as a % of the 7-day count} \]
The stratification is based on the following threshold values:

<table>
<thead>
<tr>
<th>Peaking Factors</th>
<th>Traffic characteristic</th>
<th>90% Error Intervals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rural peak</td>
<td>AADT (total traffic)</td>
<td>±7.8%</td>
</tr>
<tr>
<td></td>
<td>AADT (heavy vehicles)</td>
<td>±6.9%</td>
</tr>
<tr>
<td></td>
<td>15th Highest Hour Count</td>
<td>±12%</td>
</tr>
<tr>
<td></td>
<td>30th Highest Hour Count</td>
<td>±22%</td>
</tr>
</tbody>
</table>

Accuracy of method

The research by Papenfus and Van As (2014) has shown that AADTs estimated from 7-day counts by means of the holiday stratification method will result in the following 90% error intervals:

<table>
<thead>
<tr>
<th>Traffic characteristic</th>
<th>90% Error Intervals</th>
</tr>
</thead>
<tbody>
<tr>
<td>AADT (total traffic)</td>
<td>±7.8%</td>
</tr>
<tr>
<td>AADT (heavy vehicles)</td>
<td>±6.9%</td>
</tr>
<tr>
<td>15th Highest Hour Count</td>
<td>±12%</td>
</tr>
<tr>
<td>30th Highest Hour Count</td>
<td>±22%</td>
</tr>
</tbody>
</table>

The table shows that the accuracy of the AADT estimation improves significantly by undertaking traffic counts over a period of seven days. Such counts are therefore recommended for both network- and project-level applications. On a network-level, the counts should be used when a higher level of accuracy is required (such as on medium to high volume roads). On a project level, the counts should be adequate for many applications, but longer counts may be required in critical applications.

The accuracy of a short-term count can be slightly improved by a 14-day count, but this improvement is limited. Accurate counts can only be achieved by means of long-term counts, but such counts are not always possible or economically viable.

7.7 Manual adjustment of traffic strata

The stratification methods described in the previous sections should preferably be used without manual intervention or adjustment. The methods, however, can sometimes produce strata that are clearly erroneous or illogical and which must then be adjusted manually. A method is described below which may be used for such adjustment.

The manual adjustment of the traffic strata must be approached with great care since the selection of inappropriate strata could result in significant traffic estimation errors. The adjustments should only be undertaken by professionals that have a sound knowledge of traffic on the different roads in a network.
The stratification can be checked by plotting the strata on a map similar to the one shown in Figure 7.2. Both short- and long-term counting stations are shown on the map. Each station is plotted with a different colour indicating the stratification of the station. These colours can then be used to compare the strata of traffic stations that are located in the same area or on the same road. Judgement is then used to determine whether any difference in the stratification could be due to actual differences in traffic patterns or due to observation errors.

### 7.8 Homogeneous traffic regions

In situations where a road network is spread over a large area, or where the traffic patterns vary significantly on the road network, consideration should be given to the subdivision of the area into homogeneous traffic regions. A separate stratification system must then be developed for each such traffic region.

Considerable judgement is required for the identification of such regions, particularly in the initial development of the traffic monitoring programme. Initially, a large number of regions may be identified, but the number may later be reduced if it is found that the traffic patterns in some of the regions are the same. Thereafter, additional research monitoring may be required for further refinement of the system. Such monitoring is also required to accommodate possible changes that may occur in traffic patterns over time.
The regions should be selected such that the traffic patterns at all counting stations within a particular stratum in the region are the same. The traffic characteristics that should be checked for similarity are the following (where and when available):

a) Expansion factors for AADT, heavy vehicle traffic, 15th highest hour on normal days and the 30th highest hour on all days.

b) Average normal day traffic/AADT ratio.

c) Average traffic-flow pattern over the different hours of a day for normal days (evaluated using the hourly count as a ratio of the daily count).

d) Average traffic-flow pattern over the seven days of the week for normal days (evaluated using the average daily count per day of the week as a ratio of the average count for the seven days of the week).

15th Highest hour count on normal days only, expressed as a ratio of the average normal day daily traffic.

f) 30th Highest hour count on all days, expressed as a ratio of the AADT.

g) Annual traffic growth, expressed as a percentage growth.

h) Seasonal variability evaluated in terms of monthly distributions of traffic.

### 7.9 Number of long-term counting stations

Expansion factors derived from long-term counts can be expected to vary from counting station to station and it may be necessary to undertake counts at more than one counting station to determine the average expansion factors for each of the traffic strata in a stratification system. Confidence intervals can be used to determine the number of counting stations that are required to provide an acceptable level of accuracy. The number of long-term counting stations must be determined for each stratum in each traffic region in the network.

The variation in expansion factors obtained from the different long-term counting stations was investigated by Papenfus and Van As (2014). This variation was measured in terms of the standard deviation of the expansion factors obtained from different counting stations. These factors were obtained from a very large set of counting stations. The data set is representative of the various roads in the country under the jurisdiction of national and provincial road authorities and includes a selection of both rural and urban roads. The standard deviations can therefore be regarded as approximate population values.

The standard deviations are provided in the two tables below for 12-hour and 7-day counts respectively. The standard deviations are given as percentages of the average expansion factors. The tables also differentiate between the different traffic strata.

The standard deviations provided in the table can be used to determine the confidence interval as a function of the number of counting stations in a stratum. The following formula, which is based on the Normal distribution can be used to determine the 95% confidence interval:

\[
CI = \pm 1.96 \cdot \frac{\sigma}{\sqrt{n}}
\]
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In which:

- CI 95% Confidence interval, as a percentage of the expansion factor
- σ Standard deviation of expansion factors provided in tables
- n Number of counting stations from which expansion factors are derived

Recommended maximum confidence intervals are also provided in the tables below. The recommendations vary depending on the counting duration. These recommendations were used to derive the recommended minimum number of counting stations per stratum as provided in the tables. An absolute minimum of 3 stations was used in the tables for 12-hour counts and 2 stations for 7-day counts.

### Expansion factor confidence intervals for 12-hour counts

<table>
<thead>
<tr>
<th>Vehicle Class</th>
<th>Day of week</th>
<th>Required confidence interval (%)</th>
<th>Standard deviations (%) per stratum</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Rural</td>
</tr>
<tr>
<td>Total</td>
<td>Mon</td>
<td>±15.0%</td>
<td>16.3%</td>
</tr>
<tr>
<td></td>
<td>Tue</td>
<td>±15.0%</td>
<td>13.9%</td>
</tr>
<tr>
<td></td>
<td>Wed</td>
<td>±15.0%</td>
<td>11.6%</td>
</tr>
<tr>
<td></td>
<td>Thu</td>
<td>±15.0%</td>
<td>11.6%</td>
</tr>
<tr>
<td></td>
<td>Fri</td>
<td>±15.0%</td>
<td>8.7%</td>
</tr>
<tr>
<td>Heavy</td>
<td>Mon</td>
<td>±35.0%</td>
<td>36.4%</td>
</tr>
<tr>
<td></td>
<td>Tue</td>
<td>±35.0%</td>
<td>18.4%</td>
</tr>
<tr>
<td></td>
<td>Wed</td>
<td>±35.0%</td>
<td>16.0%</td>
</tr>
<tr>
<td></td>
<td>Thu</td>
<td>±35.0%</td>
<td>17.6%</td>
</tr>
<tr>
<td></td>
<td>Fri</td>
<td>±35.0%</td>
<td>20.4%</td>
</tr>
<tr>
<td>Recommended No of stations per stratum</td>
<td></td>
<td></td>
<td>5</td>
</tr>
</tbody>
</table>

### Expansion factor confidence intervals for 7-day counts

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Vehicle Class</th>
<th>Required CI (%)</th>
<th>Standard Deviations (%) per stratum</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>High</td>
</tr>
<tr>
<td>AADT</td>
<td>Total</td>
<td>5.0%</td>
<td>2.3%</td>
</tr>
<tr>
<td></td>
<td>Heavy</td>
<td>5.0%</td>
<td>2.5%</td>
</tr>
<tr>
<td></td>
<td>Short</td>
<td>10.0%</td>
<td>5.5%</td>
</tr>
<tr>
<td></td>
<td>Med</td>
<td>10.0%</td>
<td>8.9%</td>
</tr>
<tr>
<td></td>
<td>Long</td>
<td>10.0%</td>
<td>0.7%</td>
</tr>
<tr>
<td>15th</td>
<td>Total</td>
<td>7.5%</td>
<td>5.2%</td>
</tr>
<tr>
<td>30th</td>
<td>Total</td>
<td>15.0%</td>
<td>13.4%</td>
</tr>
<tr>
<td>Recommended No of stations per stratum</td>
<td></td>
<td></td>
<td>4</td>
</tr>
</tbody>
</table>
7.10 Long-term counting locations

Long-term monitoring for system-level purposes should be undertaken on roads that are representative of the different traffic strata that may occur in a region. For this purpose, lists of suitable traffic stations at which long-term monitoring may be undertaken should be prepared and locations for the long-term monitoring should be selected from this list.

The stations that are selected for the long-term monitoring should be evenly spread throughout a region and not be randomly selected. Randomly selected stations often tend to be clustered in certain locations of a region, in which case the stations would not be representative of roads throughout the region. However, care must be taken to ensure that stations that have been systematically selected do not have some hidden periodic trait that would compromise the representativeness of the sample. The probability of such a trait is small, but a check should nevertheless be made to prevent such an occurrence.

Traffic volumes at long-term stations should not be too low or too high. Traffic patterns at stations with low traffic volumes could be significantly affected by relatively minor exceptional events. It is therefore generally recommended that long-term counting stations should preferably only be selected from roads with AADTs of 1250 vehicles per day or more (Papenfus and Van As, 2014).

Traffic patterns at stations with high traffic volumes can also be affected by the capacity of a road. Capacity restrictions often result in traffic diverting to other roads during peak periods which could affect traffic patterns on a road. Such capacity restrictions are more likely to occur when the following traffic volumes are exceeded:

- AADT of about 5 000 vehicles per day on two-lane roads (both directions)
- AADT of about 7 500 vehicles per day per lane on multilane roads.

Care should also be taken to ensure that long-term monitoring is not undertaken near to locations where there are capacity restrictions on a road. Such locations include the following:

- Near to intersections with low capacity (particularly 3- or 4-way stopped controlled intersections).
- Two-lane roads with few passing opportunities (this is particularly a problem on two-lane roads in rolling and mountainous areas).

7.11 Long-term counting durations

System-level monitoring is undertaken at permanent counting stations over a period of at least one full calendar year. Traffic data are continuously recorded over all days of the year and the goal is to capture data for the 365 (366 for leap years) days of the year.

On occasion there may be gaps in the data due to equipment failure, construction, road closures, special events, etc. Such gaps can be allowed provided that they are limited in extent.
The research by Papenfus and Van As (2014) has shown that various traffic characteristics can be estimated with an acceptable confidence interval when the following percentages of days are counted:

- 65% of Normal days
- 85% of Abnormal days

When these percentages are counted, the following 95% confidence intervals can be achieved for the different traffic characteristics:

- ±2% for the AADT
- ±4% for the 15th highest hour volume on normal days
- ±5% for the 30th highest hour volume on all days

Confidence intervals for other combination of percentage Normal and Abnormal days counted are provided in Figures 7.3 to 7.5.

When there are gaps in the traffic data, the AADT may be estimated by dividing the total traffic volume counted during a year by the number of days on which the counts were undertaken (assuming that full days were counted). The 15th highest hour volumes on normal days can be estimated by means of the following formula:

\[ Q_{15} = T_{n,i} \cdot (1 - P_{15}) + T_{n,i+1} \cdot P_{15} \]

With:

\[ P_{15} = \frac{15}{N_{ny}} \cdot N_{nc} - i \]
\[ i = \text{Int} \left( \frac{15}{N_{ny}} \cdot N_{nc} \right) \]

In which:

- \( Q_{15} \) = Estimated 15th highest hour volume on normal days
- \( T_{n,i} \) = Traffic count during the \( i \)th highest hour on normal days
- \( N_{ny} \) = Number of hours during the normal days of the year
- \( N_{nc} \) = Number of hours counted on normal days

The 30th highest hour volumes on all days of the year can be estimated by means of the following formula:

\[ Q_{30} = T_{n,i} \cdot (1 - P_{30}) + T_{n,i+1} \cdot P_{30} \]

With:

\[ P_{30} = \frac{30}{N_{y}} \cdot N_{c} - i \]
\[ i = \text{Int} \left( \frac{30}{N_{y}} \cdot N_{c} \right) \]

In which:

- \( Q_{30} \) = Estimated 30th highest hour volume on all days of the year
- \( T_{n,i} \) = Traffic count during the \( i \)th highest hour on all days of the year
- \( N_{y} \) = Number of hours during all days of the year
- \( N_{c} \) = Number of hours counted on all days of the year
Figure 7.3: AADT Confidence intervals for different percentages of days counted

Figure 7.4: 15th Highest hour confidence intervals for different percentages of days
Figure 7.5: 30th Highest hour confidence intervals for different percentages of days
8  NETWORK-LEVEL TRAFFIC MONITORING

This chapter provides guidelines for the development of a network-level traffic monitoring programme by a road authority. Such monitoring is undertaken for the purpose of identifying and prioritising road projects.

