TMH 8

Traffic and Axle Load Monitoring Methodologies and Procedures

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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 the traffic monitoring programmes that must be implemented by road authorities in South Africa. A range of aspects associated with such monitoring are covered, including the establishment of 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 prosedures vir Buitestedelike Paaie” which was published in 1987. This previous publication is effectively withdrawn with the publication of this document.
Technical Methods for Highways:

The Technical Methods for Highways consists of a series of publications in which methods are prescribed for use on various aspects related to highway engineering. The documents are primarily aimed at ensuring the use of uniform methods throughout South Africa.

Users of the documents must ensure that the latest editions or versions of the document are used. When a document is referred to in other documents, the reference should be to the latest edition or version of the document.

Any comments on the document will be welcomed and should be forwarded to coto@nra.co.za for consideration in future revisions.

Document Versions

Working Draft (WD). When a COTO subcommittee identifies the need for the revision of existing, or the drafting of new Technical Recommendations for Highways (TRH) or Technical Methods for Highways (TMH) documents, a workgroup of experts is appointed by the COTO subcommittee to develop the document. This document is referred to as a Working Draft (WD). Successive working drafts may be generated, with the last being referred to as Working Draft Final (WDF). Working Drafts (WD) have no legal standing.

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Appendix A: Estimation of static load distributions
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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).

**Automatic monitoring**: Monitoring which is mainly undertaken by means of mechanical and electronic equipment, although some manual assistance may be involved.

**Manual monitoring**: Monitoring which is undertaken manually by humans, although use may be made of mechanical and electronic devices during the monitoring.

**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.
Coverage counting stations. Counting stations used as part of a network-level monitoring programme. Also known as secondary 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. The monitoring is undertaken continuously at permanent counting stations.

Network-level monitoring: Monitoring that is undertaken for the purpose of the management and broad planning of the road network. The network-level data are collected by means of short-term counts at coverage counting stations. The data are collected with a lower level of accuracy.

Project-level monitoring: Monitoring that is undertaken to collect traffic data required for the detail planning and design of road projects. The monitoring is normally undertaken at a higher level of accuracy compared to network-level monitoring.

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.

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 this document, however, all loads and forces are expressed in terms of equivalent mass units (kg). The conversion from force to mass must be undertaken with the standard value for gravitational acceleration.

Gravitational acceleration: The acceleration caused by gravity. A standard value of 9.80665 m/s² may 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 and axle load monitoring 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 the methodologies and procedures that must be followed in the development and implementation of a traffic monitoring programme by road authorities in South Africa. It is important that a common and uniform approach to traffic monitoring should be implemented by all road authorities in the country, and the requirements of this document are therefore prescriptive in nature. However, sufficient provision is made for flexibility and adjustments that may be required to accommodate local or specific conditions.

The document also makes important information available to engineers on the methods and procedures that are used for the collection and derivation of the traffic data that are used for the management, planning and design of roads. Information is provided on the types of traffic data as well as the accuracies with which such data are collected.

The document must be read in conjunction with the following COTO documents that are available on traffic and axle load monitoring:

- TMH 3 Specifications for the Provision of Traffic and Weigh-in-Motion Monitoring Services. Provides a specification for the undertaking and provision of Traffic and WIM monitoring services.
- TMH 14 South African Standard Traffic Data Collection Format. Specifies the format that must be used for the distribution of traffic data.
Traffic and axle load monitoring is the process of measuring and collecting traffic characteristics such as traffic counts and axle loads. The traffic and axle load characteristics that are collected as part of the monitoring programme are mainly intended for use in the engineering management, planning and design of road networks and infrastructure.

This document provides requirements for the development and implementation of a traffic monitoring programme by road authorities in South Africa (national, provincial and municipal). The requirements of the document are prescriptive in nature, although provision is made for variation in local conditions and needs.

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 and wide range of traffic data may be collected such as traffic volumes, vehicle composition and axle loads.

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.

It is therefore essential that all road authorities should implement a traffic monitoring programme and use the collected data for decision-making purposes. The requirements of this document is therefore of a prescriptive nature and must be implemented by all road authorities in South Africa (in both rural and urban areas).

1.2 Purpose

The main intention of this document is to provide requirements for the development and implementation of traffic monitoring programmes by all road authorities. It is important that a common and uniform approach to traffic monitoring should be implemented by all road authorities in the country, and the requirements of this document are therefore prescriptive in nature. However, sufficient provision is made for flexibility and adjustments required to accommodate local or specific conditions.

A further purpose of the document is to make information available to engineers on the methods and procedures that are used for the collection and derivation of traffic data.
Traffic and Axle Load Monitoring Procedures

used for the management, planning and design of roads. Information is provided on the types of data as well as the accuracies with which such data are collected.

The document prescribes the methodologies and procedures that must be used in the establishment of monitoring programmes by road authorities. Information is provide on the traffic data that must be collected as part of such programmes, some of the statistical methods that must be used in the processing of the data and the traffic characteristics which are required by the end-users of the data and which must be collected as part of the traffic monitoring programme.

It is important to note that the document does not contain information on the technologies that must be used for field measurements or observations. Such information is provided in the TMH 3 Specifications for the Provision of Traffic and Weigh-in-Motion Monitoring Service (COTO 2014) document. The TMH 3 document provides a functional specification for the provision of a range of traffic monitoring services. Information is, however, provided in this document on the monitoring services that should be selected for inclusion in a traffic monitoring programme.

1.3 Road authorities

The requirements provided in this document are applicable to all spheres of road authorities in South Africa, including national, provincial and municipal authorities. The methodologies and procedures provided in the document are applicable to both rural and urban roads. Information is provided when it is necessary to implement different methodologies or procedures for different classes of roads.

Each road authority is responsible for monitoring traffic on roads under their jurisdiction. Considerable benefit can however be obtained if different road authorities can cooperate and share traffic data and other resources. An example of traffic data which can be successfully shared is data required for the identification of the main traffic patterns in a region or an area. Another example is data that are collected at permanent counting stations for the development of traffic expansion factors.

The successful sharing of traffic data between different road authorities do require that a common set of practices be followed by different authorities. One of the purposes of this document is to establish such a common set of practices. The cost of a traffic monitoring programme can considerably be reduced if data sources can be shared by different road authorities.

1.4 Road classes

Differentiation is made in this document between roads in urban and rural areas as well as different functional classes of roads. The classes of roads used in this document are based on the definitions of the TRH 26 South African Road Classification and Access Management Manual (COTO 2012).
The TRH 26 manual differentiates between the following road classes:

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<th>TRH 26 Functional Road Classes</th>
<th>Rural Classes</th>
<th>Urban Classes</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1 Rural principal arterial</td>
<td>U1 Urban principal arterial</td>
<td></td>
</tr>
<tr>
<td>R2 Rural major arterial</td>
<td>U2 Urban major arterial</td>
<td></td>
</tr>
<tr>
<td>R3 Rural minor arterial</td>
<td>U3 Urban minor arterial</td>
<td></td>
</tr>
<tr>
<td>R4 Rural collector road</td>
<td>U4a Urban collector street – Commercial</td>
<td></td>
</tr>
<tr>
<td></td>
<td>U4b Urban collector street – Residential</td>
<td></td>
</tr>
<tr>
<td>R5 Rural local road</td>
<td>U5a Urban local street – Commercial</td>
<td></td>
</tr>
<tr>
<td></td>
<td>U5b Urban local street - Residential</td>
<td></td>
</tr>
</tbody>
</table>

Class 1 to 3 roads are mobility roads while Class 4 and 5 roads are access/activity roads.

1.5 Types of traffic data

Various types of traffic data may be required for the management, planning and design of road networks and infrastructure. This includes data such as traffic counts, axle load distributions, operating speeds, origin-destination studies, home or road-side interviews, vehicle-occupancy studies, accident records, etc.

Of these traffic data types, there are three principle types that should be regularly collected by road authorities as part of a traffic monitoring programme. These are the following:

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

The scope of this document is restricted to the above types of traffic data. Other specialised guidelines should be consulted for guidance on the collection of other types of traffic data.

Traditionally, traffic monitoring programmes have concentrated on the collection of traffic volumes, while some limited axle load monitoring has been undertaken even if such monitoring is important for the management and maintenance of road infrastructure. Speed data have been collected as part of some traffic monitoring programmes, but has not yet found wide application. This data have now also been included to address the need for information related to the level of service provided by the road network and to address the impact of speed on road safety.

1.6 Applications of traffic data

Traffic data have a wide range of applications in the management, planning and design of a road network and infrastructure. More information on these applications are provided in this document, but the following are some of the more important applications:

a) Fund allocation. The allocation of funds and other resources for road improvement and maintenance projects.
b) *Management and programming*. Traffic data are required for the identification and prioritisation of road maintenance, rehabilitation and upgrading projects. Such projects may be required for purposes such as the maintenance and rehabilitation of road pavements, improvements to the capacity of a road and for the identification of hazardous locations on the road network.

c) *Travel time and speed trends*. The evaluation of trends in travel times, speeds and other related level-of-service criteria on the road network. The purpose of such evaluation is to monitor any deterioration in the level of service as a result of increased traffic volumes and associated congestion on the road network.

d) *Road design*, including the design of road pavements, road geometry, capacity analysis, safety measures and the economic analysis (project evaluation) of alternatives and proposed road improvements.

Applications such as those listed above are essential for the effective management, planning and design of the road network and infrastructure.

### 1.7 Statistical methods

It is not economically feasible to continuously collect traffic data on all roads in network and, in an effort to reduce costs, use must be made of sampling methods in traffic monitoring programmes. Standard statistical methods and techniques are used for the selection and analysis of such samples.

Some information are provided in this document on the statistical methods that are required for a traffic monitoring programme and the analysis of traffic data. This document, however, is and cannot be a manual on statistical methods. It is therefore essential that persons involved with the development and implementation of a traffic monitoring programme for a road authority should have knowledge and experience in the field of statistical analysis, particularly with the application of statistical methods in the field of road engineering. Such knowledge should include sampling and stratification methodologies.

### 1.8 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) and speed 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 DOCUMENT OVERVIEW

2.1 Introduction

An overview is provided in this chapter of the different elements that are involved in the development and implementation 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 traffic monitoring. A broad understanding of the different elements and aspects is essential for the successful implementation of a traffic monitoring programme.

2.2 Traffic monitoring levels

The applications and purposes 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 monitoring is undertaken:

• System-level monitoring.
• Network-level monitoring.
• Project-level monitoring.

System-level data monitoring is undertaken with the purpose of establishing expansion factors for expanding traffic counts undertaken at short-term counting stations. Network-level monitoring is used for the management and broad planning of the road network while project-level monitoring is undertaken with the purpose of collecting the traffic data required for the detail planning and design of specific road projects.

2.3 Traffic monitoring services

An overview of the traffic monitoring technologies that are available for traffic monitoring are provided in Chapter 4. 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 monitoring services by service providers.

The TMH 3 specifications allow the use of any monitoring 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. Information is provided in the chapter on the monitoring types that should be used as part of a traffic monitoring programme.