8.1  Introduction

Guidelines are provided in this chapter for the establishment of a network-level traffic monitoring programme by a road authority. Such monitoring is undertaken by a road authority for the purpose of identifying and prioritising road projects. This application requires access to some methodology or software that can be used for such identification and prioritisation. The data should therefore only be collected when a road authority has access to such methodology or software, and when the data would actively be used by the authority for identification and prioritisation purposes.

The authority must also decide on whether to include the full road network or only certain roads in the network in the monitoring programme. Roads should be excluded when network-level traffic data are not required by the project identification and prioritisation methodology.

8.2  Homogeneous traffic sections

The network-level monitoring programme requires that the road network should be subdivided into homogeneous traffic sections. A homogeneous traffic section is a section of a road over which the various traffic characteristics, such as traffic counts and axle loading are the same over the length of the section. A short-term secondary counting station is required for each such section in the road network.

A homogeneous traffic section would typically be located between two major intersections (or interchanges on freeways) without any access to major traffic generators in between. Minor intersections may be located on the section, but these should not serve traffic generators that would affect traffic volumes or axle loading along the section.

During the development of a network-level monitoring programme, judgement may have to be exercised for the identification of the homogeneous traffic sections. In uncertain situations, additional short-term counting may be required to confirm the selected sections. Such counting can be undertaken on the road itself, but in many instances it would be advantageous to undertake the counts on the side streets at intersections. On a homogeneous section, the traffic volumes on the side streets at minor intersections can be expected to be very low and the counts can then be undertaken with a lower level of accuracy (i.e. using a Type D1 monitoring system or by means of manual monitoring).
8.3 Network-level monitoring durations

Network-level data are collected by means of short-term monitoring on normal days on all homogeneous traffic sections on the road network. The counting stations used for this purpose are known as secondary counting stations (the term coverage counting stations may also be used).

The required duration of the short-term monitoring at the secondary counting stations depends on the accuracy that is required by the network-level applications. The following guidelines generally apply:

- 12-Hour monitoring on normal weekdays (Mondays to Fridays) is generally undertaken on roads that are not on the priority list (or which are unlikely to be included in the priority list).
- 7-Day monitoring on normal days should be undertaken on roads on the priority list (or roads that should be included in the list).

The threshold traffic volume at which 7-day monitoring is required should preferably be determined by means of a sensitivity analysis to determine whether the accuracy of a 12-hour count could have an effect on the inclusion, or not, of a road in the list of priority roads. In such a sensitivity analysis, the traffic volumes obtained from such counts can be increased by some percentage to determine whether such roads are possible candidates for the priority list.

Generally, the following guidance can be provided on when 7-day monitoring should be implemented:

- On roads carrying AADTs of more than about 20 000 vehicles per day; it is generally not practical to undertake manual 12-hour monitoring.
- Two-lane roads carrying AADTs of more than about 2 500 vehicles per day have some likelihood of being included in the list of priority roads, and 7-day monitoring should be used.
- Gravel roads carrying AADTs of more than about 400 vehicles per day are possible candidates for improvement and 7-day monitoring should be used.

8.4 Network-level monitoring intervals

Traffic observations for network-level purposes are usually undertaken in three-year intervals. Reducing this interval would significantly increase the cost of a traffic monitoring programme. Increasing this interval, however, increases the risk of a road being excluded from the priority list until it is again counted. However, on roads that carry low volumes of traffic, and where it is highly unlikely that a significant growth can occur, the interval can be increased to five years.

It is generally recommended that the network-level monitoring programme should be implemented in three-year intervals (except those that are monitored in five-year intervals). This means that all roads in a network would be monitored over a period of three years, except those that are monitored in five-year intervals.
8.5 Network-level monitoring implementation

The implementation of a network-level monitoring programme would normally consist of the following steps:

• Step 1. Subdivide the road network into homogeneous traffic regions. The following steps are then undertaken for each of the homogeneous traffic regions.

• Step 2. Determine an inventory of all homogeneous traffic sections on the road network and estimate the AADT on the sections (using professional judgement if traffic data are not available).

• Step 3. For each homogeneous section in the road network, determine whether a 12-hour or 7-day count is required. The traffic volume thresholds given in this chapter may be used for this purpose.

• Step 4: Include all homogeneous sections in the three-year monitoring programme. Sections that require monitoring in five-year intervals are only included in every second programme.

• Step 5: Estimate the cost of the monitoring programme and establish whether it can be undertaken within the budget of the road authority. If not, it may be necessary to reduce the number of homogeneous traffic sections, expand the use of 12-hour monitoring or to increase the monitoring intervals.
9 PROJECT-LEVEL TRAFFIC MONITORING

Project-level traffic monitoring is undertaken when traffic data are required for the planning and design of a road. The data requirements for such purposes can vary significantly depending on the project-level application and the type of project. Only general guidelines on such monitoring can therefore be provided in this chapter.

9.1 Introduction

Guidelines are provided in this chapter for the undertaking of project-level traffic monitoring. Such monitoring is undertaken when traffic data are required for use in specific road projects. The data are collected on an ad-hoc basis as and when required for the planning and design of a road.

Data requirements on a project-level can vary significantly depending on the application of the traffic data. Guidelines for such project-level applications should therefore be consulted to establish the type and accuracy of traffic data that may be required. The guidelines provided in this chapter are of a broad general nature and do not address the requirements of specific applications.

9.2 Age of traffic data

Traffic observations that are used for project-level applications should preferably not be older than one or two years. The cost of short-term counts is relatively low compared to the errors that can be made by using an outdated traffic count. Where possible, it would thus be preferable that a new set of traffic observations be undertaken, unless recent observations are available.

9.3 Short-term counts

Project-level traffic counts required for road improvement projects are usually undertaken by means of short-term counts over a duration of seven days. The counts are undertaken on normal days and expanded to reflect annual traffic characteristics.

A 7-day count duration would normally be adequate for many projects. The accuracy can be slightly improved by a 14-day count, but this improvement would be limited. In situations where more accurate counts are required, consideration will have to be given to monitoring over a period of one or more years.
9.4 Peak hour observations

A project may require traffic observations during specific peak hours of the year. Such counts may be required on normal or on abnormal days. The days and hours during which the traffic counts should be taken depends on the particular application and requirements of the project.

The peak hours during which traffic should be counted may be derived as follows from hourly traffic patterns observed at long-term counting stations (in the same traffic stratum):

- Normal days. The average hourly traffic patterns for the seven days of the week can be used to determine the peak hours during which peak-hour traffic can be counted (normal days only).

- Abnormal days. The traffic counts on abnormal days at a long-term counting station should be consulted to determine the days of the year during which the design peak hours typically occur. The specific peak hours can then be determined from the hourly traffic patterns observed on these days at the long-term counting station.

To ensure that the peak hour is counted, observations are normally started an hour or two before the expected peak hour and continued for an hour or two after the peak hour. The specific peak hour can then be determined from the count itself.
10 EXPANSION FACTORS FOR TRAFFIC COUNTS

Expansion factors are used to expand short-term traffic counts into equivalent annual traffic volumes. Formulae and methods are provided in this chapter for the use and derivation of such factors.

10.1 Introduction

Information is provided in this chapter on the application and derivation of expansion factors for traffic counts. Formulae are provided in the chapter that can be used for the expansion of short-term counts while methods are provided that should be used for the derivation of expansion factors from long-term counts.

The expansion factors are only determined for the normal days of the year, excluding normal days on which exceptional events have occurred. Variations in traffic volumes on exceptional days may be very high which could significantly affect the accuracy of expanded counts.

10.2 Expansion of short-term counts

Formulae are given below that are used for the expansion of short-term traffic counts. A traffic count is divided by an expansion factor to derive the equivalent annual traffic characteristics. The formulae are as follows:

a) Annual Average Daily Traffic (AADT) from a 12-hour count (for different classes of vehicles and days of the week):

\[
\text{AADT} = \frac{\text{Total 12 hour count}}{\text{Expansion Factor}}
\]

b) Annual Average Daily Traffic (AADT) from a 7 or 14 day count (for different classes of vehicles):

\[
\text{AADT} = \frac{\text{Average daily count}}{\text{Expansion Factor}}
\]

c) Highest hour volumes (15th and 30th):

\[
\text{Highest hour volume} = \frac{\text{Maximum hourly count}}{\text{Expansion Factor}}
\]

The maximum hourly count required in the above formula is the highest hourly count that was obtained during the short-term observations.
The counts required for estimating the AADT are as follows:

• For 12-hour counts, the total 12-hour count (sum of the counts during the 12 hours).
• For 7-day or longer counts, the average daily count for the seven different days of the week. Where more than 7 days were counted, the average count must first be determined for each of the seven days of the week and the average daily count then determined for the seven weekdays combined.

### 10.3 Derivation of expansion factors

Expansion factors are derived from long-term counts over a period of one calendar year. Subsets of these counts are then selected and used to emulate short-term counts of a particular duration. Regression analysis is then used to relate these subsets of short-term counts with the actual traffic characteristic being estimated:

The following general formula is used in the regression analysis:

\[ y = f_e \cdot x \]

in which:

- \( y \) = Traffic observation obtained from the short-term subset of data
- \( x \) = Traffic characteristic obtained from the long-term count
- \( f_e \) = Expansion factor

An important condition for regression analysis is the homoscedasticity requirement that the variance of the prediction errors (or residuals) is constant or homogeneous across observations (Berthouex and Brown, 2002, Ross SM, 2004). Weighted regression analysis should be used to compensate for deviations from this requirement.

The weights required for the regression analysis are related to the standard deviation of points around the fitted value. Traffic counts often follow the Poisson distribution for which the standard deviation is equal to the square root of the average count. For this reason, weights used in the regression analysis should increase with square root of the traffic characteristic.

Based on the above requirements, Papenfus and Van As (2014) derived the following formula for the determination of the expansion factor from a set of observations:

\[ f_e = \frac{\sum y_i}{\sum x_i} \]

in which:

- \( y_i \) = Individual traffic observations obtained from the subset of data
- \( x_i \) = Individual characteristic obtained from the long-term count
- \( f_e \) = Derived expansion factor
The above formula is used as follows for determining the different expansion factors:

a) Expansion factor for the determination of the Annual Average Daily Traffic (AADT) from a 12-hour count (for different classes of vehicles and days of the week):

\[ f_e = \frac{\sum \text{12 hour counts for } n \text{ normal days of the year (specific weekdays)}}{n \cdot \text{AADT}} \]

b) Expansion factor for the determination of Annual Average Daily Traffic (AADT) from a 7-day count (for different classes of vehicles):

\[ f_e = \frac{\sum \text{Average 7 day counts from } n \text{ weeks of the year (normal days only)}}{n \cdot \text{AADT}} \]

c) 15th and 30th Highest hour volumes:

\[ f_e = \frac{\sum \text{Maximum hourly counts from } n \text{ sets of observations}}{n \cdot \text{AADT}} \]

### 10.4 Adjustment for traffic growth and seasonal variation

The formulae provided in the previous sections are applicable to roads on which no traffic growth has occurred, or where there is no seasonal variation. Where such growth or seasonal variation does occur, adjustments must first be made to the counts, before the expansion factors can be derived or applied.

The purpose of the adjustments is to adjust traffic volumes to an equivalent average volume for the year. After such adjustments, the expansion factors can then be applied as described in the previous section.

The adjustment factors must be derived from long-term counting stations. Daily traffic volumes (24-hour counts) are used for this derivation. Only normal days are used for determining the factors but the assumption is made that the growth rate and seasonal variation derived from the normal day counts are also applicable to abnormal days.

The method described below requires fitting of a formula to traffic data obtained from long-term counting stations by means of regression analysis. The parameters obtained for the fitted formula are then used to adjust the short-term counts.

The following formula is used in the model:

\[ T_d = a + b \cdot \left( d - \frac{n}{2} \right) + c \cdot \left( d - \frac{n}{2} \right)^2 \cdot \left( 1 - \frac{|d - n/2|}{0.75 \cdot n} \right) \]

In which:

- \( T_d \) = Normal day daily traffic volume during day \( d \) of the year
- \( a, b, c \) = Parameters of the model (established by means of regression analysis)
- \( d \) = Day number (1 to \( n \)), relative to start of the year
- \( n \) = Number of days in the year (365 or 366)

Note that in the above formula, \( n \) denotes the total number of days in the year while \( d \) denotes the number or index of the day (applicable to both normal and abnormal days). Only traffic data collected during normal days are, however, used to fit the model.
Examples of the application of the above formula are provided in Figure 10.1. One of the examples shows a road on which a growth rate was experienced during the year, and the other shows a road on which some seasonal variation was found.

The adjustment factor is calculated by means of the following formula:

$$ f_d = \frac{a + b \cdot \left( d - \frac{n}{2} \right) + c \cdot \left( d - \frac{n}{2} \right)^2 \cdot \left( 1 - \frac{|d - n/2|}{0.75 \cdot n} \right)}{a + c \cdot \frac{n^2}{24}} $$

The above adjustment factor is calculated for each days of the year (d). Any counts (hourly or daily) taken on these days are then divided by the daily factors to determine the equivalent count:

$$ \text{Adjusted count on day } d = \frac{\text{Traffic count on day } d}{f_d} $$

The above model is based on the following simplifying assumptions:

• There is a linear growth in traffic volumes during the year.
• The seasonal variation has minimum or maximum values at the midpoint and start/end points of the year.

Although based on relatively simple assumptions, the model was found to apply to a wide range of roads. The model was also found to provide reasonable factors in situations where the assumptions are not strictly applicable, for example, when the minimum and maximum values of the seasonal variation do not strictly occur at the middle or start/end of the year.
Figure 10.1: Examples of traffic growth and seasonal variation during a year
11 ANNUAL AVERAGE DAILY TRAFFIC

Definitions are provided in this chapter for the annual average daily traffic and other related characteristics. Traffic volume is one of the most basic and fundamental parameters in the analysis and design of roads.

11.1 Introduction

Traffic volume is a basic and fundamental parameter in the analysis and design of roads. Traffic volume is the total number of vehicles (or pedestrians) that pass over a given point along a road during a certain period of time. Volumes can be expressed in terms of daily, hourly or sub-hourly periods. Formal definitions are provided in this chapter for annual average daily traffic and other related characteristics.

11.2 Annual Average Daily Traffic (AADT)

Annual Average Daily Traffic (AADT) is perhaps the most important of all available traffic characteristics. AADT is defined as the average volume of traffic per day passing a point along a road over a period of one calendar year.

The AADT can either be obtained from an annual traffic count or estimated from a short-term count (FHWA, 2013). AADTs are estimated from short-term counts by means of expansion factors.

The AADT is usually the sum of the traffic volumes in the two directions of travel. On one-way roads, however, AADT is usually provided per direction of movement. When provided as the sum of the two directions, the traffic volume per direction can be obtained by multiplying the AADT with the directional split.

The AADT must be reported together with the year in which it was determined or estimated.

11.3 Average Daily Traffic (ADT)

The Average Daily Traffic (ADT) is sometimes used to define the average volume of traffic per day over a period other than one year. For example, it may be used to report the average daily traffic for a count undertaken over a period of one week.

The use of ADT without an indication of the period over which it was determined is meaningless. It can usually not be used as an estimate of the AADT unless it is expanded by means of an expansion factor. Care must therefore be exercised when ADT is used or reported.
11.4 Annual Directional Split

The Annual Directional Split is the proportion of the annual traffic volume in a particular direction. As in the case of AADT, the split can either be derived from an annual count or estimated by means of a short-term count.

The directional split on an annual basis is usually 50/50%, but there could be situations where traffic uses one road in one particular direction and another in the opposite direction. These situations, however, are rare and an equal split is therefore usually assumed.

11.5 Annual Vehicle Composition

The Annual Vehicle Composition is the percentage of vehicles of a particular class or type. The composition can either be derived from an annual count or estimated by means of a short-term count.

An overview of the different vehicle classes that can be used is given in Chapter 14 of this document. It is not always possible to monitor all the vehicle classes due to limitations in automatic vehicle monitoring. Manual monitoring methods can be used, but this will only produce a traffic count over a period of limited duration.
12 ANNUAL HOURLY FLOW DISTRIBUTIONS

The distribution of hourly traffic flows is an important parameter in the design of roads and other transportation facilities. This chapter provides information on annual hourly flow distributions and particularly the traffic volumes during the 15th highest hour on normal days and the 30th highest hour on all days of the year.

12.1 Introduction

The distribution of hourly traffic flows is an important parameter in the design of roads and other transportation facilities. For such purpose, it is necessary to identify design hours of the year for which a road must be designed and then to obtain traffic characteristics for these hours.

The design hours that are typically used in South Africa are described in this chapter together with a motivation for the use of these hours. Methods for deriving various characteristics from long-term counts are also described. The characteristics can be estimated from short-term counts by means of expansion factors (as described previously).

12.2 Annual hourly flow distributions

The annual distribution of hourly flows is typically studied by plotting hourly flows from the highest to the lowest against the number of hours a particular flow is exceeded during the year. It is, however, more meaningful to plot the flow as a percentage of the AADT against the percentile hour in the year. The two approaches are equivalent but it more convenient to plot the distributions using percentile values.

Examples of distributions are provided in Figures 12.1a and 12.1b. Two peaking characteristics are provided in each of the figures, one for all days of the year and the other for the normal days of the year. The two figures apply to two different traffic strata (based on the holiday traffic stratification method).

In the graphs provided in the two figures, the hourly flows are shown as a percentage of the AADT while the hours are shown as a percentage of the total number of hours in the year (8760, except in leap years). The graphs have also been plotted on logarithmic scales with the purpose of increasing the scale of the graph for the highest hours of the year (particularly around the 15th and the 30th highest hours of the year).
Figure 12.1a: Traffic-flow peaking characteristics – Negative holiday traffic

Figure 12.1b: Traffic-flow peaking characteristics – High holiday traffic
The distribution shown in Figure 12.1a is typical of a road which is not significantly affected by holiday traffic. On such roads, the hourly traffic (as a percentage of the AADT) is fairly constant for the 10% highest hours of the year. This is in contrast with Figure 12.1b which is typical of a road that is affected by holiday traffic. On these roads, the hourly traffic can vary significantly over the different hours of the year (except for normal days of the year where the traffic is fairly constant for the 10% highest hours on normal days).

12.3 Annual hourly flow distributions – Linear approximation

The shapes of the curves in Figures 12.1a and 12.1b have been investigated by Jordaan (1985) and Papenfus (1992) who found that the curves tend to be linear over segments of the curves when plotted on logarithmic scales. An example of the linear approximation is shown in Figure 12.2. The linear approximation has the advantage that it is only necessary to define a few linear segments over the different hours of the year to obtain traffic flows for all the hours of the year.

The graph in Figure 12.2 has been divided into a total of six segments using the hours or percentile hours intervals provided in the table below. The first segment for the seven highest hours is not modelled separately but is extrapolated from the 8 to 88 hour segment.

<table>
<thead>
<tr>
<th>Hours of the year</th>
<th>8 to 88</th>
<th>88 to 263</th>
<th>263 to 876</th>
<th>876 to 6132</th>
<th>6132 to 8760</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentile hours</td>
<td>0.1 to 1%</td>
<td>1 to 3%</td>
<td>3 to 10%</td>
<td>10 to 70%</td>
<td>70 to 100%</td>
</tr>
</tbody>
</table>
The model based on logarithmic scales can be expressed mathematically as follows:

\[ k_n = \alpha_i \cdot \left( \frac{n_i}{N} \right)^{-\beta_i} \]

In which:
- \( k_n \) = Hourly flow as a proportion of the AADT at hour \( n \)
- \( n \) = Hour ranking (1 to \( N \))
- \( N \) = Number of hours in the year
- \( \alpha_i, \beta_i \) = Parameters of the model for segment \( i \)

The traffic flow \( q_n \) (vehs/hour) for a specific hour \( n \) is given by:

\[ q_n = k_n \cdot \text{AADT} \]

The parameters \( \alpha_i \) and \( \beta_i \) can be derived by means of the following formulae:

\[ \alpha_i = k_{ni} \cdot \exp(\beta_i \cdot \ln \frac{n_i}{N}) \]
\[ \beta_i = \frac{\ln(k_{ni}/k_{n_{i+1}})}{\ln(n_{i+1}/n_i)} \]

In which:
- \( k_{ni} \) = Hourly flow as a proportion of the AADT at hour \( n_i \).
- \( n_i \) = Hour ranking at lower end of a segment \( i \)

The sum of the values of \( k_n \) over the different hours of the year (1 to \( N \)) must be equal to 1/24 (to account for the difference of the hourly units of \( k_n \) and the daily units of AADT). This means that the parameters of the model must be derived subject to the condition that:

\[ \sum_{i} \frac{\alpha_i}{1 - \beta_i} \left( \left( \frac{n_{i+1}}{N} \right)^{1 - \beta} - \left( \frac{n_i}{N} \right)^{1 - \beta} \right) = \frac{1}{24} \]

The values of \( k_{ni} \) required for fitting the above model can be found by minimising the sum of squared errors (of the logarithmic values of \( k_n \)), subject to the condition that the sum of \( k_n \) over the different hours of the year is equal to 1/24.

### 12.4 Design hours

A road that is designed to accommodate only the average hourly volume would be overloaded for long periods during the year. On the other hand, however, it would also not be economical to design for the highest flow that can be expected in a year, as the facility would be underutilised for most of the year. The selection of the design hour is therefore a compromise between providing an adequate level of service for most hours of the year and economic efficiency.

According to the Highway Capacity Manual (TRB, 2010), the customary practice in the United States is to base rural highway design on a design hour between the 30th and the 100th highest hour of the year. The point is made, however, that the arbitrary selection of an analysis hour cannot be a rigid criterion on which to base an informed judgement.
The customary practice in South Africa is to base rural highway design on the 30th highest hour volume of a year. Urban roads, however, are mostly designed for the peak hour of a normal day of the week. The roads are then typically designed for a relatively poor, but still acceptable, level of service (LOS) during these design hours. Delays will occur during the design hours, but the delays would not be excessive.

The 30th highest hour approach is more suitable for roads on which traffic peaking is high such as shown in Figure 12.1b. Designing a road for the 30th highest hour means that the poor level of service would only be experienced over a limited number of hours of the year. The approach, however, is not suitable for roads on which traffic peaking is low, such as shown in Figure 12.1a. Designing a road for the 30th highest hour in this case would mean that the poor level of service would be experienced during a relatively large number of hours of the year.

The above limitation of the 30th highest design hour can be addressed by using a second design hour. The hour that was selected for use in South Africa is the 15th highest hour on normal days only (excluding abnormal days). The number of normal days in the country is approximately half the total number of days in the year, which means that the two design hours have approximately the same percentile values.

The design hours that are prescribed in TMH 12 (COTO 2012) have been selected based on the above arguments. The two design hours are as follows:

• 15th Highest hour volume measured on the normal days of the year.
• 30th Highest hour volume measured on all days of the year.

Designing a road for both the 30th and 15th highest hours would ensure that the road operates at acceptable levels of service for both abnormal and normal days of the year (although the levels of service that are acceptable may be different for the two hours). Designing a road for the two hours would prevent excessively poor operating conditions over a large number of hours of the year.

### 12.5 Heavy vehicle hourly distributions

The distribution of heavy vehicle hourly flows cannot be studied using distributions similar to those provided in Figures 12.1a and 12.1b, since this would only provide peaking characteristics for the hours in which heavy vehicle flow is the highest. An analysis is required of the peaking characteristics for the hours in which the total traffic is the highest.

An example of the peaking characteristics of heavy vehicles is shown in Figure 12.3 for the highest hours based on total traffic (and not only heavy vehicle traffic). In this figure, the heavy vehicle flow is expressed as a percentage of the AADT of heavy vehicles. The data are plotted against the percentile hours applicable to the total traffic flow. The data are therefore only plotted as points rather than using curves as for the total traffic stream.

The figure shows that there is a considerable variation in the proportion of heavy vehicles in the traffic stream over the different hours of the year. Hours with approximately the same total traffic could have significantly different proportions of heavy vehicles. The selection of a heavy vehicle proportion for a specific hour of the year can therefore lead to either an over- or underestimation of this proportion during the highest hours of the year.
Figure 12.3: Example of peaking characteristics for hourly heavy vehicle flow

Generally, it appears that the proportion of heavy vehicles (expressed as proportion of the heavy vehicle AADT) is approximately the same for up to about 20% highest hours of the year. This, however, must be checked by inspecting graphs similar to that provided in Figure 12.3. The heavy vehicle proportion during the design hours can therefore be determined as the average for the highest 1% of hours.

12.6 Design hour directional splits

The directional split during the design hour is a further important factor in many applications. Operations on a road with a 50/50 directional split would be significantly different from a road with a 0/100 directional split.

The directional split can vary significantly during the different hours of the year. An example of this variation is shown in Figure 12.4. Generally, it appears that the directional split is approximately the same for about the 1% highest hours of the year. This, however, must be checked by inspecting graphs similar to that provided in the figure. The directional split during the design hours can then be determined as the average for these hours.
Figure 12.4: Example of variation in the directional splits over different hours

12.7 Design hour peak-hour factors

Certain applications require an estimate of the peak 15-minute flow rate during the design peak hour. Consideration of the peak 15-minute interval can be important since congestion that occurs during a short period of time could take a long time to dissipate. Certain land developments tend to generate very high traffic volumes over relatively short periods of time.