2.4 Traffic variation and variability

It is not cost effective to undertake permanent 24-hour, 365 day monitoring on all roads in the country, and use must be made of short-term monitoring. 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 annual traffic volumes on a road unless provision is made for such variation.

The variability of traffic must therefore be taken into account in the development of 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 variability.

2.5 System-level traffic monitoring

Requirements are provided in Chapter 6 for establishing a system-level traffic monitoring programme by a road authority. This programme is required for the determination of expansion factors needed for the expansion of short-term counts undertaken at the network and project levels. Various stratification systems that can be used for deriving such expansion factors are discussed in the chapter.

2.6 Network-level traffic monitoring

In Chapter 7, requirements are provided for road authorities for the establishment of network-level traffic monitoring programmes. Network-level data are collected for purposes such as the identifying and prioritising road maintenance, rehabilitation and improvement projects. Observations made as part of network-level traffic monitoring must be expanded using expansion factors obtained from system-level monitoring.

2.7 Project-level traffic monitoring

Guidelines are provided in Chapter 8 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.
2.8 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 9 of this document. Short-term observations undertaken on abnormal and exceptional days must be excluded from traffic expansion calculations.

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 and vehicle composition.
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 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 Traffic information systems

Traffic monitoring programmes involves the collection, storage and analysis of vast amounts of traffic data. It is therefore essential that computer software in the form of a traffic management system must be available that can be used for this purpose. Requirements for traffic information systems are provided in Chapter 16.

In South Africa, the South African Traffic Information System (SATIS) of the South African National Roads Agency Ltd (SANRAL) is available for use by other road authorities in the country. This system can accommodate various types of monitoring programmes and is suitable for all classes of roads, including rural and urban roads. A major advantage of using SATIS is that it provides an opportunity for different road authorities to share traffic data (which could lead to significant cost reductions).

2.16 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 should be undertaken are provided in Chapter 17 of this document.
2.17 RSA Data format

Chapter 18 provides an overview of the data format that must 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.

2.18 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 19 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.

2.19 References

References to other documents are provided in Chapter 20. These references may be consulted when more detailed information is required on a particular topic.
3 TRAFFIC MONITORING LEVELS

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 monitoring is undertaken, namely:

- System-level monitoring.
- Network-level monitoring.
- Project-level monitoring.

System-level data monitoring is undertaken with the purpose of establishing factors for the expansion of traffic counts undertaken at short-term counting stations. Network-level monitoring is used for the management and broad planning of the road network while project-level monitoring is undertaken with the purpose of collecting the traffic data required for the detail planning and design of specific road projects.

3.1 Introduction

Information is provided in this chapter on the traffic monitoring programmes that must be implemented by road authorities. An overview is provided on the traffic data that should be collected as well as the applications of the applications for which such data should be used. More details of these requirements are provided in other chapters of this document.

A fundamental issue in the development of a traffic monitoring programme is that it is not cost-effective to undertake permanent or continuous monitoring of traffic on all roads in a network. Sampling methods must therefore be used which involves a combination of short- and long-term monitoring. The long-term monitoring is undertaken at a relatively small number of permanent while short-term monitoring is used for most traffic observations.

There are generally three main levels at which traffic monitoring is undertaken, namely:

- System-level monitoring.
- Network-level monitoring.
- Project-level monitoring.

The traffic data that must be collected at each of the above levels together with the applications of such data are discussed in the following sections of this chapter.

3.2 System-level monitoring

System-level monitoring is undertaken with the purpose of establishing expansion factors that must be used for expanding traffic observations at short-term counting stations. The
majority of traffic observations on road networks are made at short-term counting stations and such observations must be expanded to provide annual traffic characteristics. The system-level monitoring is undertaken at a relatively small number of permanent counting stations representative of the major traffic patterns on the road network.

System-level monitoring is an essential component of any traffic monitoring programme and must therefore be implemented in all such programmes. Different authorities may, however, co-operate and share data in appropriate situations.

It is important to note that system-level data are only collected with the purpose of establishing expansion factors. The data could also coincidentally 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 monitoring

Network-level monitoring is undertaken for the collection of traffic data that are required for the management and broad planning of the road network and infrastructure. The network-level data are collected by means of short-term counts at coverage counting stations.

Network-level data are normally collected at a lower level of accuracy than that required at a project level. Data collected at the network level may therefore not be adequate at the project level and additional data may be required at the project level. There are, however, situations in which data collected at the network level could also be used at a project level. In some cases, it may be possible to extend the network level data at no or little additional cost for use at the project level.

Network-level data do not have to be collected for all roads (or homogenous traffic segments) under the jurisdiction of the authority. The traffic monitoring should mainly be focussed on the more important classes of roads as well as those carrying higher volumes of traffic. Monitoring on other roads may not be required, or only required for specific purposes or at reduced sampling rates.

The management and broad planning of a road network requires that traffic data should be collected for the following purposes:

a) *Project identification and prioritisation*. The identification of various types of road related projects, the ranking or prioritisation thereof and the allocation of funds to the different projects. The following are some of the more important types of projects for which network-level traffic data are required:

i) *Road pavement maintenance and rehabilitation projects* for the maintenance and rehabilitation of road pavements. These projects also include the upgrading of gravel roads to paved roads.

ii) *Road safety projects* for the identification of hazardous locations on the road network and the prioritisation of road safety improvements. Traffic volumes and accident records are required for this purpose.

iii) *Capacity analysis projects* aimed at improving the capacity of and the level of service provided by the roads in the network. However, care should be taken when using traffic counts in congested road networks. In
such networks, traffic counts may not be representative of actual traffic demand and traffic demand models should then rather be used for estimating the required traffic volumes.

b) *Travel statistics.* The collection of travel statistics on the network and the monitoring of trends in such statistics over time. The following are some important statistics for which network-level data are required:

i) **Amount of travel.** This statistic involves determination of the annual vehicle-kilometres of travel on the road network. The purpose of this statistic is to provide an indication of the service provided by the road network. The statistic may also be used for purposes of fund allocation.

ii) **Travel speeds.** The collection and analysis of trends in travel speeds on the road network. The purpose of this statistic is to monitor possible deterioration in the level of service experienced by traffic as a result of increased traffic volumes and congestion on the road network.

Ideally, statistics should also be collected on travel times and delays experienced on the road network, but such statistics cannot be collected by means of normal traffic monitoring methods. It is, however, possible to measure spot speeds by such methods and such speeds should be used for evaluating the trends.

The most important of the above purposes for which network-level data are collected is the identification of *road pavement maintenance and rehabilitation projects.* This application is the main justification for undertaking network-level monitoring. The other purposes are also important, but if it was not for the need to road pavement preservation, would not have been sufficient to warrant an extensive network-monitoring programme. The requirements of this document are therefore primarily aimed at traffic data required by pavement management systems. Other purposes are also taken into account, but are not considered to be the main focus of the network-level monitoring programme.

### 3.4 Project-level data

Project-level monitoring is monitoring that is required for the collection of data required for detailed planning and design purposes. The data are also collected by means of short-term counts, but normally at a higher level of accuracy than that required at the network level.

Project-level data should be collected for all road projects, irrespective of the class or importance of the project. In some instances, the data collected at the network-level may be sufficient for such use, but in many cases additional data may be required at the project level. This would also include other types of data not covered by this document.

It is important that provision should be made in the traffic monitoring programme for the collection of project-level data on an ad-hoc basis (including data that are not covered by this document). Where possible, the collection of such data should be coordinated with the collection of network-level data. This would be possible if projects can be identified before the start of a monitoring year and the project-level monitoring combined with the
network-level monitoring. The data collected for the project-level application can then also be used at the network level.

Some of the applications for which project-level data may be used are listed below. However, different projects have different needs and it is not possible to provide a comprehensive list to cover all applications. Some guidance on the traffic data that are required at the project level is provided in this document, but this guidance is of a general nature. The engineers and planners involved with a project are responsible for identification of the traffic data required for each specific project.

a) Road pavement analysis and design, including strength requirements.
b) Road safety analysis and modelling, including the analysis and evaluation of alternative remedial measures.
c) Geometric design of roads, including road alignment, road width and the provision of passing and climbing lanes.
d) Capacity analysis. The analysis of the capacity and level of service provided by the road (the road itself as well as intersections along the road).
e) Traffic engineering applications, such as traffic signal design (traffic signal plans, phasing and timings) and traffic impact assessments.
f) Noise and vehicle emission analysis and modelling, as well as the evaluation of alternative mitigating measures.
g) Economic analysis (project evaluation) of alternatives and proposed road improvements.
4 TRAFFIC MONITORING SERVICES

This chapter provides an overview of technologies that can be used for the monitoring of traffic. An important consideration in the development of a monitoring programme is that all monitoring technologies have certain limitations that must be taken into account when developing the 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. Requirements for the monitoring types that must be included in a monitoring programme are provided in the chapter.

4.1 Introduction

In South Africa, the TMH 3 Specifications for the Provision of Traffic and Weigh-in-Motion Monitoring Service (COTO 2014) are available for the specification of the provision of traffic and WIM monitoring services by service providers. These specifications are of a functional nature and it is only necessary to specify the type and accuracy of traffic data that are required without specifying the technology that must be used for the provision of traffic monitoring services.

The main purpose of this chapter is to describe the services that are available in TMH 3 and the services that should be included in a traffic monitoring programme. A range of options are provided in TMH 3 and it is necessary to indicate the options that should be selected for inclusion in a traffic monitoring programme.

An important consideration in the selection of a traffic monitoring service is that each type of service has certain limitations with regard to data that can be collected. It is not possible to monitor all traffic characteristics and traffic monitoring programmes must therefore be limited to those are considered essential for a traffic monitoring programme.

4.2 TMH 3 Specifications

The TMH 3 (COTO, 2014) specifications are used in South Africa for specifying the provision of traffic and weight-in-motion monitoring services. Differentiation is made in the document between automatic and manual monitoring, but otherwise the specifications are of a generic or 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. These include, inter alia, requirements such as detection capabilities (capabilities of detecting certain traffic characteristics) and accuracy requirements.

The specifications also provide for the certification of monitoring systems and service providers by an independent certification organisation. Any service provider that is certified by this organisation may offer his services, but on condition that such services is provided by means of a certified monitoring system (for automatic monitoring). The specifications provide for the following certification:

- **Traffic and WIM Monitoring Service Provider Certification**: The certification of service providers for the provision of automatic monitoring services.
- **Manual Traffic Monitoring Service Provider Certification**: The certification of service providers for the provision of manual monitoring services.
- **Traffic and WIM Monitoring System Certification**: The certification of monitoring systems that may be used for automatic traffic monitoring.

Particular emphasis is given in TMH 3 to the quality assurance measures that must be implemented by service providers in the provision of monitoring services. Such measures must be implemented for both automatic and manual traffic monitoring services.

### 4.3 Automatic monitoring

Automatic traffic and WIM monitoring is monitoring that is undertaken by means of mechanical and electronic equipment, although some manual assistance may be involved in the monitoring. Any technology may be used for automatic monitoring, provided that it complies with the functional and accuracy specifications of TMH 3.