The Peak Hour Factor (PHF) is used to estimate the peak 15-minute flow. This factor is defined as the hourly volume divided by the 15-minute flow rate (both expressed in units of vehicles per hour). According to the Highway Capacity Manual (TRB, 2010), this factor generally ranges between 0.80 and 0.98 in urban areas. Lower values signify greater variation of flow within the design hour, while higher values signify lower variation.

The PHF can vary significantly during the different hours of the year as shown in Figure 12.5. Generally, it appears that the PHF is approximately the same for about the 1% highest hours of the year. This, however, must be checked by inspecting graphs similar to that provided in the figure. The factor for the design hours of the year can then be determined as the average for these hours.
Figure 12.5: Example of variation in the peak hour factor over different hours
13  AXLE LOAD OBSERVATIONS

Axle loading is a very important parameter in a variety of applications in road planning and design. Although important for the analysis and design of road pavement, axle loading may also find application in the economic analysis of a road and the development of road safety programmes.

13.1  Introduction

Axle loading is an important parameter in a variety of applications. Such applications are not only limited to the design of road pavements, but may also include economic analysis and the development of road safety programmes. The most important application, however, is pavement design where reliable and accurate traffic-loading estimates are required to prevent the serious and costly consequences of an under- or overdesign of such pavements.

Although axle load monitoring is described as a separate topic in this chapter, it is important to recognise that such monitoring must be integrated with other types of traffic monitoring. Axle load data cannot be used in isolation and must be combined with other data, such as traffic volumes, for the purposes of managing, planning and designing road pavements.

13.2  Axle load data

Axle load data that are required for the design of road pavements include the following:

a)  Number of axle groups per vehicle for different axle group types.

b)  Static axle load distributions per axle group type. A number of examples of such distributions are provided in Figure 13.1. These distributions in this figure show the percentage of axles that has a particular axle load.

The axle load distributions shown in Figure 13.1 have been produced using 100 kg intervals. In practice, the distributions are more often presented using 1 ton intervals.

Provision is made for the following axle group types:

a)  Steering axles

b)  Single axle groups, excluding steering axles

c)  Tandem axle groups (axle groups with two axles)

d)  Tridem axle groups (axle groups with three axles)

For tandem and tridem axle groups, the assumption is usually made that the axle loads are evenly distributed amongst the different axles within the axle group.
Figure 13.1: Examples of axle load distributions
13.3 Axle load observations

Axle load observations are mostly undertaken using High-Speed Weigh-in-Motion (HS WIM) equipment. It is also possible to undertake such measurements using Low-Speed Weigh-in Motion (LS WIM) equipment, but such equipment requires that vehicles must either be stopped, or their speeds significantly reduced. The low-speed systems are therefore mostly only used for calibration purposes, while most axle load monitoring is undertaken using high-speed systems.

The most common high-speed WIM technology that is used in South Africa is the bending plate system. Other technologies are, however, also available such as piezo-electric and quartz sensors, fibre optic cables, load cells (hydraulic and mechanical), capacitance mats and bridges/culverts instrumented with strain gauges (FHWA, 2013).

In South Africa, the TMH 3 Specifications for the Provision of Traffic and Weigh-in-Motion Monitoring Service (COTO, 2014) is available that can be used for specifying WIM axle load monitoring services. The following system types and accuracy classes are generally recommended for such observations:

a) **Traffic monitoring.** Type B2 traffic monitoring systems are generally recommended in combination with WIM monitoring.

b) **WIM Monitoring.** Class II level of accuracy is recommended for roads that carry medium to high volumes of heavy vehicle traffic. It is unlikely that WIM monitoring will be undertaken on low-volume roads, but, if required, a Class III level of accuracy would normally be adequate for such roads.

13.4 WIM sensor configurations

Axle loads can be measured by means of wheel or axle load sensors. An axle load sensor can consist of two wheel load sensors in which case the axle load would be determined as the sum of the two wheel loads. When a single wheel sensor is used, the axle load is taken as twice the wheel load.

Axle load sensors are more accurate than single wheel sensors since many heavy vehicles are not loaded symmetrically. The distribution of axle loads between the two wheels can also be affected by factors such as the cross-fall of the road and cross wind at the time of measurement.

Accuracy can also be improved by installing more than one wheel sensor on the two sides of a lane. The average of multiple measurements would tend to cancel errors of individual measurements. A further advantage of multiple sensors is that it can assist in addressing the issue of dynamic loads caused by vehicle suspension and the rolling action of a moving vehicle. Multiple measurements of dynamic loads would produce a closer estimate of the static load.

While the accuracy of axle load measurements can be improved by means of multiple sensors, the cost of such installations is very high. Single wheel sensor installations are therefore recommended for most installations, but multiple sensors may be required in critical applications where decisions regarding the design of a pavement could be affected by the loss of accuracy.
The accuracy of WIM observations can be significantly improved by installing a WIM system at a suitable location along the road. Factors such as pavement smoothness, cross fall, gradient and horizontal curves can have a significant impact on WIM measurements. Detailed requirements are provided in TMH 3 (COTO 2014) that can be used for the selection of suitable WIM sites. Requirements are provided for the road geometry as well as the pavement of the road.

A general problem with WIM observations is the issue of clipping. Such clipping occurs when wheels do not fully pass a sensor and the sensors are clipped by the wheels, resulting in very low axle loads being registered. This has been found to be a major source of WIM measurement errors (Van As, 2013b). To address this problem, off-scale sensors are now prescribed by TMH 3 (COTO 2014) and must be used at all WIM installations.

13.5 System-level axle load monitoring

System-level monitoring is required when expansion factors must be derived for the purpose of expanding short-term observations. Research into axle load characteristics that was undertaken in South Africa (Van As, 2012), however, was unable to identify any meaningful trends or relationships that could be used for such purposes. The conclusion of the research was that axle load statistics must be obtained from axle load observations on each road.

There is, therefore, no need for system-level monitoring of axle loads. It is, however, recommended that authorities should continue with long-term axle load monitoring for research purposes. The introduction of the TMH 3 (COTO, 2014) specifications will significantly improve the quality of axle load observations in future, and it may be possible that the availability of improved axle loading data could lead to the development of a future expansion system for axle loads.

13.6 Network-level axle load monitoring

Network-level axle load data are collected for the purpose of identification and prioritisation of road projects. Similar to traffic counts, the axle load data are firstly used to identify roads that may require rehabilitation or some form of improvement, and secondly, to prioritise the road projects. Once such road projects have been identified and prioritised, additional data may be collected that are required for project-level investigations.

Axle load monitoring, however, is a costly exercise and it is therefore not possible to undertake such monitoring on each road in the country. For many roads in the network, network-level analysis would have to rely on assumed or typical axle load characteristics. Network-level axle load monitoring would only be undertaken on roads carrying very high volumes of freight traffic, or roads on which axle loads are very high due to the type of freight being transported.
Considerable knowledge of the road network and professional judgement is required to identify roads on which network-level axle load monitoring is required. This can be done by identifying the major freight transport corridors on the road network, together with the origins and destinations of such corridors. A suitable location for network-level monitoring can then be identified for each of the freight corridors. For freight corridors involving multiple origins or destinations, it may be necessary to undertake monitoring at more than one location.

Freight corridors may be identified by plotting heavy vehicle volumes on a map. It is also possible to plot total annual axle loads on a map such as shown in Figure 13.2 (by using assumed axle load characteristics together with heavy vehicle volumes). Such maps would show the heavier loaded roads and corridors on the network on which axle load monitoring should be undertaken.

Network-level axle load observations are usually undertaken in three-year intervals. Increasing the monitoring frequency would significantly increase the cost of axle load monitoring. Reducing the frequency, however, could significantly increase the risk of a road being excluded from the priority list.
13.7 Project-level axle load monitoring

Project-level axle load monitoring is undertaken for the purposes of the planning and designing of roads and related infrastructure. The axle load data for project-level applications should preferably not be older than one or two years, but data that are three to five years old may also be acceptable. In many cases, axle load monitoring may no longer be possible since the condition of the road pavement may have deteriorated so badly that it is no longer possible to undertake axle load measurements on the road.

13.8 Axle load sample sizes

The sample sizes that are required for axle load observations can be determined on the basis of acceptable confidence intervals. The confidence intervals that are acceptable for a particular purpose can be derived by means of a sensitivity analysis (or professional judgement).

Research undertaken into axle load distributions in South Africa (Van As, 2012) showed that relatively large sample sizes are required to improve the accuracy of axle load data. The reason for this is that pavement design is mostly affected by the heavier axle loads on the roads. While there may be many axles travelling across a road, not all of these may be heavy. A relatively large number of axle load observations are therefore required to provide a relatively small sample of heavier axle loads.

The research by Van As (2012) was based on the impact of sample sizes on the E80 equivalent number of standard axles. A standard axle load is 80 kN or approximately 8.2 ton. The formula used for the determination of the equivalent number of axle loads is the following:

\[ E_{80} = \left( \frac{W}{8.2} \right)^n \]

In which:

- \( E_{80} \) = Equivalent number of standard axles
- \( W \) = Axle load in tons
- \( n \) = Coefficient (typically 4.2)

A limitation of the E80 approach is that the value of the coefficient \( n \) may depend on the pavement type, and that it may even change over the design life of a particular pavement. The E80 approach, however, was found to be useful for the determination of the confidence intervals associated with different sample sizes. For a value of \( n = 1 \), equal weight is given to the different axle loads and the average E80 is thus equal to the average axle load (divided by 8.2). For values greater than \( n = 1 \), greater weight is given to the higher axle loads.
The confidence intervals for axle loads were determined by means of a simulation (bootstrap) method. The actual averages of E80 axles for different values of \( n \) were determined for a full year of observations (assuming that a year’s observations are representative of the population). Random samples were then selected from the data and the difference between the samples and the actual average were then used to determine confidence intervals and error distributions. The worst confidence interval that was obtained for any of the axle groups was then selected.

The confidence intervals (half widths) that were obtained are shown in Figure 13.3 as a function of sample sizes for different values of \( n \). The sample sizes in the figure are given as percentages of days of the year over which axle load monitoring was undertaken.

Figure 13.3 shows that confidence intervals are significantly affected by the value of \( n \). The best confidence intervals are obtained for \( n=1 \), but the confidence intervals become progressively poorer for large values of \( n \).

The confidence intervals are also significantly affected by the sample size. Confidence intervals quickly improve from very small sample sizes up to a sample size of about 25% of the days of the year (three months). For larger sample sizes, the confidence interval only gradually improves, and very large sample sizes are required to further improve the confidence intervals.

Based on Figure 13.3, it is generally recommended that axle load observations should be undertaken over a period of three months. A sensitivity analysis can be undertaken to determine whether decisions would be affected by improving the accuracy through increasing the sample sizes. Relatively high levels of accuracy can be achieved if axle load monitoring is undertaken over a period of 85% of the days (10 months) in a year.
13.9 Systematic calibration of axle load observations

An important issue with axle load observations by means of WIM equipment is the calibration of such equipment. The calibration of such equipment in the field requires either the use of test vehicles or the selection of random samples of vehicles from the traffic stream. A further problem is that the calibration may also drift over time due to equipment problems or the deterioration of the road surface.

An alternative calibration method was developed by De Wet (2008, 2010) which utilises the WIM observations of the axle loads of selected axles and heavy vehicle types. Research has shown that the axle loads of these axles and vehicle types do not vary significantly between different roads. These loads can then be used to establish calibration factors that can be applied to all axle load observations.

The calibration is undertaken on a monthly basis and a calibration factor is determined for each month of observations. This approach is required to accommodate drift in the calibration factor over time.

For the determination of the calibration factors, heavy vehicles are selected from the WIM observations that conform to the following requirements:

- Heavy vehicles with a total of 6 or 7 axles
- Axle spacing of 2.9 m – 3.9 m between 1st and 2nd axle
- Axle spacing of 1.2 m – 2.4 m between 2nd and 3rd axle
- Axle spacing of 4.5 m – 9.0 m between 3rd and 4th axle
- Average calibrated axle load (all axles) of between 6.5 – 8.5 t

The average axle load used in the above selection must be the calibrated load. An iteration process must therefore be followed in which an initial calibration factor is selected. Vehicles are then selected and a new calibration factor calculated. The iteration process is repeated until there is no change in the vehicles selected for calibration.

Research has shown that the average tractor mass of the selected trucks is stable at approximately 21.8 ton with a coefficient of variation of only 1.2%. This average load is therefore highly suitable as a target for post-calibration purposes.

The calibration factor may be calculated by means of the following formula:

\[ k = \frac{21.8}{T_{TT}} \]

in which:

- \( k \) = Calibration factor
- \( T_{TT} \) = Average tractor mass

The tractor mass used in the above formula is determined as the sum of the axle loads for the different axles of a tractor (2 or 3 axles) of the selected heavy vehicles.

The calibration factor can then be used as follows to determine calibrated axle loads:

\[ \text{Calibrated load} = k \cdot \text{Observed axle load} \]
Although the average tractor mass for the selected trucks is very stable at approximately 21.8 ton, it could be possible that there may be circumstances where the mass may be different at a particular WIM. These circumstances may include the following:

- A particular make or type of heavy vehicle may dominate in an area because of the transport of particular types of freight.
- Deceleration or acceleration may result in load transfer to and from the tractor from the trailers.

### 13.10 WIM Recalibration tests

The calibration method described in the previous section is applied to monthly sets of data. In the application of the method, it is assumed that no change has occurred at the WIM which could affect the calibration factor. Such changes would typically be caused when the WIM equipment is recalibrated in the field. In situations where such recalibration was undertaken, the calibration method must be applied separately to the periods before and after the field calibration and two sets of calibration factors must be determined.

Ideally, reports must be submitted on dates on which the WIM equipment was recalibrated in the field. In practice, such reports are not always reliable and can therefore not be fully relied on. Older WIM data may also be available for which such reports are not available.

A test that can be used for the identification of the WIM recalibration dates was developed by Van As (2013b). The test has the limitation that it cannot be used to identify smaller changes in WIM recalibration but it can, at least, be used to identify larger changes.

The test utilises the same six- and seven-axle tucks used in the calibration method, except that the average axle load criterion of 6.5 to 8.5 tons is not applied. The reason for this is that the calibration factors are not available at the time the test is undertaken. The exclusion of this criterion could, however, lead to significant variation in the tractor mass which would affect the accuracy of the test.

In the method proposed by Van As (2013b), use is only made of the front axle loads rather than the tractor mass. The front axle loads have been found to be relatively stable and are not significantly affected by the total load on the heavy vehicles. The front axle loads are affected by factors such as acceleration and deceleration and are not as stable as the tractor mass. For the purpose of the recalibration tests, however, the front axle load would be the more stable criterion.

The dates on which the WIM recalibration has occurred can be identified by means of “change detection” methods (Van As, 2013a). The so-called binary tree algorithm can be used for this purpose. The algorithm starts with a series consisting of the full set of data for the month. The point at which the greatest change in the average front axle load has occurred is then determined. If the change is significant, the process is repeated. Otherwise the process is terminated.

The above process is repeated for each subseries in the data. For each subseries, the point at which the greatest change in the average front axle load has occurred is determined and tested, to determine whether the change is significant. This process is
then repeated for all the identified subseries of data until no additional change points have been detected.

The change points should be selected such that no subseries will consist of less than 300 heavy vehicles (complying with the selection criteria). The change in the average front axle load is determined by means of the following formula:

\[ E = 2 \cdot \frac{|T_A - T_B|}{T_A + T_B} \]

in which:

- \( E \) = Change in average front axle loads, expressed as proportion
- \( T_A \) = Average front axle load for the first part of the subseries
- \( T_B \) = Average front axle load for the second part of the subseries

The change is considered to be significant when \( E \) in the above formula is greater than 0.05 (5%). This could, however, be confirmed visually by plotting the average front axle loads for the different days of the month.

### 13.11 Static load distributions

Loads measured by means of WIM systems consist of two components, namely the static and dynamic load components. Engineering applications of axle loads, however, only require estimates of the static load component rather than the actual impact forces, as measured by WIM sensors. The reason for this is that the dynamic load component depends on the condition of the road pavement which can be expected to change in future as the road deteriorates or when the road is rehabilitated. Pavement analysis software therefore typically contains procedures for the estimation of the dynamic loads as a function of the condition of the pavement and adds this component to the static load.

The axle loads measured by Weigh-in-Motion (WIM) systems include both the static and dynamic load components and statistical procedures must be applied to remove the dynamic component from the measurements. The procedure that is recommended for this method is the EMS algorithm described by Van As (2011). A detailed description of this procedure is provided in Appendix A.

An example of the application of the EMS algorithm is shown in Figure 13.4. This example shows the original observed axle load distribution, as well as the adjusted static load distribution (after the removal of the dynamic component).

The figure also shows the noise that can occur in axle load distributions (shown by spikes in the distribution). This noise is often caused by the difference in the resolution to which axle loads are collected and the resolution in which the observations are recorded (100 kg). The EMS algorithm therefore includes a smoothing step which is aimed at removing the noise.
Figure 13.4: Dynamic load adjustment
14 VEHICLE CLASSIFICATION

This chapter provides information on vehicle classification systems that can be used when monitoring traffic. Vehicle classification is an important consideration in traffic monitoring and observations.

14.1 Introduction

Vehicle classification is an important consideration in traffic monitoring. Many applications require estimates of traffic characteristics for the different vehicle classes. For example, heavy vehicle volume is a particularly important traffic characteristic in the design of road pavements.

Various classification systems are described in this chapter. Two of these are those that have been adopted for automatic traffic monitoring in South Africa as defined in TMH 14 South African Standard Automatic Traffic Data Collection Format (COTO, 2014). A classification system that can be used for manual counts is also provided. A system is also provided for non-motorised traffic.

14.2 General definitions

A number of general definitions are provided in TMH 14 (COTO, 2014) for a number of vehicle classes. These definitions are as follows:

a) Light vehicles: Any vehicle that has not been fitted with tyres of a size (bead seat diameter) greater than 406.4 millimetres (16 inches) and which does not have a wheel fitted with two more tyres. Motorcycles and tricycles, however, are categorised as light, irrespective of the tyre size and number of tyres. The following are a number of light vehicle definitions:
   i) Motorcycles. A motorcycle is a light vehicle which has two wheels, with or without a side-car.
   ii) Tricycles. A light vehicle which is similar to a motorcycle but which has three wheels. The controls are similar to those of a motorcycle.
   iii) Motor vehicles. A light vehicle that is predominantly used for the conveyance of persons but which is not a minibus or a bus. Includes passenger cars, sport utility vehicles and bakkies.
   iv) Minibuses. A light vehicle that is used for public transport and which carries up to 16 persons (including the driver).
   v) Light commercial vehicles. A light vehicle that is predominantly used for the conveyance of freight.
b) Heavy vehicle. A vehicle which is not a light vehicle. The following heavy vehicle classes are defined:
   i) Midi-buses. A heavy vehicle that is predominantly used for public transport and which carries between 17 and 35 persons (including the driver).
   ii) Buses. A heavy vehicle that is predominantly used for public transport and which carries more than 35 persons (including the driver).
   iii) Rigid (Single-Unit) trucks. A heavy vehicle in which the towing vehicle also carries freight. The vehicle may also tow one or more trailers.
   iv) Articulated trucks. A heavy vehicle in which the tractor does not carry freight (although it may carry part of the load). The vehicle may tow one or more trailers.

14.3 Length-based classification system

The length-based classification system is used most often in South Africa for automatic traffic monitoring. The system requires length measurements to differentiate between heavy vehicles with different lengths. The Type C1 and C2 monitoring systems of TMH 3 (COTO, 2014) can therefore be used for the length-based classification of vehicles (refer to Chapter 4 of this document). The classification system, however, is relatively simple and can only be used to differentiate between a limited number of vehicle classes.

The following four vehicle classes are defined (COTO, 2014):
   • Light Vehicles
   • Short Heavy Vehicles
   • Medium Heavy Vehicles
   • Long Heavy Vehicles

The length thresholds that are used to differentiate between the three heavy vehicle classes are provided in TMH 14 (COTO, 2014).

14.4 Detailed classification system

A detailed classification system is provided in TMH14 (COTO, 2014) that can differentiate between most of the vehicle classes defined previously in this chapter. At the time of publication, however, no automatic monitoring systems were available that can be used to identify all the vehicles in the classification system with a high degree of accuracy. The Type A and B monitoring systems of TMH 3 (COTO, 2014) can differentiate between some of the vehicle classes but not all. Manual monitoring is required to differentiate between all the vehicle classes.

The detailed system provides for the following light vehicle classes:
   • Any light vehicle
   • Motorcycle or Tricycle
   • Motor vehicles (cars, SUVs, bakkies, etc)
   • Minibus (up to 16 persons)
   • Light commercial vehicle
Provision is made for the following heavy vehicle classes:

- Any heavy vehicle
- Midi-bus (17 to 35 persons)
- Bus (more than 35 persons)
- Rigid two-axle truck (Single-Unit), excluding trailer axles
- Rigid three-axle truck (Single-Unit), excluding trailer axles
- Rigid truck with four or more axles, excluding trailer axles
- Articulated truck with two-axle tractor
- Articulated truck with three-axle tractor
- Articulated truck with tractor with four or more axles

**14.5 Manual vehicle classification**

Manual traffic observations allow for the identification of many of the vehicle classes described in the previous sections, but not all. In particular, it is not possible to implement the length-based system described previously, but it is possible to implement the detailed system.

All vehicle classes in the detailed classification system can be identified when undertaking a manual count. It is not possible to measure tyre sizes, but differentiation between light and heavy vehicles can be based on whether or not any wheel on a vehicle has been fitted with two or more tyres. Vehicles on which at least one such wheel is identified are classified as heavy.

In addition to the detailed vehicle classes, it is also possible to identify special vehicle types such as the following by means of manual monitoring:

- Agricultural vehicle
- Construction vehicle
- Abnormal load vehicle

The fact that a large number of vehicle classes can be identified does not imply that provision should be made for all the classes. Only classes should be selected for which there is a need to obtain a classified count.

**14.6 Non-motorised traffic**

Non-motorised traffic counts can differentiate between classes such as the following:

- Pedestrians. Further differentiation can be made between children and adults.
- Cyclists. Further differentiation can also be made between children and adults.
- Animal-drawn vehicles

More information on the monitoring of non-motorised traffic is provided in the next chapter.
15 NON-MOTORISED TRAFFIC

15.1 Introduction

Non-motorised traffic typically includes pedestrians, cyclists and animal-drawn vehicles. Such traffic is usually monitored by means of manual counting methods. One of disadvantage of such monitoring is that it is only possible to undertake short-term counts while no expansion factors are available for the estimation of equivalent annual traffic characteristics.

Non-motorised traffic counting is usually undertaken by means of manual counting methods. Automatic equipment is available that can be used for this purpose.

This chapter provides some basic guidance on non-motorised monitoring. One of the major issues with such monitoring is that the monitoring is usually undertaken by means of short-term counts. Long-term counts are difficult to undertake and it is therefore not possible to develop expansion factors for non-motorised traffic.

15.2 Non-motorised traffic monitoring

Non-motorised traffic counting is usually undertaken by means of manual counting methods. Automatic equipment is available that can be used for the monitoring, but the cost of the equipment is high while the equipment may not always be accurate. Both long- and short-term counts are difficult to undertake and at the time of writing this document, it is unlikely that system- and network-level monitoring programmes will be established for non-motorised traffic. Such monitoring will therefore mostly undertaken for project-level purposes using short-term counts.

The issue with short-term counts is the lack of expansion factors that can be used for expanding the counts to annual equivalent traffic volumes. Due to the lack of long-term counts, it is also very difficult to establish periods of the year during when peak non-motorised traffic flows can be expected. This is particularly a serious issue when counts of recreational non-motorised traffic are required.

Short-term non-motorised traffic counts may therefore be expected to be inaccurate and significantly under- or overestimate actual traffic demand. This issue must be recognised and taken into account when non-motorised traffic counts are used in applications.
15.3 Challenges in monitoring non-motorised traffic

There are many challenges that need to be taken into account when planning for non-motorised traffic counts. These include the following (FHWA 2013):

- Non-motorised traffic is less confined to fixed roads or lanes of traffic than motorised traffic. Movements often also tend to be unpredictable. Pedestrians often take shortcuts over roads and are often prone to jaywalking. Cyclists are more disciplined, but can use either the roadway or sidewalks along the roadway.

- Pedestrians and cyclists sometimes travel in closely spaced groups. The monitoring of such groups can become difficult and may require more observers.

A further issue that must be recognised in the planning of counts is that roads are sometimes used for commercial and social activities. In such cases, simple traffic counts may not adequately account for the impact of non-motorised traffic on operations or road safety. Such impacts may be underestimated by traffic counts under such circumstances.

15.4 Duration of non-motorised traffic monitoring

Non-motorised traffic counts should preferably be counted over a period of 12 hours (FHWA, 2103) to allow for the calculation of hourly traffic flow patterns over the day. Shorter counts of 4 to 6 hours are possible, but judgement may then be required to determine the periods with the heaviest non-motorised use.

Non-motorised traffic counts may also be undertaken during the peak hours of vehicular traffic. In such cases, the non-motorised traffic may be counted for a period of one or two hours during the morning and afternoon peaks. An issue with such counts is that the peak hours for non-motorised traffic may not coincide with those of vehicular traffic.