Differentiation is made in TMH 3 between five types of automatic traffic monitoring systems (types A to E) and between two accuracy levels (1 and 2). The following systems can be specified:

a) **Type A** traffic monitoring systems which provide for vehicle, speed, axle and single/dual tyre detection. These systems provided for the monitoring of characteristics such as traffic volumes, vehicle lengths, speeds, number of axles, axle spacing and tyre configuration (single or dual). 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 accuracy.

The main difference between Type A and the other systems is the provision for **single/dual tyre detection**. This data 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, speed and axle detection but without single/dual tyre detection. These systems provide for the monitoring of characteristics such as traffic volumes, vehicle lengths, speeds, number of axles and axle spacing, 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 or 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. These systems provide for the monitoring 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 for vehicle length measurements (either directly or derived). 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.

d) **Type D** traffic monitoring systems without speed, axle and single/dual tyre detection. These are basic systems which only provide for traffic counts and not for the monitoring of characteristics such as vehicle lengths, 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.

e) **Type E** traffic monitoring systems without vehicle and single/dual tyre detection but with speed and axle detection. These systems provide for the monitoring of characteristics such as number of axles and axle spacing, but vehicle units and lengths cannot be directly detected or measured but can be indirectly identified or estimating from axle spacing data. Differentiation is made between the following two accuracy classes:

i) **Type E1** systems with a relatively high level of detection and a medium to low level of vehicle classification (categorization) accuracy.

ii) **Type E2** systems with relatively low levels of detection and vehicle classification (categorization) accuracy.

The Type E1 systems have some capability of identifying light and heavy vehicles and also to differentiate between different lengths of heavy vehicles, but they are most useful to classify heavy vehicles in accordance to number of axles. The systems become less accurate at higher volumes of traffic and are therefore more suitable for use on low to medium volume roads.

For high-speed weigh-in-motion (HS WIM) axle load monitoring, provision is made in TMH 3 for the following three accuracy classes:

a) **Class I** - Relatively high level of accuracy. This level of accuracy can usually only be achieved on roads with very smooth surfaces.

b) **Class II** - Higher level of accuracy. This level of accuracy is recommended for roads that carry medium to high volumes of heavy vehicle traffic and where a higher level of accuracy is required.

c) **Class III** - Lower level of accuracy. This level of accuracy is recommended for roads that carry low volumes of heavy vehicle traffic and where a lower level of accuracy is acceptable.

Axle load monitoring is usually undertaken in combination with traffic monitoring. Type B2 traffic monitoring should be undertaken in the lanes in which HS WIM monitoring is undertaken while Type C1 monitoring is usually undertaken on other lanes.

### 4.4 Manual monitoring

Manual monitoring is monitoring that is undertaken manually by humans, although use may be made of mechanical and electronic devices during the monitoring.

Provision is made in TMH 3 for the following three types of manual monitoring, each with a different level of accuracy and quality control:

a) **Type M1 video-based monitoring** in which videos are used to record traffic and the traffic is manually monitored from the videos. This method offers a high level of accuracy and quality control for manual traffic monitoring.

b) **Type M2 individual monitoring** in which devices are used to register particulars of each passing vehicle on the road. This method offers an intermediate level of accuracy and quality control for manual traffic monitoring.
c) **Type M3 interval monitoring** in which cumulative counts of passing traffic are made in time intervals. This method offers a lower level of accuracy and quality control for manual traffic monitoring.

A significantly higher level of quality control is possible with Types M1 and M2 monitoring compared with Type M3 monitoring. The cost of Type M1 and M2 monitoring may be higher than that of Type M3 monitoring, but the additional cost may be justified.

Specifications are also provided in TMH 3 for two types of sites at which manual traffic monitoring may be undertaken. Provision is made for the following:

a) **Link monitoring sites** where monitoring is undertaken between intersections. The site may be located some distance away from the intersection or directly adjacent to an intersection. The monitoring should preferably be undertaken per direction of travel, but would normally not be required per lane. This is the default specification of TMH 3, but it may be amended if non-directional or per-lane monitoring is required.

b) **Intersection monitoring sites** where monitoring is undertaken at intersections. The specifications only provide for manual traffic monitoring at priority and signal controlled intersections and roundabouts and interchanges are excluded from the scope of the specifications. The specifications require that the turning movements from the different approaches must be monitored separately.

Type M3 monitoring at both link and intersection sites should preferably be undertaken in 15-minute intervals. This is also the default specification of TMH 3, but it may be amended if other intervals are required.

The specifications do not provide for intersections such as roundabouts and interchanges, although individual intersections at roundabouts and in interchanges may be counted. Roundabouts and interchanges often require more complex surveys such as origin-destination studies which are not covered by the TMH 3 specifications.

The specific sites at which manual monitoring must be undertaken must be specified. For link monitoring, however, provision is made in TMH 3 for the specification of a road link rather than a specific position on the link. In such situations, it becomes the responsibility of the service provider to select a location on the link which is reasonably representative of average traffic volumes on the link.

When manual link monitoring is required on lower-volume roads, significant cost savings can be achieved if the monitoring is undertaken adjacent to intersections. Fieldworkers can then simultaneously count traffic on more than one link of the road network. This approach, however, may only be followed when the traffic count adjacent to an intersection is fairly representative of average traffic volumes on the link.
4.5 Traffic monitoring types

As indicated in the previous sections, provision is made in TMH 3 for a wide range of monitoring types with different levels of capabilities in order to accommodate a range of applications. The monitoring type that is most suitable for a particular application will depend on the type of data that is required as well as the cost of the monitoring service.

The following monitoring types are recommended for use in traffic monitoring programmes. The monitoring type with the lowest cost should be selected in instances where a choice is available between alternatives.

a) **System-level monitoring** at permanent counting stations:
   i) Type C1 (automatic) traffic monitoring.

b) **Network-level monitoring** at coverage counting stations. The monitoring types depend on the required monitoring durations, as follows:
   i) 7 or 14-Day monitoring: Type C1 automatic.
   ii) 1 or 2-Day monitoring: Types C1 or E1 automatic.
   iii) 12 or 18-Hour monitoring: Manual or Types C1 or E1 automatic.

c) **Project-level monitoring.** A range of monitoring types may be used, depending on the application. A monitoring programme should therefore make provision for a relative wide range of possible applications. The following are the types that would find most application:
   i) Road design (paved and gravel roads): Type C1 (automatic), possibly supplemented with manual monitoring (for additional vehicle classes such as public and non-motorised transport).
   iii) Toll monitoring at toll plazas: Type B1 automatic.
   iv) Research purposes: Preferably Type A1 automatic but other types may also be used.

d) **Axle load monitoring:**
   i) HS WIM Lanes: Type B2 automatic monitoring in the HS WIM (high-speed weigh-in-motion) lanes
   ii) Other lanes: Type C1 automatic monitoring (on other lanes).

The following classes of HS WIM monitoring are recommended:
   i) Class II on roads carrying medium to high volumes heavy vehicle traffic.
   ii) Class III WIM on roads carrying low volumes heavy vehicle traffic.

For manual traffic monitoring, preference should be given to Types M1 and M2 monitoring due to the higher level of quality control possible with these systems. Type M3 can be considered for purposes of network-monitoring but Types M1 and M2 should preferably be used for project level monitoring.
5 TRAFFIC VARIATION AND VARIABILITY

Variability in traffic is an important consideration in the development of a traffic monitoring programme. 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

A fundamental issue in the development of a traffic monitoring programme is that is not cost-effective to undertake permanent or continuous traffic monitoring on all roads of a network and use must be made of short-term monitoring. Traffic monitoring is therefore basically a sampling process in which use is made of statistical methods to establish the most cost-effective monitoring programme.

Short-term counts can result in a significant under- or overestimation of the annual traffic volumes on a road. In the development of a traffic monitoring programme, it is therefore essential that the factors that may affect traffic sampling should be well understood. The purpose of this chapter is to address these issues, including the issues of systematic and random variability in traffic data.

5.2 Systematic and random variability

Traffic flow is subject to both systematic and random variation. Systematic variation is the variation that is found in average flows. Random variation is the variation that occurs around the averages due to random factors. Systematic variation can usually be predicted while random variation is unpredictable.

An example of systematic variation is the variation in average daily flow patterns over the different hours of the day or days of the week as shown in Figure 5.1. This figure provide examples of average 24-hour daily patterns on rural and urban roads.

Random variation is the variation of traffic around average flow patterns and cannot easily be shown on graphs such as provided in Figure 5.1. Such variation is therefore usually studied using statistical distributions as provided in the other figures in this chapter.

Random variation has a significant impact on the sampling of traffic. If there were no random variation in traffic, then it would only be necessary to take a sample over say one day or week of the year to obtain an accurate estimate estimation of the annual traffic characteristics (assuming that the systematic variation in the average pattern is known).
Random fluctuation, however, can significantly reduce the accuracy with which the annual characteristics can be derived.

Systematic variation can be addressed by means of the use of expansion factors. These factors are used for expanding a short-term count to equivalent annual characteristics assuming that the average traffic pattern over the year is known (derived from another long-term counting station). These factors, however, cannot be used for addressing random variation, and the impact of such variation can only be addressed by either the judicial selection of samples or by increasing the duration over which traffic is sampled (effectively increasing sample sizes).

5.3 Traffic variation

Research in South Africa (Papenfus and Van As, 2014) has indicated that the following variation in traffic volumes is typically found on most roads:

- 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.

5.4 Time-of-day variation

Time-of-day variation is the variation in traffic that occurs over the different hours of a day as illustrated in Figure 5.1. The same variation is also shown in Figure 5.2, for different days of the week. Examples are provided in these figures of the systematic variation in average traffic flow patterns on roads in different types of areas (rural, semi-urban and urban).

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 used to address the systematic variation in average flow over the day. In the use of such factors, the assumption is made that the average traffic flow pattern is known for the day (derived from another long-term counting station). Expansion factors are then derived from this assumed traffic flow pattern and applied to the short-term count in order to estimate the 24-hour count.
The examples provided in Figures 5.1 and 5.2 only show the systematic variation in traffic and not the random variation. The random fluctuation must be studied using statistical distributions such as shown in Figure 5.3(a) and 5.3(b). These figures show the distribution 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 particular counting station.

The random variation are shown in the figures by means of cumulative frequency distributions. These distributions show the cumulative proportion of days with a ratio smaller than or equal to a particular value. Only normal day traffic counts were used for the derivation of the distributions. Differentiation is made in the figures between five days of the week (Mondays to Fridays). The figures are typical of the variability found at most counting stations. In general, there is some random variation in the 12/24 hour count on normal days, but for the total traffic, this variation is generally limited or very small (on normal days only and not for heavy vehicles).

There is also variation in the 12/24 hour count ratios (normal days) between different counting stations as shown in Figures 5.4(a) and 5.4(b). These figures show the distribution of average 12/24 hour count ratios (for normal days) for a large range of counting stations.

Figure 5.4(a) shows the variation for the total traffic stream. The figure shows that generally 80% (0.8) of the total traffic stream travels during the 12-hour period on normal days, but there are some roads on which this proportion is either lower or higher. In general, it would appears that the 24-hour normal day traffic can be estimated with a relatively high level of accuracy from a 12-hour normal-day count.

Figure 5.4(b) shows the variation for heavy vehicles. This figure shows a relatively high variation for heavy vehicles. The accuracy with which 24-hour daily heavy vehicle traffic can be estimated from a 12-hour count can therefore be expected to be poor.

It is important to note that Figures 5.1 to 5.4 only show variation that occurs on normal days. The variation on abnormal days are significantly greater than on normal days and the accuracy of traffic counts on abnormal days are significantly poorer than counts on normal days.

5.5 Day-of-the-week variability

Day-of-the-week variability is the variation in traffic over the different days of the week. Examples of the systematic variation in the average normal day patterns are shown in Figure 5.2 for different rural and urban road classes. The examples are fairly typical of patterns found in South Africa (on normal days), but there are roads on which different patterns may be found. In general, the Friday pattern tend to be different from the other days of the week. There are also examples in which the Monday pattern is also different. The patterns for Tuesdays, Wednesdays and Thursday are in many cases the same. Also note the flattening of the afternoon peak on Fridays on urban roads. Such flattening often occurs in urban areas.

Examples of the random variation in daily traffic at a particular counting station are shown in Figures 5.5(a) and 5.5(b). These figures show the cumulative frequency distributions of
Traffic and Axle Load Monitoring Procedures

daily flows (expressed as a ratio of the AADT). Figure 5.5(a) is applicable to normal days and 5.5(b) to abnormal days.

The different figures do show that the significant differences in traffic volumes can occur during the different days of the week. The volumes on Fridays are often particularly different from those on the other days of the week. Weekday variation is therefore a significant factor that must be accounted for by means of expansion factors.

5.6 Normal and abnormal day variation

Studies in South Africa has shown that traffic patterns are fairly stable on normal days but that significant variation may occur on other days of the week. This is illustrated by the cumulative distributions provided in Figures 5.5(a) and 5.5(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 5.5(a) shows that the variation in daily flows is relatively small on normal days. This is typical for most roads in South Africa. Figure 5.5(b), however, shows a large variation for abnormal days. The figure does show that there may be abnormal days on which the traffic is similar to that of normal days, but no methodology is available for the identification of such days. The methodology that is used for the identification of normal days (described elsewhere in this document) is conservative to ensure that most abnormal days are identified.

The examples provided in Figures 5.5(a) and 5.5(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 the volumes 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. Expansion factors, however, are still required to expand a normal day count to an annual traffic volume (to account for the impact of abnormal day traffic).

5.7 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:
Traffic and Axle Load Monitoring Procedures

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, but 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 5.6.

Traffic observations that are undertaken on days on which such exceptional variation occurs must 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.

For long-term observations, days with exceptional variation must 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.

The above requirements are summarised in the following table:

<table>
<thead>
<tr>
<th>Count Application</th>
<th>Included Days</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short-term counts for expansion</td>
<td>Normal days, excluding exceptional and extreme days</td>
</tr>
<tr>
<td>Long-term counts used for determination of expansion factors</td>
<td>Normal days, excluding exceptional and extreme days</td>
</tr>
<tr>
<td>Long-term counts used for derivation of annual characteristics</td>
<td>Normal and Abnormal days, including exceptional days but excluding extreme days</td>
</tr>
</tbody>
</table>

5.8 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. Where such growth occurs, use must be made of monthly adjusted factors to account for such growth.
5.9 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 some seasonal variation do occur in light vehicle traffic but that it is mostly heavy vehicle traffic which can be significantly affected by such variation. The seasonal variation in heavy vehicle traffic occurs 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.
Figure 5.1: Examples of typical average daily traffic patterns
Figure 5.2: Examples of typical average weekly traffic patterns

1. 1125: Wonderfont R33 (MS18) R033/ 01 Km 37.8
   Between Carolina and Wonderfontein
   Rural stratum

2. 1009: Technopark N001/ 21 Km 13.8
   Eastern side of Brakfontein N1/N14/R28 I/C
   Semi-urban stratum

3. 5024: Polkadraai PAN R310/ Km 19.0
   Between Blackheath and Stellenbosch
   Urban stratum
Figure 5.3(a): Example of variation in 12-Hour/24-Hour count ratios – Total traffic

Figure 5.3(b): Example of variation in 12/24-Hour count ratios – Heavy vehicles
Figure 5.4(a): Variation in average 12/24-Hour count ratios – Total traffic

Figure 5.4(b): Variation in average 12/24-Hour count ratios – Heavy vehicles
Figure 5.5(a): Example of variation in daily traffic – Normal Days

Figure 5.5(b): Example of variation in daily traffic – Abnormal Days
Figure 5.6: Examples of exceptional traffic (extreme events)
6 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.

6.1 Introduction

Due to the cost involved with traffic monitoring, most traffic data that are required on network and project levels are collected by means of short-term monitoring. Data collected during such monitoring is expanded by means of expansion factors derived from system-level monitoring.

System-level monitoring is undertaken at a relatively small number of permanent counting stations with the purpose of deriving 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 the only purpose of system-level monitoring is to collect the data that is required for establishing expansion factors. The data could also coincidentally be used for network- and project-level applications, but such use should not be taken into account when planning a system-level monitoring programme.

6.2 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.

6.3 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. It is also important that the system should be continuously monitored and adjusted to accommodate possible changes in traffic patterns on the road network.

The initial research can be based on short-term traffic data collected as part of the network-level monitoring programme. Counts of 24 hours or longer can be used for the identification of daily traffic patterns while 7-day counts or longer can be used for the identification of weekly patterns on the road network (normal days only). Provision should, however, also be made for long-term (365 day) monitoring at strategic locations on the road network with the purpose of identifying the different annual traffic patterns on the road network (for both normal and abnormal days of the year).

### 6.4 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 traffic regions, and a stratification system should be developed for each such region.

Several alternative stratification methods were investigated by Papenfus and Van As (2014) as well as by Van As (2016). The following stratification methods were identified:

a) Trip-purpose stratification method  
b) Holiday stratification method  
c) Dual stratification method (combination of trip-purpose and holiday methods)

Road authorities may implement any of these methods. The dual stratification method, however, is generally more accurate and is therefore the recommended method. For 7-day counts and longer, however, accuracy is not significantly improved by the method and the holiday stratification method is recommended for such counts. More details are given in the following sections of this chapter.

<table>
<thead>
<tr>
<th>Count duration</th>
<th>Recommended stratification method</th>
</tr>
</thead>
<tbody>
<tr>
<td>12, 18, 24 and 48 h</td>
<td>Dual stratification</td>
</tr>
<tr>
<td>7 and 14 days</td>
<td>Holiday stratification</td>
</tr>
</tbody>
</table>
6.5 Trip purpose stratification method

The trip purpose stratification method may be used as a stand-alone system or in combination with the holiday stratification method (as explained in the following section in this chapter). The trip purpose method is primarily based on the peaking characteristics of typical traffic flow patterns found on South Africa roads (on normal days).

The trip-purpose stratification is based on the following three traffic 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.
- **Semi-urban stratum** with traffic patterns typically found on roads serving urban areas but with relatively low peaking during the morning (AM) peak period. The term “urban-low” can also be used for this stratum.
- **Urban stratum** with traffic patterns typically found on roads also serving urban areas but where the peaking is relatively high. The term “urban-high” can also be used for this stratum.

**Peaking Factor**

The differentiation between the above three strata is based on a traffic characteristic called the “Peaking Factor”. Only the morning (AM) peak is taken into account for determining this factor 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 when counts are taken over more than one day:

- For 48-hour (2-day) counts, separate Peaking Factors are determined for each day counted and a stratum determined for each day.
- For 7-day and 14-day counts, a single Peaking Factor is determined for the average pattern of the three midweek days, i.e. Tuesdays to Thursdays during a week and a stratum determined for each week.

The formula is also used when stratifying long-term counting stations for purposes of determining expansion factors:

- For the expansion of one or two day counts, separate Peaking Factors are determined for the average patterns of the five days of the week, i.e. Mondays to Fridays and a stratum determined for each day.
- For the expansion of 7-day or 14-day counts, a single Peaking Factor is determined for the average pattern of the three midweek days, i.e. Tuesdays to Thursdays and a single stratum determined for the count.
Trip-purpose stratification

The trip-purpose stratum for a count is determined as follows:

- *Rural stratum.* This stratum is selected when the peak hour is found to occur later than 09:00 in the morning.
- *Semi-urban stratum.* This stratum is selected when the Peaking Factor $F_{PE}$ is smaller than or equal to the threshold values given below.
- *Urban 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 Figures 5.1 and 5.2 provided in Chapter 5 of this document. 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 stratum is higher than that of the semi-urban stratum.

The threshold values for differentiation between the semi-urban and urban strata are as follows:

<table>
<thead>
<tr>
<th>Peaking Factor threshold values for Semi-urban and Urban</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mon</td>
</tr>
<tr>
<td>-----</td>
</tr>
<tr>
<td>14%</td>
</tr>
</tbody>
</table>

Extended trip-purpose stratification

An extended version of the trip-purpose stratification method is available that can be used for the expansion of 7- and 14-day traffic counts (Papenfus and Van As, 2014). For this purpose, a weekend factor is used to subdivide each of the primary strata (rural, semi-urban and urban) into a further three substrata resulting in a total of nine strata in the stratification system.

The three substrata for each of the primary strata are as follows:

- *Weekend Low* indicating a relatively low amount of traffic on normal weekends.
- *Weekend Medium* indicating a medium amount of traffic on normal weekends.
- *Weekend High* indicating a relatively high amount of traffic on normal weekends.

A Weekend Factor $F_{WE}$ is used to subdivide the primary strata into the above three substrata. The weekend factor for 7-day counts (normal days) is calculated as follows:

$$F_{WE} = \text{Traffic count from 18:00 on Friday to 06:00 on Monday as a \% of the 7-day count}$$

The threshold values for differentiation between the three substrata are as follows:

<table>
<thead>
<tr>
<th>F_{WE} threshold values for substrata</th>
</tr>
</thead>
<tbody>
<tr>
<td>Substrata</td>
</tr>
<tr>
<td>Low</td>
</tr>
<tr>
<td>Medium</td>
</tr>
<tr>
<td>High</td>
</tr>
</tbody>
</table>
The research by Papenfus and Van As (2014) has shown that expansion factors for some of the nine substrata could be similar which would allow the combination of substrata. Reducing the number of substrata has the advantage that fewer system-level counting stations are required. Substrata may therefore be combined when it is found that the traffic patterns for the different substrata are similar.

### 6.6 Holiday traffic stratification method

The aim of the holiday traffic stratification method is to account for variation in traffic on abnormal days. 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. Other terms that may be used include “abnormal” and “recreational”. The method can either be used as a stand-alone system or in combination with the trip purpose system in the dual stratification system.

The holiday stratification method is based on the following five traffic 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.