15.5 Weather conditions

Non-motorised traffic volumes can be significantly affected by weather conditions. Non-motorised traffic should therefore not be monitored during days with heavy precipitation or during exceptionally cold or hot weather conditions. It is therefore important that the weather conditions should be recorded when the count is undertaken.
16 DATA VERIFICATION

The verification of traffic observations is a very important and fundamental aspect of traffic data. Data that contain serious errors could have serious consequences in the planning and design of roads. Information is therefore provided on the data verification that should be undertaken before traffic observations can be used.

16.1 Introduction

The verification of traffic observations is a very important aspect of traffic monitoring. Data that contain serious errors could have serious consequences in the planning and design of roads. Road authorities should therefore ensure that data verification forms an important part of a traffic monitoring programme.

Data verification is also required to identify exceptional days on which traffic volumes differ significantly from those that typically occur on other days. Such days can occur on either normal or abnormal days. It may be necessary to recount traffic if a count was undertaken on one or more exceptional days.

An overview of the data verification tests required for automatic monitoring is provided in the TMH 3 Specifications for the Provision of Traffic and Weigh-in-Motion Monitoring Service (COTO 2014). These tests were developed on the basis of a study into the variability of traffic measurements by Van As (2013b).

16.2 Data verification test levels

Three levels of data verification tests are described in TMH 3 (COTO, 2014), as follows:

a) First-level tests which can be undertaken on data sets of any duration.

b) Second-level tests that are applied to the full data set in the case of short-term counts or to monthly data sets in the case of long-term counts.

c) Third-level tests that are applied to long-term counts and which are applied to annual (calendar year) data sets.
16.3 First-level tests

First-level tests are undertaken on data sets of any duration:

a) Data format tests. These tests are undertaken to determine whether data have been provided correctly according to the requirements of the TMH14 South African Standard Automatic Traffic Data Collection Format (COTO 2014). These must, inter alia, include the following tests:

i) Tests that individual data items comply with the specified TMH14 format.

ii) Tests that data items are within the minimum and maximum ranges specified in the TMH14 format.

iii) Tests that data separators (e.g. spaces and commas) comply with the TMH14 format.

iv) Tests for whether header data have been provided and whether this data are correct in terms of the TMH14 requirements.

b) Lower and upper bound tests. These tests are undertaken to determine whether the data falls outside the lower and upper bounds. Data that fail these tests are marked as suspect. These tests must be undertaken for the following data items:

i) Total vehicle length. This is the measurement from the front to rear bumpers of the vehicle, including any trailers.

ii) Number of trailers. This is the number of trailers counted per individual vehicle.

iii) Number of axles. This is the total number of axles counted per individual vehicle.

iv) Number of steering axles. An axle on a vehicle is considered to be a steering axle when the first group of axles are spaced less than 1.6 m apart.

v) Axle spacing. The axle spacing test is applied per axle. A vehicle fails a test if any of the axle spacing measurements exceed the thresholds.

vi) Average axle load (per axle). The average axle load is the total load of the vehicle divided by the number of axles. Axle loads must be calibrated before this test is applied.

vii) Individual axle load. This test is applied per individual axle. A vehicle fails the test if any of the axle loads exceed the thresholds. Axle loads must be calibrated before the test is applied.

viii) Axle load/average load ratios. These ratios are determined as the individual axle load divided by the average axle load of a vehicle. The tests are only applied to the first and second axles of a vehicle. Since a ratio is used, it is not necessary to calibrate loads before the test is applied.

Thresholds for the above tests are provided in the table below. These thresholds were determined on the basis of the variation in the different measurements (Van As, 2013b) that were obtained from traffic observations prior to 2010. The thresholds may therefore have to be adjusted in future as automatic traffic monitoring technology is improved.
## Observation

<table>
<thead>
<tr>
<th>Observation</th>
<th>Minimum threshold</th>
<th>Maximum threshold</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total vehicle length</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All vehicles</td>
<td>1.5 m</td>
<td>35 m</td>
</tr>
<tr>
<td>Heavy vehicles</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 axle vehicles</td>
<td>1.5 m</td>
<td>25 m</td>
</tr>
<tr>
<td>3 axle vehicles</td>
<td>2.5 m</td>
<td>35 m</td>
</tr>
<tr>
<td>4+ axle vehicles (N = No of axles)</td>
<td>2.0N – 4.5 m</td>
<td>35 m</td>
</tr>
<tr>
<td><strong>Number of trailers</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Light vehicles</td>
<td>Not required</td>
<td>2</td>
</tr>
<tr>
<td>Heavy vehicles</td>
<td>Not required</td>
<td>3</td>
</tr>
<tr>
<td><strong>Number of axles</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Light vehicles</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Heavy vehicles</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td><strong>Number of steering axles</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Light vehicles</td>
<td>Not required</td>
<td>1</td>
</tr>
<tr>
<td>Heavy vehicles</td>
<td>Not required</td>
<td>1</td>
</tr>
<tr>
<td>2 axle heavy vehicles</td>
<td>Not required</td>
<td>1</td>
</tr>
<tr>
<td>3+ axle heavy vehicles</td>
<td>Not required</td>
<td>2</td>
</tr>
<tr>
<td><strong>Axle spacing (individual)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All vehicles</td>
<td>0.5 m</td>
<td>12 m</td>
</tr>
<tr>
<td>Heavy vehicles</td>
<td>0.5 m</td>
<td>16 m</td>
</tr>
<tr>
<td><strong>Average axle load – Heavy vehicles (*)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2-4 axle vehicles</td>
<td>0.25 ton</td>
<td>16 ton</td>
</tr>
<tr>
<td>5+ axle vehicles</td>
<td>1.5 ton</td>
<td>16 ton</td>
</tr>
<tr>
<td><strong>Individual axle loads – Heavy vehicles (*)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Front axle</td>
<td>0.25 ton</td>
<td>15 ton</td>
</tr>
<tr>
<td>Second axle</td>
<td>0.25 ton</td>
<td>20 ton</td>
</tr>
<tr>
<td>Other axles</td>
<td>N/A</td>
<td>20 ton</td>
</tr>
<tr>
<td><strong>Axle load ratio – Heavy vehicles</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Front and second axles</td>
<td>0.30</td>
<td>N/A</td>
</tr>
<tr>
<td>Other axles</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

(*) Axle loads adjusted using the systematic calibration factor

### 16.4 Second-level tests

Second-level tests are undertaken for full data sets in the case of short-term counts or for monthly data sets in the case of long-term counts. The following tests are undertaken:

a) **Traffic pattern tests.** These tests are undertaken using 24-hour traffic counts. A pattern matching algorithm is used for these tests and will group the patterns in similar clusters. The tests are used for the identification of suspect or missing data as well as for the classification of the data as Normal, Abnormal and Exceptional. Details of the traffic pattern tests are provided in Appendix B.
Traffic and Axle Load Monitoring Procedures

<table>
<thead>
<tr>
<th>Observation</th>
<th>Warning Level</th>
<th>Severe Level</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Vehicle length</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Light and heavy vehicles with any number of axles</td>
<td>0.50%</td>
<td>1.00%</td>
</tr>
<tr>
<td>Heavy vehicles with 2 to 8 axles</td>
<td>0.50%</td>
<td>1.00%</td>
</tr>
<tr>
<td><strong>Number of trailers</strong></td>
<td>1.50%</td>
<td>2.50%</td>
</tr>
<tr>
<td><strong>Number of axles</strong></td>
<td>1.50%</td>
<td>2.50%</td>
</tr>
<tr>
<td><strong>Number of steering axles</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Light vehicles with 2 to 5 axles</td>
<td>0.20%</td>
<td>0.50%</td>
</tr>
<tr>
<td>Heavy vehicles with 2 to 8 axles</td>
<td>0.50%</td>
<td>1.00%</td>
</tr>
<tr>
<td><strong>Axle spacing</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Light vehicles with 2 to 5 axles</td>
<td>0.10%</td>
<td>0.20%</td>
</tr>
<tr>
<td>Heavy vehicles with 2 to 8 axles</td>
<td>0.25%</td>
<td>0.50%</td>
</tr>
<tr>
<td><strong>Axle load tests (heavy vehicles with 2 to 8 axles)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average axle load – Lower bound</td>
<td>0.50%</td>
<td>0.75%</td>
</tr>
<tr>
<td>Average axle load – Upper bound</td>
<td>0.05%</td>
<td>0.10%</td>
</tr>
<tr>
<td>Individual axle loads – Lower bound</td>
<td>0.05%</td>
<td>0.10%</td>
</tr>
<tr>
<td>Individual axle loads – Upper bound</td>
<td>0.05%</td>
<td>0.10%</td>
</tr>
<tr>
<td>Axle load ratio</td>
<td>1.50%</td>
<td>2.50%</td>
</tr>
</tbody>
</table>

b) Daily traffic count tests (normal days). These tests are undertaken using total counts on normal days. The counts are compared with the average count and any outliers should be investigated further. Such outliers could be due to data errors or due to exceptional events. The average count must be determined for at least 50 normal days (over a period of a few months), and differentiation must be made between the different days of the week (Tuesdays to Thursdays can be grouped together).

c) Monthly failure rate tests. Tests are undertaken of the percentage of vehicles that fail the lower and upper bound tests previously described. Should these percentages exceed the maximum allowable percentages, then the data are marked as suspect for the whole month.

Threshold values for the failure rate tests are provided in the above table above. Thresholds are provided for two levels, namely warning and severe. Observations not complying with the warning level thresholds should be considered suspect. Those not complying with the severe level thresholds may have to be rejected.

The minimum sample size for the failure rate test is 500 vehicles. Where necessary, vehicles from a previous month(s) must be added to the sample to ensure this sample size.
d) Systematic calibration tests. These tests are performed as part of the systematic calibration of axle loads. The tests are only applied to trucks selected to form part of the calibration. The following tests are undertaken:

i) Allowable range for the calibration factors.
ii) Maximum standard deviation for the total tractor load.
iii) Allowable range for average front axle load.
iv) Maximum standard deviation for the front axle load.
v) Average axle spacing between 2nd and 3rd axles.
v) Standard deviation of axle spacing between 2nd and 3rd axles.

Threshold values for the above tests are provided in the table below. Thresholds are provided for two levels, namely the warning and severe levels. Observations should be considered suspect when not complying with the warning level thresholds. Observations not complying with the severe level thresholds may have to be rejected.

e) Recalibration tests. These tests are applied on a monthly basis to determine whether any adjustments have been made to WIM equipment which may affect the systematic calibration.

<table>
<thead>
<tr>
<th>Calibration test</th>
<th>Warning level</th>
<th>Severe level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allowable range of calibration factors</td>
<td>0.90 to 1.10</td>
<td>0.75 to 1.25</td>
</tr>
<tr>
<td>Maximum standard deviation of total tractor load</td>
<td>2.2 t</td>
<td>2.5 t</td>
</tr>
<tr>
<td>Average front axle load</td>
<td>5.5 to 6.5 t</td>
<td>5 to 7 t</td>
</tr>
<tr>
<td>Standard deviation of front axle load</td>
<td>0.85 t</td>
<td>1.0 t</td>
</tr>
<tr>
<td>Average spacing between 2nd and 3rd axles</td>
<td>1.34 to 1.40 m</td>
<td>1.32 to 1.45 m</td>
</tr>
<tr>
<td>Std Dev of spacing between 2nd and 3rd axles</td>
<td>0.07 m</td>
<td>0.13 m</td>
</tr>
</tbody>
</table>

16.5 Third-level tests

Third-level tests are undertaken on an annual basis (calendar year) with the purpose of testing whether any unexpected changes may have occurred over the long term.

Use is made of monthly averages which are plotted over time to establish whether there are any unexpected changes or trends in the observations. Observations are usually required over a period of several months before it would be possible to identify such changes or trends.

The third-level tests must be undertaken manually by means of graphs showing the variation in monthly averages over the year. No thresholds for the maximum allowable variation have been developed, and professional judgement must be exercised to determine whether observations are suspect.
The following characteristics are included in the tests:

i) Traffic count tests. The monthly averages are determined for normal days only, and differentiation must be made between the different days of the week.

ii) Percentage composition. The percentage composition test is used to check the consistency of the percentage of heavy vehicles classified as short, medium and long. No differentiation is made between normal and abnormal days or the seven days of the week.

iii) Systematic calibration factor. This factor should normally remain constant over time, but it could be affected by the recalibration of equipment in the field. It is also possible for the calibration of the equipment to drift over time.

iv) Average front axle load. The average front axle load consistency check uses the average observed load of the front axle of the 6- and 7-axle trucks used in the calibration method, but without the application of the average axle load criterion of 6.5 to 8.5 tons. The front axle loads are adjusted using the calibration factor.

v) Standard deviation in front axle load. The front axle load standard deviation consistency check uses the same trucks and axles as for the average front axle load test.

vi) Average number of E80’s per axle. The tests are undertaken for each of the short, medium and long heavy vehicle classes.

vii) Average number of axles per vehicle. The averages are determined for heavy vehicles classified as short, medium and long.

viii) Average vehicle length. The tests are undertaken for the short, medium and long heavy vehicle classes.

ix) Percentage unclassified vehicles. Unclassified vehicles are those that could not be classified by the equipment.
This chapter provides an overview of the data format that should be used in South Africa for the transfer of data between different road authorities and other organisations. The format that is prescribed for this purpose is the TMH 14 South African Standard Automatic Traffic Data Collection Format (COTO 2014).