#### Normal Day ADT Ratio

The differentiation between the five holiday strata is based on a traffic characteristic called the “Normal Day ADT Ratio”. The ratio is defined as:

\[
\text{Normal Day ADT Ratio} = \frac{\text{Normal day ADT}}{\text{AADT}}
\]

In which:

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

The following thresholds are used for determining the holiday strata:

<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>
Derivation of the Normal Day ADT Ratio

The Normal Day ADT Ratios required for the holiday stratification for long-term counting stations are directly derived from the traffic data. For such counting stations, the ratios can be precisely calculated and the holiday stratum ratios are therefore precisely known.

For short-term counts, however, it is not possible to determine the ratios from the traffic data since neither the normal day ADT or the AADT are available from such counts. It is, however, possible to obtain an estimate of the ratio by means of linear regression analysis involving certain traffic characteristics derived from the short-term count (Van As, 2014).

The holiday stratification can be used as a stand-alone system or combined with the trip purpose method in the dual stratification system. When used in a stand-alone system, a single set of regression formulae is used for estimating the Normal Day ADT Ratio:

\[
\text{Normal Day ADT Ratio} = \beta_0 + \beta_1 \cdot T_1 + \beta_2 \cdot T_2 + \cdots 
\]

Stand-alone system

In the dual stratification system, separate sets of regression formulae are used for each of three trip purpose strata (i.e. rural, semi-urban and urban), as follows:

- **Rural stratum**
  \[
  \text{Normal Day ADT Ratio} = \beta_{R0} + \beta_{R1} \cdot T_1 + \beta_{R2} \cdot T_2 + \cdots 
  \]

- **Semi-urban stratum**
  \[
  \text{Normal Day ADT Ratio} = \beta_{S0} + \beta_{S1} \cdot T_1 + \beta_{S2} \cdot T_2 + \cdots 
  \]

- **Urban stratum**
  \[
  \text{Normal Day ADT Ratio} = \beta_{U0} + \beta_{U1} \cdot T_1 + \beta_{U2} \cdot T_2 + \cdots 
  \]

In which:

- \(\beta_i\) = Regression parameters (for different formulae)
- \(T_i\) = Traffic characteristics used for estimating the Normal Day ADT Ratio

Traffic characteristics

Various traffic characteristics may be used in the regression analysis formulae for the estimation of the Normal Day ADT Ratio. A number of such characteristics was identified in an investigation by Van As (2016) that showed some correlation with the ratio. The characteristics are listed below and are defined as follows:

a) **Daily factors** (for different vehicle classes). The number of vehicles counted during a certain period of the day as a proportion of the total number of vehicles counted during the day (or part of the day for counts shorter than 24 hours). These factors are available for all count durations.

b) **Weekly factors** (for different vehicle classes). The number of vehicles counted during a day of the week (Mondays to Sundays) as a proportion of the total number of vehicles counted during the week. Counts on Tuesdays, Wednesdays and Thursdays are combined and an average “midweek” count determined for the days. The weekly factors are only available for 7-day counts (and longer).

c) **Proportion heavy vehicles.** The number of heavy vehicles counted as a proportion of the total number of vehicles, either for a specific day of the week (Mondays to Sundays) or for the full period of the count.

d) **Short heavy vehicle split.** The number of short heavy vehicles counted as a proportion of the number of heavy vehicles for the full period of the count. This parameter is optional and can be used when available from a short-term count.
Traffic characteristics for estimating the Normal Day ADT Ratio

<table>
<thead>
<tr>
<th>Class</th>
<th>Characteristic</th>
<th>Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light</td>
<td>Daily Factor</td>
<td>06:00-12:00</td>
</tr>
<tr>
<td>Heavy</td>
<td>Daily Factor</td>
<td>12:00-18:00</td>
</tr>
<tr>
<td></td>
<td>Proportion</td>
<td>12 Hours</td>
</tr>
<tr>
<td>Short</td>
<td>Split</td>
<td>12 Hours</td>
</tr>
</tbody>
</table>

12-Hour Counts

<table>
<thead>
<tr>
<th>Class</th>
<th>Characteristic</th>
<th>Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light</td>
<td>Daily Factor</td>
<td>00:00-06:00</td>
</tr>
<tr>
<td></td>
<td></td>
<td>06:00-12:00</td>
</tr>
<tr>
<td></td>
<td></td>
<td>12:00-18:00</td>
</tr>
<tr>
<td>Heavy</td>
<td>Daily Factor</td>
<td>00:00-06:00</td>
</tr>
<tr>
<td></td>
<td></td>
<td>12:00-18:00</td>
</tr>
<tr>
<td></td>
<td>Proportion</td>
<td>24 Hours</td>
</tr>
<tr>
<td>Short</td>
<td>Split</td>
<td>24 Hours</td>
</tr>
</tbody>
</table>

24-Hour Counts

<table>
<thead>
<tr>
<th>Class</th>
<th>Characteristic</th>
<th>Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light</td>
<td>Daily Factor</td>
<td>00:00-06:00</td>
</tr>
<tr>
<td></td>
<td></td>
<td>06:00-12:00</td>
</tr>
<tr>
<td></td>
<td></td>
<td>12:00-18:00</td>
</tr>
<tr>
<td>Heavy</td>
<td>Daily Factor</td>
<td>00:00-06:00</td>
</tr>
<tr>
<td></td>
<td></td>
<td>12:00-18:00</td>
</tr>
<tr>
<td></td>
<td>Proportion</td>
<td>24 Hours</td>
</tr>
<tr>
<td>Short</td>
<td>Split</td>
<td>24 Hours</td>
</tr>
</tbody>
</table>

18-Hour Counts

<table>
<thead>
<tr>
<th>Class</th>
<th>Characteristic</th>
<th>Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light</td>
<td>Daily Factor</td>
<td>00:05-06:00 plus</td>
</tr>
<tr>
<td></td>
<td>Daily Factor</td>
<td>06:00-12:00</td>
</tr>
<tr>
<td>Heavy</td>
<td>Daily Factor</td>
<td>00:05-06:00 plus</td>
</tr>
<tr>
<td></td>
<td></td>
<td>18:00-22:00</td>
</tr>
<tr>
<td></td>
<td>Proportion</td>
<td>18 Hours</td>
</tr>
<tr>
<td>Short</td>
<td>Split</td>
<td>18 Hours</td>
</tr>
</tbody>
</table>

7-Day Counts

<table>
<thead>
<tr>
<th>Class</th>
<th>Characteristic</th>
<th>Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light</td>
<td>Weekly Factor</td>
<td>Sunday</td>
</tr>
<tr>
<td></td>
<td>Weekly Factor</td>
<td>Saturday</td>
</tr>
<tr>
<td></td>
<td>Daily Factor</td>
<td>Saturday 18:00-24:00</td>
</tr>
<tr>
<td></td>
<td>Daily Factor</td>
<td>Saturday 12:00-18:00</td>
</tr>
<tr>
<td></td>
<td>Daily Factor</td>
<td>Friday 00:00-06:00</td>
</tr>
<tr>
<td>Heavy</td>
<td>Daily Factor</td>
<td>Midweek 00:00-06:00</td>
</tr>
<tr>
<td></td>
<td>Daily Factor</td>
<td>Midweek 12:00-18:00</td>
</tr>
<tr>
<td></td>
<td>Proportion</td>
<td>Week</td>
</tr>
<tr>
<td>Heavy</td>
<td>Split</td>
<td>Week</td>
</tr>
</tbody>
</table>

Figure 6.1: Map showing holiday traffic strata for different counting stations
Manual stratification adjustment

The regression formulae for the estimation of the Normal Day ADT Ratio cannot be expected to produce perfectly correct holiday strata in all situations and errors can therefore be expected, especially when shorter traffic counts are undertaken (particularly 12-hour counts). An advantage of the holiday stratification system is that it provides an opportunity for manually adjusting the stratification in situations where it is clear that the formula has resulted in the selection of an erroneous stratum.

The manual adjustment of a holiday traffic stratum must be approached with great caution since the selection of inappropriate strata could result in significant errors. The adjustments should only be undertaken when there is a high level of confidence that the stratification can be improved by manual adjustment.

The manual adjustment can be undertaken with the assistance of a stratification map similar to the one shown in Figure 6.1. This map shows the holiday strata derived from both 7-day and long-term counting stations. 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 in an area or along a road. Judgement can then be applied to identify erroneous strata and for selecting more appropriate strata.

Occurrence of holiday strata

The holiday strata described above were derived using data that were obtained from various locations in the country. It is therefore possible that some of the holiday strata may not occur in a specific area. Road authorities should therefore undertake an investigation to determine the set of strata that is most appropriate to their circumstances.

The data that were used by Papenfus and Van As (2014) were analysed to determine the occurrence of the holiday strata. The table below shows the percentage distribution of traffic strata for the holiday stratification method for different trip-purpose strata in the data set. The table shows the following:

- **d)** Rural trip-purpose stratum. For this stratum, there is a relatively even distribution of holiday strata, except for the negative holiday stratum. This stratum does occur but in small numbers.
- **e)** Semi-urban trip purpose stratum. For this stratum, the majority of holiday strata falls in the range of low to negative holiday traffic, although the high and medium strata do occur but in relatively small numbers.
- **f)** Urban trip-purpose stratum. For this stratum, there are few locations with holiday traffic. The holiday strata, however, can be expected to occur in greater numbers in major holiday destinations.

<table>
<thead>
<tr>
<th>Holiday strata</th>
<th>Rural</th>
<th>Semi-urban</th>
<th>Urban</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td>High holiday</td>
<td>5.0%</td>
<td>2.4%</td>
<td>0.0%</td>
<td>7.4</td>
</tr>
<tr>
<td>Medium holiday</td>
<td>5.2%</td>
<td>5.0%</td>
<td>0.1%</td>
<td>10.3</td>
</tr>
<tr>
<td>Low holiday</td>
<td>5.9%</td>
<td>16.5%</td>
<td>0.1%</td>
<td>22.5</td>
</tr>
<tr>
<td>No holiday</td>
<td>3.7%</td>
<td>17.3%</td>
<td>5.5%</td>
<td>26.5</td>
</tr>
<tr>
<td>Negative holiday</td>
<td>0.5%</td>
<td>18.8%</td>
<td>13.9%</td>
<td>33.3</td>
</tr>
</tbody>
</table>
The above distribution is also illustrated by the annual traffic graphs shown in Figure 6.2. Graphs are shown for two different counting stations classified as rural according to the trip-purpose method. The one station, however, has been stratified as negative holiday and the other as high-holiday traffic. The expansion factors required for these two stations would therefore be significantly different, even if both have been stratified as rural.

The above analysis shows that holiday traffic is a major consideration on roads, particularly those with a rural stratification. It is also an important factor on semi-urban roads, but less important for roads that have been stratified as urban. However, holiday traffic will be a major factor at holiday destinations.

6.7 Accuracy of short-term counts

Research was undertaken in South Africa on the accuracies that can be obtained from short-term traffic counts using the different traffic stratification systems (Papenfus and Van As (2014), Van As (2016)). The data that were used for the research were mostly collected on rural roads as well as the higher classes of urban roads. Very limited data were available for urban streets and the results obtained during the investigation are therefore not applicable to such streets.

The results of the investigation by Van As (2016) are shown in Table 6.1 below. The accuracies provided in the table are the highest of the 5% and 95% percentiles of the error distributions. The percentage errors in the traffic characteristics will be smaller than those indicated in 90% of cases (or slightly more).

The accuracies are provided for the following traffic characteristics:

a) AADT of the total traffic stream.
b) AADT of heavy vehicles.
c) Hourly volume in the 30th highest hour of the year (normal and abnormal days).
d) Hourly volume in the 15th highest normal hour of the year.

The above traffic characteristics were obtained by expanding the following traffic counts:

a) The AADT (of the total traffic stream) is expanded from the average daily count.
b) The AADT of heavy vehicles is expanded from the average heavy vehicle count.
c) The 30th and 15th highest volumes are expanded from the following counts:
   i) For counts shorter than 7 days, from the average daily traffic count.
   ii) For counts of 7 days and longer, from the highest observed hourly count.

The above methods for estimating the 30th and 15th highest volumes were found to be the most accurate by Van As (2016).

The accuracies are shown in the tables for the different counting durations:

a) 12 Hour count from 06:00 to 18:00.
b) 18 Hour count from 04:00 to 22:00.
c) 24 Hour count from 00:00 to 24:00.
d) 48 Hour count over two days.
e) 7-Day counts.
f) 14-Day counts.
Accuracies are provided for the following stratification systems:

a) None – No stratification system applied.
b) Trip purpose stratification system (without the holiday system).
c) Holiday stratification system (without the trip purpose system).
d) Dual stratification system (combination of trip purpose and holiday systems).
e) Perfect knowledge based dual stratification system. This system is similar to the regression based system but assumes that the Normal Day ADT Ratio is precisely known (and not estimated by means of regression analysis). This is a theoretical system since such knowledge is only available for long-term counts. The system does, however, provide an indication of the upper limit for the accuracy that can be achieved with a regression based system.

The investigation by Van As (2016) was based on three data sets and the accuracies provided in the table were those obtained from a data set in which counts were available for light and heavy vehicles (but not for short, medium and long classes of heavy vehicles). The accuracy of the holiday stratification system can be further improved if such data are incorporated in the regression analysis but such data are not always available.

**Growth rates**

Short-term counts are normally not repeated every year with the result that traffic volumes must be estimated during years in which counts are not available. These volumes are then estimated on the basis of growth rates which are derived from previous counts. These growth rates, however, cannot be expected to be accurate and will probably contain errors in the same order than the counts.

The accuracies of traffic volumes estimated on the basis of both inaccurate counts and inaccurate growth rates will be significantly worse than those provided in Table 6.1. This applies to all traffic stratification systems and counting durations, but the counting systems with the poorer accuracies can be expected to become progressively poorer. The inaccuracies can become excessive if traffic has to be projected over long periods of times. This can be avoided by repeating traffic counts at more regular intervals.

**Comparison of traffic stratification systems**

Table 6.1 shows that accuracies are generally improved by the implementation of a stratification system. The accuracy of all traffic characteristics are improved although some improvements are very slight (such as with the 15th highest hour volumes). In general, however, it is beneficial to implement some form of stratification system.

The holiday and dual stratification methods generally provide better accuracies than the trip-purpose system. The dual method does not improve the accuracy significantly except for the short-duration counts. For the longer duration counts (e.g. 7-days and longer) it is adequate to only implement the holiday stratification system.
Table 6.1: 90% Error Intervals (*) for different stratification methods

<table>
<thead>
<tr>
<th>Estimated characteristic</th>
<th>Stratification Method</th>
<th>Count duration</th>
<th>12 hr</th>
<th>18 hr</th>
<th>24 hr</th>
<th>48 hr</th>
<th>7 Day</th>
<th>14 Day</th>
</tr>
</thead>
<tbody>
<tr>
<td>AADT</td>
<td>None</td>
<td></td>
<td>33%</td>
<td>26%</td>
<td>20%</td>
<td>20%</td>
<td>14.3%</td>
<td>14.0%</td>
</tr>
<tr>
<td></td>
<td>Trip purpose</td>
<td></td>
<td>31%</td>
<td>23%</td>
<td>18%</td>
<td>18%</td>
<td>8.6%</td>
<td>7.7%</td>
</tr>
<tr>
<td></td>
<td>Holiday</td>
<td></td>
<td>24%</td>
<td>16%</td>
<td>15%</td>
<td>13%</td>
<td>6.9%</td>
<td>6.2%</td>
</tr>
<tr>
<td></td>
<td>Dual</td>
<td></td>
<td>23%</td>
<td>16%</td>
<td>15%</td>
<td>13%</td>
<td>6.9%</td>
<td>6.2%</td>
</tr>
<tr>
<td></td>
<td>Perfect knowledge</td>
<td></td>
<td>19%</td>
<td>14%</td>
<td>13%</td>
<td>11%</td>
<td>5.9%</td>
<td>5.0%</td>
</tr>
<tr>
<td>AADT Heavy vehicles</td>
<td>None</td>
<td></td>
<td>58%</td>
<td>32%</td>
<td>21%</td>
<td>19%</td>
<td>7.8%</td>
<td>7.2%</td>
</tr>
<tr>
<td></td>
<td>Trip purpose</td>
<td></td>
<td>47%</td>
<td>27%</td>
<td>18%</td>
<td>16%</td>
<td>7.4%</td>
<td>6.6%</td>
</tr>
<tr>
<td></td>
<td>Holiday</td>
<td></td>
<td>48%</td>
<td>20%</td>
<td>15%</td>
<td>13%</td>
<td>7.2%</td>
<td>6.6%</td>
</tr>
<tr>
<td></td>
<td>Dual</td>
<td></td>
<td>44%</td>
<td>19%</td>
<td>16%</td>
<td>13%</td>
<td>7.2%</td>
<td>6.5%</td>
</tr>
<tr>
<td></td>
<td>Perfect knowledge</td>
<td></td>
<td>34%</td>
<td>19%</td>
<td>17%</td>
<td>13%</td>
<td>7.1%</td>
<td>6.4%</td>
</tr>
<tr>
<td>30th Highest hour of the year</td>
<td>None</td>
<td></td>
<td>60%</td>
<td>54%</td>
<td>51%</td>
<td>49%</td>
<td>43%</td>
<td>42%</td>
</tr>
<tr>
<td></td>
<td>Trip purpose</td>
<td></td>
<td>51%</td>
<td>42%</td>
<td>41%</td>
<td>39%</td>
<td>26%</td>
<td>25%</td>
</tr>
<tr>
<td></td>
<td>Holiday</td>
<td></td>
<td>54%</td>
<td>43%</td>
<td>41%</td>
<td>37%</td>
<td>18%</td>
<td>16%</td>
</tr>
<tr>
<td></td>
<td>Dual</td>
<td></td>
<td>49%</td>
<td>42%</td>
<td>41%</td>
<td>39%</td>
<td>18%</td>
<td>16%</td>
</tr>
<tr>
<td></td>
<td>Perfect knowledge</td>
<td></td>
<td>36%</td>
<td>32%</td>
<td>28%</td>
<td>29%</td>
<td>16%</td>
<td>15%</td>
</tr>
<tr>
<td>15th Highest hour on Normal days</td>
<td>None</td>
<td></td>
<td>35%</td>
<td>30%</td>
<td>27%</td>
<td>28%</td>
<td>14%</td>
<td>12%</td>
</tr>
<tr>
<td></td>
<td>Trip purpose</td>
<td></td>
<td>34%</td>
<td>29%</td>
<td>26%</td>
<td>26%</td>
<td>12%</td>
<td>9%</td>
</tr>
<tr>
<td></td>
<td>Holiday</td>
<td></td>
<td>33%</td>
<td>28%</td>
<td>27%</td>
<td>26%</td>
<td>12%</td>
<td>9%</td>
</tr>
<tr>
<td></td>
<td>Dual</td>
<td></td>
<td>33%</td>
<td>28%</td>
<td>27%</td>
<td>26%</td>
<td>12%</td>
<td>9%</td>
</tr>
<tr>
<td></td>
<td>Perfect knowledge</td>
<td></td>
<td>31%</td>
<td>26%</td>
<td>25%</td>
<td>25%</td>
<td>12%</td>
<td>9%</td>
</tr>
</tbody>
</table>

(*) 90% Error Intervals reported as the largest of the 5th and 95th error percentiles

The higher accuracy obtained with the holiday stratification method compared to the trip-purpose method is mainly due to the following two factors:

a) The regression analysis used by the holiday stratification method accounts for a greater number of traffic characteristics than the trip-purpose method.

b) Holiday traffic is an important consideration that is directly taken into account by the holiday stratification method. Holiday traffic is only indirectly accounted for by the trip-purpose method.

Comparison of counting durations

A general conclusion that can be made from Table 6.1 is that accuracies are significantly affected by the count duration (on rural roads). Significant improvements in accuracy can be obtained by counting over longer periods. Taking the impact of growth rates derived from counts into account, the relatively poor accuracies of shorter counts can be expected to become significantly poorer during the later years in a counting cycle. This impact can be reduced by using a shorter counting cycle, but this will significantly increase monitoring costs.
The accuracies of 12-hour counts are particularly poor, particularly for heavy vehicles. These accuracies can be expected to be even worse when growth rates must be estimated from the 12-hour counts. This implies that 12-hour counts should only be used when a very low level of accuracy is required.

Significant improvements can be obtained by counting over 18 hours, particularly for heavy vehicles. Growth rates based on 18-hour counts, however, cannot be expected to be accurate and will result in increased inaccuracies over time. This implies that 18-hour counts should only be used when a relatively low level of accuracy is required.

Better accuracies can be obtained by means of 48-hour counts. Growth rates will still be relatively inaccurate, but will have less of an impact compared to the shorter-duration counts. The 48-hour counts can therefore be used when a medium level of accuracy is required.

The best accuracies can be obtained from 7- or 14-day counts. Growth rates may still contain errors, but the impact of these errors would be significantly lower compared to the shorter-duration counts. These counts should therefore be used when a relatively high level of accuracy is required.

One of the main issues with counts shorter than 24 hours is the high variability that is found in heavy vehicle volumes during the different hours of the day (on rural roads). Counting throughout the 24 hours of the day is therefore important to improve the accuracy of heavy vehicle volumes (FHWA, 2013). In Chapter 3 it was stated that the main focus of a network-level counting programme is the identification of road pavement maintenance and rehabilitation projects. The accuracy with which such projects would be identified can be significantly improved by using counts over periods of 48 hours and longer.

**Important note:** The accuracies provided above are only applicable to rural roads and the higher classes of roads in urban areas (mostly Class 1 and 2) and not to urban streets. On urban streets, it is generally accepted that greater accuracy can be obtained. In many cases, 12-hour counts on urban street are generally considered to provide sufficient accuracy. Further research is, however, required to confirm the accuracies of traffic counts on urban streets.