17 RSA DATA FORMAT

17.1 Introduction

An overview is provided in this chapter of the data format that should be used in South Africa for the transfer of data between different road authorities and other organisations. This is particularly important when automatic monitoring is undertaken due to the large volumes of data that can be collected. For this purpose, the TMH 14 South African Standard Automatic Traffic Data Collection Format (COTO 2014) should be used.

17.2 Development of the RSA data format

The original RSA data format was developed in 1994 in response to the need for standardisation of data format for exchange purposes (Schildhauer, 2008). The original version was based on a fixed ASCII text format.

A major update of the format (Version 2) was published in 2005. This update provided for a number of new vehicle properties that required a significant change to the original version of the data format. These included properties such as “Following Vehicle”, “Bumper-to-1st Axle Distance” and “Inverse of Speed”. Another improvement was the provision for two different vehicle classification schemes.

The two original versions of the document were mostly based on the collection of summary data according to which collected data were summarised in bins or intervals. The need for the collection of individual vehicle data rather than summaries was, however, identified. Although provision was made for individual vehicle data, the format was somewhat inflexible and resulted in very large data files. The need for a more compact and flexible database was identified.

For the third version of the format (COTO, 2014), two alternative formats were evaluated, namely the XML and the comma delimited format. The XML format was the most flexible format available, but it would have significantly increased the size of the data files. The comma delimited format was therefore selected for Version 3, primarily because of the need to reduce the size of data files.

Version 3 represents a significant deviation from previous versions. It is, however, possible to convert data between the different formats, although there could be some loss of detail when converting data to earlier versions. In the new version, the fixed column
Traffic and Axle Load Monitoring Procedures

format of the older versions was changed to the comma delimited format. New features were also added and some of the unused data types dropped from the standard.

17.3 Overview of the format

The most important feature of Version 3 of the RSA data format is the provision that is made for individual vehicle data. Data are recorded for each vehicle in lines (or records) of data. Provision is made also made for data related to the counting station and equipment used for the traffic monitoring.

The data format provides for the capturing of a range of vehicle characteristics. A particular monitoring system may not be able to capture all the characteristics, which mean that some of the characteristics may not always be available.

The characteristics that are provided for are those that are specified in TMH 3 Specifications for the Provision of Traffic and Weigh-in-Motion Monitoring Service (COTO 2014). Provision is made for two sets of characteristics, the first of which is associated with traffic monitoring and the second with axle load observations.

17.4 Traffic monitoring characteristics

The data format makes provision for the following minimum number of characteristics required by TMH 3 (COTO 2014):

- Departure date and time. The departure date and time at which the back of the vehicle crosses a specific point on the site.
- Direction of travel (forward/reverse). The direction of travel over the site. Vehicles normally travel in the forward direction, but vehicles may be travelling in the reverse direction.
- Physical lane number. The physical lane number on which a vehicle was physically detected, irrespective of the direction in which the vehicle was travelling.
- Assigned lane number (physical or virtual). The lane number to which a vehicle travelling in the reverse direction is assigned.
- Vehicle class. Provision is made for the capturing of two vehicle classes using different classification systems.

The following characteristics are required for systems that are capable of recording speeds and other related characteristics:

- Vehicle speed. The speed of the vehicle as recorded at a fixed position of the vehicle (normally the front bumper or axle) and a fixed point on the site.
- Vehicle length. The length of a vehicle as measured from front to rear bumper.
- Vehicle following property. The system must be able to classify a vehicle as either following or free flowing.

More advanced systems must be capable of recording the following characteristics:

- Number of trailers. The total number of trailers towed by the vehicle.
- Number of axles. The number of axles on the vehicle.
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- Bumper-to-1st axle spacing. The distance measured from the front bumper to the centre of the first axle.
- Axle spacing for all axles (except first axle). The spacing between subsequent axles.
- Single/dual tyres. The presence of single or dual tyres on wheels of the vehicle.

17.5 Axle loading characteristics

Provision is made in the data format for the recording of the following characteristics when axle loads are monitored:

- Number of axles as recorded by the load sensors.
- Load measurement resolution. The load resolution with which the wheel or axle loads on the vehicle were measured. This resolution may change from vehicle to vehicle, but not from axle to axle on the same vehicle.
- Axle spacing. The spacing between subsequent axles as measured by the load sensors. The system must be able to record an axle spacing of up to 20 m.
- Wheel or axle loads. The wheel loads for each axle as measured by the load sensors.
- Load sensor clipping. The system must indicate whether the load sensor was clipped by any of the wheels of the vehicle. Such clipping must be detected by means of off-scale sensors.
18 TRAFFIC DATA SUMMARIES

This chapter provides recommendations for data summaries that should be produced and made available to data users. These summaries can be produced in a traffic monitoring data book which is published annually or made available electronically in a suitable format.

18.1 Introduction

Recommendations are provided in this chapter for data summaries that should be produced and made available to users of the data. These recommendations are limited to those data items that are generally required. There may, however, be applications that require specific data items and the guidelines for such applications should be consulted regarding the required data summaries.

The summaries may be made available to users in a traffic monitoring data book that is published annually. Alternatively, the summaries may be made available electronically using a suitable format (such as comma delimited files).

18.2 General data

The following general data should be provided for counting stations:

a) Monitoring station identification number and name.
b) Road/route number, kilometre position and location description.
c) Station layout with direction descriptions and lanes.
d) Monitoring dates and duration.
e) Vehicle classification system used at station.

18.3 Traffic count summaries

The following traffic count summaries should be provided, irrespective of whether the counts were undertaken at a long or short-term counting station. For short-term counting stations, the data should be estimated by means of expansion factors.

a) Stratification
   i) Stratification system and stratum.
b) Annual average daily traffic count data (all days of the year)
   i) AADT (Annual average daily traffic).
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ii) Annual average percentage vehicle composition (as a percentage of annual traffic).

iii) Annual average directional distribution per vehicle type (as a percentage of annual traffic).

iv) Average monthly distribution over the year per vehicle type (monthly traffic as a percentage of the annual traffic).

c) Normal day annual average daily traffic count (normal days only)

i) Average daily distribution over the seven days of the week per vehicle type (average annual traffic per day of the week as a percentage of the average weekly traffic).

ii) Average hourly distribution over the different hours of the day for the seven days of the week per vehicle type (average hourly traffic as a percentage of the average daily traffic for the particular day).

d) Design hour flow data

i) Design hour traffic flows for the 15th highest hour on normal days and the 30th highest hour on all days (per vehicle type).

ii) Peak hour factor during the 15th and 30th highest hours.

iii) Directional split during the 15th and 30th highest hours.

18.4 Axle load summaries

The following summaries should be provided for locations at which axle load monitoring has been undertaken:

a) Annual average number of axle groups per vehicle

i) Annual average number of axle groups per vehicle (per vehicle type).

ii) Monthly average number of axle groups per vehicle (per vehicle type).

b) Axle load distributions

i) Axle load distributions in 1-ton intervals for steering, single, tandem and tridem axle groups (per vehicle type).

ii) Monthly adjustment factors for axle loads for steering, single, tandem and tridem axle groups (per vehicle type).
19 REFERENCES

AASHTO (2009), AASHTO Guidelines for traffic data programs, USA.


CSRA (Committee of State Road Authorities) 1991, TRH 16, Traffic Loading for Pavement and Rehabilitation Design, Department of Transport, Pretoria.


FHWA (Federal Highway Administration), 2013, Traffic Monitoring Guide. Washington D.C.


APPENDIX A

ESTIMATION OF STATIC LOAD DISTRIBUTIONS

A.1 Introduction

WIM (Weigh-In-Motion) equipment measures the actual forces imposed on the equipment by vehicles. These imposed forces are the result of various forces acting on the vehicle or caused by the dynamics of the moving vehicle. The forces include static or gravitational forces, centrifugal forces as well as dynamic forces resulting from the vehicle suspension. For vehicles travelling at a constant speed on a straight and level road, it is generally assumed that only two forces are imposed, namely static and dynamic forces.

For the purposes of pavement design it is necessary to obtain separate estimates of these two forces, particularly the static force component. The dynamic force component can be assumed or estimated using empirical models in which factors such as speed and the roughness of the road surface are taken into account. The static component must be derived from WIM observations, which consist of a combination of the static and dynamic components.

In order to estimate the static component from WIM observations, the dynamic component must be removed from the observations. A statistical procedure that can be used for this purpose is described in this appendix.

A.2 Axle load distribution

The static force component for a particular axle, on a specific vehicle, is a constant value independent of vehicle speed and other factors. The dynamic force component can vary over the length of the road and this force can be either negative or positive. Repeated WIM measurements of the same axle (on the same vehicle) will show variation as a result of the dynamic impacts.

When the axle loads of different vehicles and axles are combined, the resultant loads will be some combination of the individual axle load distributions. The distributions of the static and dynamic loads can be assumed to be statistically independent, in which case the axle load distribution would be the convolution of the static and dynamic load distributions, as follows (Van As, 2011):

$$p_w(w) = \sum_{t=-\infty}^{\infty} p_t(t) \cdot p_e(w-t, t)$$

In which:

- $p_w(w) = $ Probability distribution of the observed axle load $w$
- $p_t(t) = $ Probability distribution of the static load $t$
- $p_e(e,t) = $ Probability distribution of the dynamic load $e$ for a given static load $t$
In the above relationships, the observed and dynamic load distributions are assumed to be known. The static load distribution can be therefore by obtained by inverting the above relationships. This process of inversion is also known as deconvolution.

### A.3 Expectation-Maximisation (EM) algorithm

The inversion of the relationship between the static, dynamic and observed axle load distributions can be undertaken by means of the so-called Expectation-Maximisation (EM) algorithm (Van As, 2011)

The EM algorithm consists of the following steps:

- Assume an initial solution for \( p_T(t) \).
- Expectation step: Estimate proportions \( q_T(w) \).
- Maximisation step: Use the estimated proportions \( q_T(w) \) to obtain a new estimate of the static load distribution \( p_T(t) \).
- Repeat the expectation and maximisation steps until convergence is reached.

During the expectation step, the proportions \( q_T(w) \) are estimated using the previously estimated static load distribution \( p_T(t) \):

\[
q_T(w) = p_w(w) \cdot \frac{p_T(t) \cdot p_R(w-t, t)}{\sum_{\tau} p_T(\tau) \cdot p_R(w-\tau, \tau)}
\]

During the maximisation step, a new estimate of the static load distribution \( p_T(t) \) is obtained as follows:

\[
p_T(t) = \sum_{w} q_T(w)
\]

The iteration continues until the static load distribution has converged.

### A.4 Smoothed EMS algorithm

Tests of the EM algorithm showed that the algorithm tends to produce unstable results (Van As, 2011). Axle load observations contain a considerable amount of variation or noise. The algorithm tends to attenuate this noise and then becomes unstable.

The smoothed EMS algorithm adds an additional step to the EM algorithm in which smoothing is applied to the estimated static load distribution. This smoothing step immediately follows the maximisation step, and thus forms part of the iteration process. A relatively simple form of smoothing is used for this purpose.
A.5 Dynamic load correction algorithm

An algorithm is provided below which can be used for deriving a static axle load distribution from an observed distribution given that the dynamic load distribution is known. The algorithm uses the Lognormal distribution for the dynamic load distribution, but can readily be adjusted for the Normal distribution. The algorithm is written in the Basic compiler language for use in a spreadsheet macro, but can readily be converted for use in any other language.