### 6.8 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 may 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. The system can be based on an initial selection of regions, but the number of regions may have to be adjusted based on the traffic patterns that were observed in the different regions. Once a system has been established, continuous investigations will be required to adjust the regions in accordance to possible changes that may occur in traffic patterns.
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 normal day hour and the 30th highest hour (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).
e) 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 the monthly distribution of traffic.

6.9 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) and Van As (2016). This variation was measured in terms of the coefficients of variation 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 coefficients of variation can therefore be regarded as approximate population values (for rural areas).

The coefficients of variations were determined as the ratio of the standard deviation to the mean of the expansion factors, expressed as a percentage. The coefficients are provided in the two tables below for 12-hour and 7-day counts respectively. The coefficients for the 12-hour counts are the largest that were obtained from any of the days of the week.

The coefficients provided in the tables 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, is used to determine the 95% confidence interval:

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

- **CI**: 95% Confidence interval, as a percentage of the expansion factor
- **CV**: Coefficient of variation of an expansion factor as provided in the tables
- **n**: Number of counting stations from which expansion factors are derived

Recommended maximum confidence intervals are provided in the tables below. 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 per traffic stratum.

The recommended number of stations provided in the tables is the minimum needed for establishing expansion factors with acceptable confidence intervals. The tables do not provide for additional “research” stations that may be required for the identification of annual traffic patterns in a region. The provision of such stations is discussed in the following section.

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

#### Trip Purpose Stratification

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Vehicle class</th>
<th>Required CI (%)</th>
<th>Coefficients of Variation (%) per stratum</th>
</tr>
</thead>
<tbody>
<tr>
<td>AADT</td>
<td>Total</td>
<td>±15.0%</td>
<td>Rural 16%</td>
</tr>
<tr>
<td></td>
<td>Heavy</td>
<td>±35.0%</td>
<td>Rural 36%</td>
</tr>
<tr>
<td>30&lt;sup&gt;th&lt;/sup&gt; Total</td>
<td>±35.0%</td>
<td>Rural 37%</td>
<td>Semi-urban 25%</td>
</tr>
<tr>
<td>15&lt;sup&gt;th&lt;/sup&gt; Total</td>
<td>±20.0%</td>
<td>Rural 21%</td>
<td>Semi-urban 19%</td>
</tr>
</tbody>
</table>

| Recommended No of stations per stratum | 5 | 4 | 3 |

#### Holiday Traffic Stratification

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Vehicle Class</th>
<th>Required CI (%)</th>
<th>Coefficients of Variation (%) per stratum</th>
</tr>
</thead>
<tbody>
<tr>
<td>AADT</td>
<td>Total</td>
<td>±15.0%</td>
<td>High 15%</td>
</tr>
<tr>
<td></td>
<td>Heavy</td>
<td>±35.0%</td>
<td>High 26%</td>
</tr>
<tr>
<td>15&lt;sup&gt;th&lt;/sup&gt; Total</td>
<td>±35.0%</td>
<td>High 29%</td>
<td>Medium 25%</td>
</tr>
<tr>
<td>30&lt;sup&gt;th&lt;/sup&gt; Total</td>
<td>±20.0%</td>
<td>High 23%</td>
<td>Medium 25%</td>
</tr>
</tbody>
</table>

| Recommended No of stations per stratum | 6 | 6 | 3 | 3 | 3 |

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

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Vehicle Class</th>
<th>Required CI (%)</th>
<th>Coefficients of Variation (%) per stratum</th>
</tr>
</thead>
<tbody>
<tr>
<td>AADT</td>
<td>Total</td>
<td>2.5%</td>
<td>High 2%</td>
</tr>
<tr>
<td></td>
<td>Heavy</td>
<td>2.5%</td>
<td>High 3%</td>
</tr>
<tr>
<td>15&lt;sup&gt;th&lt;/sup&gt; Total</td>
<td>5.0%</td>
<td>High 13%</td>
<td>Medium 12%</td>
</tr>
<tr>
<td>30&lt;sup&gt;th&lt;/sup&gt; Total</td>
<td>15.0%</td>
<td>High 5%</td>
<td>Medium 4%</td>
</tr>
</tbody>
</table>

| Recommended No of stations per stratum | 5 | 3 | 3 | 3 | 3 |
6.10 Research monitoring

The recommendations provided in the previous section are applicable to the number of system-level counting stations that are required for establishing expansion factors. The recommendations, however, do not provide for additional "research" counting stations that may be needed for the development of the system-level monitoring programme and identification of traffic patterns on a road network. Additional long-term counting stations are required for this purpose.

The development of the system-level monitoring can be partly based on traffic data collected as part of the network-level monitoring programme, but such data does not provide sufficient information on the variation of traffic patterns over a year. "Research" monitoring must therefore be undertaken over a full year to identify such annual traffic patterns.

It is recommended that the research monitoring should be undertaken at a minimum of three (3) locations in each traffic region. This number should be increased to about ten (10) per region during the initial development of the stratification system. The research monitoring should be undertaken for a period of one calendar year at different locations on the road network. New locations must be selected each year on the road network for this purpose. The aim of such monitoring is to identify the different annual traffic patterns on the road network and for the derivation of the holiday stratification map.

6.11 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 can 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 (on rural roads):

- AADT of about 7 500 vehicles per day on two-lane roads (both directions)
- AADT of about 10 000 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 the road network. Such locations include the following:

- Near to intersections with poor 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).

### 6.12 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 combinations of percentage Normal and Abnormal days counted are provided in Figures 6.3 to 6.5.

When there are gaps in the traffic data, the AADT may be estimated as a weighted average using the following formula:

\[
AADT = \frac{N_{ny} \cdot ADT_n + N_{ay} \cdot ADT_a}{N_{ny} + N_{ay}}
\]

In which:

- \(ADT_n\) = Average daily traffic on normal days that were counted
- \(ADT_a\) = Average daily traffic on abnormal days that were counted
- \(N_{ny}, N_{ay}\) = Number of normal and abnormal days in the full year

The 15th highest hour volume on normal days is estimated as follows:

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

With:

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

In which:

\( Q_{15} \) = Estimated 15\(^{th} \) 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

For the estimation of the 30\(^{th} \) highest hour volume on all days of the year, the hourly volumes for all days of the year counted must be sorted from high to low and a highest hour \( i \) determined in which:

\[ H_i < 30 \leq H_{i+1} \]

with:

\[ H_i = \sum_{j=1}^{i} h_j \]

\( h_j = \frac{N_{ny}}{N_{nc}} \) when highest hour \( j \) falls on a normal day
\( h_j = \frac{N_{ay}}{N_{ac}} \) when highest hour \( j \) falls on an abnormal day

In which:

\( N_{ny}, N_{ay} \) = Number of normal and abnormal hours (or days) during the full year
\( N_{nc}, N_{ac} \) = Number of normal and abnormal hours (or days) counted

The 30\(^{th} \) highest hour volume is then interpolated by means of the following formula:

\[ Q_{30} = \frac{T_{a,i} \cdot (H_{i+1} - 30) + T_{a,i+1} \cdot (30 - H_i)}{H_{i+1} - H_i} \]

In which:

\( Q_{30} \) = Estimated 30\(^{th} \) highest hour volume on all days of the year
\( T_{a,i} \) = Traffic count during the \( i \)\(^{th} \) highest hour on all days counted
Figure 6.2: Daily normal and abnormal day traffic volumes (Rural stratum)
Figure 6.3: AADT Confidence intervals for different percentages of days counted

Figure 6.4: 15th Highest hour confidence intervals for different percentages of days counted
Figure 6.5: 30th Highest hour confidence intervals for different percentages of days
7 NETWORK-LEVEL TRAFFIC MONITORING

Requirements are provided in this chapter for the establishment of network-level traffic monitoring programmes by road authorities. Such monitoring is undertaken for the purpose of managing and the broad planning of the road network, including the identification and prioritisation of road maintenance and improvement projects.

Due to the high cost of traffic monitoring, it is not possible to continuously monitor traffic on each road section in the network. Network-level monitoring is therefore undertaken by means of short-term observations which may be frequently repeated to ensure that the latest traffic information is available. The stations at which network-level monitoring is undertaken are known as coverage counting stations (the term secondary counting stations may also be used).

7.1 Introduction

Requirements are provided in this chapter for the establishment of network-level traffic monitoring programmes by road authorities. Such monitoring is undertaken for the purpose of managing and the broad planning of the road network, including the identification and prioritisation of road maintenance and improvement projects.

Due to the high cost of traffic monitoring, it is not possible to continuously monitor traffic on each road section in the network. Network-level monitoring is therefore undertaken by means of short-term observations which may be frequently repeated to ensure that the latest traffic information is available. The stations at which network-level monitoring is undertaken are known as coverage counting stations (the term secondary counting stations may also be used).

7.2 Homogeneous traffic sections

The first step in the development of a network-level traffic monitoring programme is to subdivide the road network 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 approximately the same over the length of the section.

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 major traffic generators that would significantly affect traffic volumes or axle loading along the section.

Increasing the number of homogeneous sections on a road network would improve the accuracy of traffic counts but also significantly increase the cost of traffic monitoring. A compromise between accuracy and cost is thus required. As a guideline, the following maximum differences may be allowed:

a) The maximum difference between the volumes at any point on a link and the point at which the count is taken should not exceed 10% of the traffic count.

b) The maximum difference between any two volumes on a link should not exceed 15% of the lower of the two counts.
During the development of a network-level monitoring programme, judgement will have to be exercised in estimating the variation in traffic volumes on a road section. In uncertain situations, additional traffic counts may be required to confirm the selected sections. Such counts can be undertaken with a lower level of accuracy than required for normal network-level monitoring.

### 7.3 Network-level monitoring durations and frequencies

Once the road network has been subdivided into homogeneous road sections, a network-level monitoring programme can be developed. Such a programme involves establishing the durations of traffic counts and the frequency with which the monitoring is undertaken (as well as the scheduling of the monitoring).

The required duration and frequency of traffic counts at the network level is a compromise between the cost of such counts and the cost of the impact of wrong decisions made on the basis of inaccurate traffic data. Decisions risks can be reduced by increasing count duration and frequency but this could result in very high counting costs.

A count which is too high compared to actual traffic volumes has less of an impact than a count that is too low. A high count would indicate a need for road maintenance or rehabilitation too early but such decision will be based on a project-level count. The only consequence of a too high count is therefore that an unnecessary project-level count was undertaken. This cost of this consequence is therefore fairly low.

However, a count which is too low compared to the actual traffic can have a significant impact since such count may result in a road maintenance or rehabilitation project being delayed. Every year that such a project is delayed will result in an unnecessary increase in fuel consumption, tyre wear and vehicle maintenance costs resulting from a deterioration of the road pavement. Such increase will be experienced by all vehicles and not only heavy vehicles. These costs can be significantly higher than the cost of traffic monitoring (particularly at higher traffic volumes).