A description of variables and arrays used in the algorithm together with definitions of the variables is provided in the algorithm. Provision is made for loads measured in intervals (or bins) of 0.1 of a ton with a maximum load of 20.0 tons.
Option Explicit: Option Base 1

'*******************************************************************************
' WIM Dynamic load correction: EMS Algorithm
'*******************************************************************************

Sub WimEMS()

Dim Iter1 As Integer 'First iteration counter
Dim Iter2 As Integer 'Second iteration counter
Dim iLde as Integer 'First load bin index
Dim jLde as Integer 'Second load bin index
Dim sDynR As Double 'Std Dev of dynamic load ratio distribution
Dim pDynR(200, 200) As Double 'Dynamic load ratio probability array
Dim pObsW(200) As Double 'Observed axle load probability distribution
Dim pAdjW(200) As Double 'Corrected load distribution
Dim wBinE(200) As Double 'Bin end-points
Dim dCalW(200) As Double 'Intermediate array
Dim pCalW(200) As Double 'Intermediate array
Dim pConW(200) As Double 'Intermediate array
Dim AA As Double 'Intermediate array
Dim PP As Double 'Intermediate array
Dim FF As Double 'Intermediate array

'-- Load data ---------------------------------------------------------------
    sDynR = Standard deviation of dynamic road ratio
    For iLde = 1 To 200
        pObsW(iLde) = Observed axle load distribution
    Next iLde

'-- Check data -----------------------------------------------------------------
    If sDynR < 0.0000001 Then sDynR = 0.0000001

'-- Set bin endpoints ---------------------------------------------------------
    For jLde = 1 To 200
        wBinE(jLde) = Log((jLde + 0.5) / 10#)
    Next jLde

'-- Calculate dynamic load ratio array ----------------------------------------
    For iLde = 1 To 200
        PP = 0#
        AA = Log(iLde / 10#)
        For jLde = 1 To 199
            FF = NormDist(wBinE(jLde), AA, sDynR)
            pDynR(jLde, iLde) = FF - PP: PP = FF
        Next jLde
        pDynR(200, iLde) = 1# - PP
    Next iLde

'-- Initial estimate of corrected load distribution --------------------------
    For iLde = 1 To 200
        pAdjW(iLde) = pObsW(iLde)
    Next iLde

'-- Iteration process control ------------------------------------------------
    For Iter1 = 1 To 100
        For iLde = 1 To 200
            pConW(iLde) = pAdjW(iLde)
        Next iLde
    For Iter2 = 1 To 20

End Sub
/*-- Perform expectation/maximization algorithm -----------------------------------*/
For iLde = 1 To 200
  dCalW(iLde) = 0#
Next iLde
For jLde = 1 To 200
  For iLde = 1 To 200
    pCalW(iLde) = pAdjW(iLde) * pDynR(jLde, iLde)
    FF = FF + pCalW(iLde)
  Next iLde
  If FF > 0# Then FF = pObsW(jLde) / FF
  For iLde = 1 To 200
    dCalW(iLde) = dCalW(iLde) + FF * pCalW(iLde)
  Next iLde
Next jLde

/*-- Smoothing algorithm ---------------------------------------------------------*/
pAdjW(1) = (0.3 * dCalW(1) + 0.2 * dCalW(2) + _
  0.1 * dCalW(3) + 0.05 * dCalW(4)) / 0.65
pAdjW(2) = (0.2 * dCalW(1) + 0.3 * dCalW(2) + _
  0.2 * dCalW(3) + 0.1 * dCalW(4) + 0.05 * dCalW(5)) / 0.85
pAdjW(3) = (0.1 * dCalW(1) + 0.2 * dCalW(2) + 0.3 * dCalW(3) + _
  0.2 * dCalW(4) + 0.1 * dCalW(5) + 0.05 * dCalW(6)) / 0.95
FF = pAdjW(1) + pAdjW(2) + pAdjW(3)
For iLde = 4 To 197
  pAdjW(iLde) = 0.05 * dCalW(iLde - 3) + 0.1 * dCalW(iLde - 2) + _
  0.2 * dCalW(iLde - 1) + 0.3 * dCalW(iLde) + 0.2 * dCalW(iLde + 1) + _
  0.1 * dCalW(iLde + 2) + 0.05 * dCalW(iLde + 3)
  FF = FF + pAdjW(iLde)
Next iLde
pAdjW(198) = (0.1 * dCalW(200) + 0.2 * dCalW(199) + 0.3 * dCalW(198) + _
  0.2 * dCalW(197) + 0.1 * dCalW(196) + 0.05 * dCalW(195)) / 0.95
pAdjW(199) = (0.2 * dCalW(200) + 0.3 * dCalW(199) + _
  0.2 * dCalW(198) + 0.1 * dCalW(197) + 0.05 * dCalW(196)) / 0.85
pAdjW(200) = (0.3 * dCalW(200) + 0.2 * dCalW(199) + _
  0.1 * dCalW(198) + 0.05 * dCalW(197)) / 0.65
FF = FF + pAdjW(198) + pAdjW(199) + pAdjW(200)
For iLde = 1 To 200
  pAdjW(iLde) = FF * pAdjW(iLde)
Next iLde
Next It

/*-- Check convergence ---------------------------------------------------------*/
For iLde = 1 To 200
  If Abs(pAdjW(iLde) - pConW(iLde)) > 0.000001 Then GoTo X9
Next iLde
Exit Sub
X9:
Next Iter
End Sub
APPENDIX B
TRAFFIC PATTERN TESTS

B.1 Introduction

Traffic patterns tests have been found to be essential for the identification of some data errors or issues which cannot be identified by means of other tests. These tests are based on a comparison of the hourly traffic pattern over a day with an average pattern. Any significant deviation from the average pattern is an indication that there could be an error or some other issue with the data.

The tests have the disadvantage that some manual assessments are required of the traffic patterns. These assessments require the visual inspecting of graphs of the traffic patterns to identify significant deviations in the traffic patterns which may have been caused by data errors. The process is relatively simple but it can be laborious if each daily pattern has to be inspected. Therefore, statistical methods are used to group traffic patterns into clusters with similar traffic patterns. It is then only necessary to assess the patterns of a group and not each individual pattern.

B.2 Traffic patterns

The traffic patterns required for the tests can be obtained from 24-hour counts. The tests can only be performed when counts are available for the full 24 hours of the day.

The patterns are determined as hourly proportions (or percentages) using the following formula:

\[
\text{Hourly Proportion} = \frac{\text{Hourly Count}}{\text{Total count over 24 hours of the day}}
\]

Note that the proportions are obtained by dividing the hourly traffic counts by the total count for the specific day and not by the average daily traffic.

B.3 Pattern classes

Daily traffic patterns are classified as one of the following:

a) Normal patterns. These are the patterns that typically occur on the normal days of the year. These patterns exclude patterns that deviate significantly from the typical patterns due to, either errors in the data, or exceptional events which may have affected the patterns.

The normal patterns may also occur on abnormal days of the year. At some locations on the road network, there are days of the year that are classified as abnormal but where the traffic has not been affected by holidays. Such patterns are then classified as normal, even if they have been observed on abnormal days.
b) Abnormal patterns. These are the patterns that typically occur on the abnormal days of the year. These patterns exclude patterns that deviate significantly from the typical patterns due to either errors in the data or exceptional events.

Patterns on abnormal days that have a typical normal shape should be classified as a normal pattern, as described previously. However, patterns on normal days may not be classified as abnormal. Any such patterns must be classified as either exceptional or erroneous.

c) Exceptional patterns. These are patterns that deviate significantly from those typically found on normal or abnormal days. Such patterns are the result of events that occur rarely on a road. Exceptional patterns are classified as extreme patterns when the events occur very rarely.

d) Extreme patterns. These are exceptional patterns which are classified as extreme due to events which are very rare. Such events are those that do not occur annually, although they can occur at intervals longer than one year. Typically, these events are caused by road closures that occur over extended periods of time and where traffic has to be diverted to other roads. Such a diversion can result in either a reduction on roads on which the closure has occurred, or an increase on roads to which traffic has been diverted.

e) Erroneous patterns. These are patterns that are caused by incorrect traffic monitoring (human or equipment related). Examples of such counts include the following:

- Counts that have been identified with the wrong day of the week.
- Counts that have “shifted” in time due to incorrect time settings.
- Erroneous or missing counts over a few hours of the day.

Examples of erroneous traffic patterns are provided in Figures B.1 to B.3.

The classification of traffic patterns into one of the above classes must be undertaken manually by visually inspection of traffic pattern graphs. Professional judgement must be exercised to determine whether a pattern can be classified as normal, abnormal, exceptional, extreme or erroneous.

B.4 Pattern clusters

The manual classification of patterns is not a difficult process but it can be very laborious if it has to be applied to every daily pattern. Use is therefore made of a process in which similar patterns are grouped into groups or clusters of patterns. Once grouped, it is only necessarily to assess a group of patterns and not each individual pattern in the group.

The grouping of daily traffic patterns into clusters can be undertaken by means of the cluster analysis method. This method can be applied to individual counting stations but also to a group of counting stations in a traffic stratum, provided that traffic patterns are similar at the different count stations. Tests should, however, be undertaken to determine if the traffic patterns are similar before the method can be applied to such a group of counting stations.

The grouping of the traffic patterns also differentiate between the seven days of the week. Patterns on Tuesdays, Wednesdays and Thursday, however, tend to be similar and traffic
patterns obtained on these days can thus be grouped together. The following five day-of-the-week groups are therefore used:

- Mondays
- Tuesdays to Thursdays
- Fridays
- Saturdays
- Sundays

Once traffic patterns have been grouped into clusters, it is only necessarily to manually assess and classify groups of traffic patterns rather than individual patterns. A further advantage of the process is that once a cluster has been evaluated, it is not necessary to evaluate the cluster again when new data are added.

**B.5 Cluster analysis**

Cluster analysis is a methodology according to which different systems, such as traffic patterns, can be grouped into fairly homogeneous groups or clusters (Van As, 2013b). The method uses a criterion of some kind to establish distances between the different systems and groups the systems in clusters so that they are near to each other.

Cluster analysis can be undertaken by means of a method known as hierarchical clustering. This method is computationally very extensive, however, and was found to be impractical for use with traffic patterns. Because of the large number of traffic patterns that can be found at some traffic stations, the hierarchical method can result in several hours of computation time for one station alone. The method is also relatively complex and difficult to implement in software.

An alternative approach is the k-means clustering method, which is a relatively simple and fast method that can be applied to very large datasets. The disadvantage of the method is that it is not exact and it could result in different clusters, depending on the initial assignment of clusters. It minimises so-called intra-cluster variance, but does not ensure that the result has a global minimum of variance.

A further disadvantage is that it requires an estimate of the number of clusters (k). An approach was developed in which all traffic patterns are initially first assigned to one cluster (k = 1). The number of clusters is then successively increased (k = 2, 3, 4 …) until no cluster is found with traffic patterns that do not adequately match each other.

The cluster analysis methodology consists of the following steps (applied for each day of the five day-of-the-week groups):

a) Initially assign all traffic patterns (for the day-of-the-week group) to one cluster. Calculate an average pattern for the cluster.

b) Undertake the following calculations for each traffic pattern in the data set:
   i) Find the nearest cluster and determine the distance to the average pattern in this cluster.
   ii) Keep track of the traffic pattern with the longest distance to the nearest cluster.
   iii) If the traffic pattern is not assigned to the nearest cluster, the pattern is reassigned to this cluster. The average patterns of the two affected clusters are not recalculated during this step, but the clusters are marked for later recalculation.
c) Test if any patterns have been reassigned to new clusters during the above steps. If reassignment has occurred, the following steps are undertaken:
   i) Recalculate average patterns for each cluster.
   ii) Repeat process from step b) above until no reassignment occurs.

d) Test if the longest distance calculated in step b) above meets an acceptable threshold value. If not, the following steps are undertaken:
   i) Create a new cluster and move the traffic pattern with the longest distance to this cluster. Establish average pattern for the new cluster.
   ii) Repeat process from step b) above.

The process is repeated until no distances between traffic patterns and cluster averages exceed the acceptable distance threshold. These distance are calculated by means of a distance criterion discussed in the next section.

### B.6 Distance criterion

The cluster analysis method uses a distance criterion to determine the degree to which a particular traffic pattern differs from the average pattern for a cluster. A pattern is considered to match a particular average pattern when the distance is less than a particular threshold value.

The following distance criterion $D$ was developed for this purposes (Van As, 2013b):

$$D = \sqrt{\sum_{i=1}^{24} (P_{Hi} - P_{Ai})^2}$$

In which:

$D$ = Distance criterion  
$P_{Hi}$ = Proportion of daily traffic in hour i (hourly volume as a proportion of $T_H$)  
$P_{Ai}$ = Average proportion for traffic cluster  
$T_H$ = Total 24-hour count for the day

The match between a traffic pattern for a particular day is considered “acceptable” when the distance criterion $D$ is less than or equal to the following threshold value:

$$D_m = 0.05 + \frac{1}{\sqrt{1 + T_H}}$$

In which:

$D_m$ = Distance threshold  
$T_H$ = Total 24-hour count for the day
B.5 Cluster classification

Once clusters of traffic patterns have been established, each cluster must be classified into one of the five classification groups. This is a process that must initially be done manually. Once a number of patterns have been classified, then additional patterns can be added to the previously classified patterns. A new pattern may emerge during the process, but this can then again be classified manually.

One method was identified by Van As (2013b) that can assist in the identification of erroneous patterns. This method is based on the calculation of the average hour for a cluster pattern. A pattern is classified as erroneous when the average hour is before 08:00 or after 17:00. The average hour $H$ is determined as follows:

$$H = \sum_{i=1}^{24} (i - 0.5) \cdot P_{Ai}$$

The average hour test is not perfect, but can assist in the identification of many erroneous counts.
Figure B.1: Example of traffic count on a wrong date

Figure B.2(a): Example of shifted traffic counts (1 hour)
Figure B.2(b): Examples of shifted traffic counts (6 to 12 hours)
Figure B.3: Examples of erroneous traffic counts