The accuracy of traffic counts is affected by both the monitoring (counting) duration as well as frequency. Counting frequency has a particularly significant impact on accuracy since traffic volumes must be estimated by means of growth rates during intermediate years. Growth rates based on previous inaccurate counts will also be inaccurate with the result that the traffic projections will become progressively worse if applied over too long periods. Network-level monitoring should therefore be repeated at regular intervals.

The recommended network-level monitoring durations and frequencies provided in the table below were derived on the basis of the above considerations. Road authorities may deviate from these recommendations on the basis of a cost-benefit analysis of the consequence of inaccurate counts.

The durations and frequencies provided in the table depend on the AADT volumes and different classes of road. Differentiation is made in the table between Class R1 to R5 rural roads and Class U1 to U5 urban roads. The AADT will not be available during the initial development of a traffic monitoring program and judgement will be required to estimate an initial AADT. For subsequent counts, the AADT obtained from previous counts may be used to determine the required duration and frequency.
**AADT (veh/day) at which different count durations and frequencies are required**

<table>
<thead>
<tr>
<th>Road Class</th>
<th>12-hour</th>
<th>18-hours</th>
<th>48-hour</th>
<th>7-day</th>
<th>14-day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class R1-R3</td>
<td>&lt; 250</td>
<td>&lt; 750</td>
<td>&lt; 2 500</td>
<td>&lt; 7 500</td>
<td>&gt; 7 500</td>
</tr>
<tr>
<td>Class R4-R5</td>
<td>&lt; 250</td>
<td>&lt; 750</td>
<td>&lt; 2 500</td>
<td>&lt; 7 500</td>
<td>&gt; 7 500</td>
</tr>
<tr>
<td>Class U1-U3</td>
<td>&lt; 250</td>
<td>N/A</td>
<td>&lt; 10 000</td>
<td>&lt; 25 000</td>
<td>&gt; 25 000</td>
</tr>
<tr>
<td>Class U4/U5</td>
<td>&lt; 10 000</td>
<td>N/A</td>
<td>N/A</td>
<td>&lt; 25 000</td>
<td>&gt; 25 000</td>
</tr>
<tr>
<td>Gravel Roads</td>
<td>&lt; 250</td>
<td>&lt; 500</td>
<td>&gt; 500</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

### 7.4 Network-level monitoring durations

The requirements for network-level monitoring given in the previous section are based on the monitoring durations provided below. It is important to note that all short-term monitoring should be undertaken on normal days.

- **a)** 12-Hour monitoring undertaken during the period from 06:00 to 18:00 on normal weekdays (Mondays to Fridays).
- **b)** 18-Hour monitoring undertaken during the period from 04:00 to 22:00 on normal weekdays (Mondays to Fridays).
- **c)** 48-Hour monitoring. This monitoring is undertaken over 24-hour periods on two normal weekdays (Mondays to Fridays).
- **d)** 7-Day monitoring. This monitoring is undertaken over 24-hour periods on each of the normal seven days of the week (Mondays to Sundays).
- **e)** 14-Day monitoring. This monitoring is similar to 7-day monitoring, except that each of the seven days of the week must be monitored twice.

According to TMH 3 Specifications for the Provision of Traffic and Weigh-in-Motion Monitoring Service (COTO 2014), automatic monitoring does not have to be undertaken on consecutive days. It is, however, required that the days may not be selected further than 3 months apart (but all days must be selected from the same year).

### 7.5 Network-level monitoring frequencies

The requirements for network-level monitoring provide for the following two monitoring frequencies:

- **a)** 3-Year frequency, which would require recounting during each three-year monitoring programme.
- **b)** 5-Year frequency, which would require recounting during approximately every second three-year monitoring programme.

Where possible, an attempt should be made to repeat the counts at a counting station during the same month of the year. This would reduce the possible impact of traffic growth during the year as well as seasonal variation over the year when it is necessary to determine a traffic growth rate.
7.6 Travel statistics

The requirements provided in the previous sections of this chapter are applicable to network-level monitoring that is required for the purpose of identifying and prioritising road maintenance and improvement projects. The counts required for this purpose must be collected on most of the rural classes of roads and the higher classes of urban roads. Such counts, however, are not necessarily representative of general travel on a road network and may therefore not be adequate for the production of general travel statistics.

Provision is made in this document for the production of the following travel statistics:

a) Amount of travel, the total vehicle-kilometre of travel on the road network.
b) Travel speeds, the monitoring in trends in travel speeds on the road network.

This document only provides for a limited or partial monitoring of travel speeds on a selection of roads of the network. The monitoring is limited to speeds that are normally collected during automatic traffic observations and no additional monitoring for obtaining speed data is required. Travel speeds alone does not provide a full indication of the impact of congestion on the road network since delays experienced at intersections (and other bottlenecks) are not taken into account. Travel speeds can, however, provide a useful indicator of the service provided by freeways as well as other major roads in rural areas. It is therefore recommended that trends in speeds should be monitored, but that such monitoring should be restricted to a selected number of major roads in the network (particularly freeways).

The determination of the total amount of travel on a road network, however, cannot be determined on the basis of monitoring on a restricted selection of major roads on the network. Traffic monitoring required for this purpose, however, does not have to be undertaken on all roads on the network and the amount of travel can be estimated from a representative sample of roads on the network.

The sample of roads must be selected randomly from all homogeneous road sections in the road network, irrespective of whether or not the road sections have been included in the normal counting programme. It is obviously not necessary to recount road sections for which counts are already available, but additional counts will be required on roads that have either not been selected previously or which do not form part of the counting programme. Older counts may be used provided that the counts are not older than six (6) years. Appropriate growth rates must be applied to such older counts.

The road sections must be selected by means of a random number generator. An algorithm must be used in which weights are assigned to road links in proportion to the length (in km) of the links. There must be a greater probability of selecting a longer link than a shorter link.

A method is given below that can be used to determine the size of the sample of selected road sections that are required to produce a required confidence interval. This method is approximate and can only be used when sample sizes are large. Various other simplifying assumptions are also made but these should be acceptable for this particular application.
The total annual amount of travel (in units of millions of veh-km) on the road network is estimated by means of the following formula:

\[ T = \frac{365 \cdot \overline{AADT} \cdot L}{1000000} \]

In which:
- \( T \) = Total annual amount of travel (millions of veh-km)
- \( \overline{AADT} \) = Average AADT on the network (veh/day)
- \( L \) = Total length of the road network (km)

The average AADT can be determined by means of stratified sampling methods in which the different road classes are used for the stratification. This stratification should not be confused for the traffic stratification method used for deriving expansion factors and this stratification is purely used for obtaining representative samples. The samples are selected from each road class (stratum) in proportion to the number of homogeneous road sections each class. The following formula is used for this purpose:

\[ n_k = p_k \cdot n \]

\[ p_k = \frac{N_k}{N} \]

In which:
- \( n \) = Total sample size
- \( n_k \) = Proportional number of samples in road class \( k \)
- \( N \) = Total number of homogeneous sections on road network
- \( N_k \) = Number of homogeneous sections in road class \( k \)
- \( p_i \) = Proportion of homogeneous sections in road class \( k \)

The average AADT on the network can be determined from the sample by using the following formula:

\[ \overline{AADT} = \sum_k p_k \cdot \overline{AADT}_k \]

With:

\[ \overline{AADT}_k = \frac{\sum i l_{ik} \cdot AADT_{ik}}{\sum i l_{ik}} \]

In which:
- \( \overline{AADT} \) = Average AADT on the network (veh/day)
- \( \overline{AADT}_k \) = Average AADT for class \( k \) roads in the network (veh/day)
- \( p_k \) = Proportion of homogeneous sections in road class \( k \)
- \( AADT_{ik} \) = AADT determine for the \( i^{th} \) sample in road class \( k \) (veh/day)
- \( l_{ik} \) = Length of the \( i^{th} \) sample in road class \( k \) (km)

The required sample size \( n \) can be determined by means of confidence intervals. For the determination of such confidence intervals, it is first necessary to investigate the underlying population distribution of AADT volumes on the different road sections on the road network. Examples of such distributions are shown in Figure 7.1. These distributions were obtained from about 4500 counting stations on the rural roads (Classes 1 to 5). Similar data were not available for urban roads.
The distributions in Figure 7.1 show that the AADT volumes on different road sections tend to follow a Lognormal Distribution. The weighted mean and standard deviation for this distribution can be determined using the following formula:

\[
\begin{align*}
m_k &= \frac{\sum l_{ik} \cdot \ln(AADT_{ik})}{\sum l_{ik}} \\
s_k &= \sqrt{\frac{n_k \cdot \sum l_{ik} \cdot (\ln(AADT_{ik}) - m_k)^2}{(n_k - 1) \cdot \sum l_{ik}}} 
\end{align*}
\]

In which:

- \( m_k \) = Weighted mean for the Lognormal Distribution for road class \( k \)
- \( s_k \) = Weighted standard deviation for the Lognormal Distr for road class \( k \)
- \( AADT_{ik} \) = AADT determine for the \( i \)th sample in road class \( k \) (veh/day)
- \( l_{ik} \) = Length of the \( i \)th sample in road class \( k \) (km)
- \( n_k \) = Sample size for road class \( k \)

The following means and standard deviations were determined for the distributions shown in Figure 7.1:

<table>
<thead>
<tr>
<th>Road class k</th>
<th>Class R1</th>
<th>Class R2</th>
<th>Class R3</th>
<th>Class R4</th>
<th>Class R5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean ( m_k )</td>
<td>8.18</td>
<td>7.50</td>
<td>6.23</td>
<td>5.26</td>
<td>4.89</td>
</tr>
<tr>
<td>Std Dev ( s_k )</td>
<td>1.080</td>
<td>1.394</td>
<td>1.572</td>
<td>1.384</td>
<td>1.292</td>
</tr>
</tbody>
</table>
The confidence interval for the Lognormal Distribution can be determined by means of the following approximate formula. The formula can only be used when sample sizes are large (as can be expected). Only the formula for the upper confidence interval is given since this interval is wider than the lower confidence interval. The formula also determines the confidence interval as a proportion of the mean AADT. The approximate formula for the upper 95% confidence interval $C$ is as follows:

$$C \equiv \exp\left(1.96 \cdot \sqrt{\frac{(N - n)}{N} \cdot \sum_k p_k \cdot s_k^2 \cdot \left(1/n_k + \frac{1}{2} \cdot s_k^2 / (n_k - 1)\right)} - 1\right)$$

The following is a further approximation that does not introduce a significant error for large sample sizes:

$$C \equiv \exp\left(1.96 \cdot \sqrt{\frac{(N - n)}{N \cdot n} \cdot \sum_k p_k \cdot s_k^2 \cdot \left(1 + \frac{1}{2} \cdot s_k^2\right)} - 1\right)$$

The above formula can now be inverted to provide the required sample size for a required confidence interval:

$$n \approx \frac{N}{\left(\frac{\ln(1 + C)}{1.96}\right)^2 - 1 + N \cdot \sum_k p_k \cdot s_k^2 \cdot \left(1 + \frac{1}{2} \cdot s_k^2\right)}$$

In which:

- $n$ = Required total sample size
- $C$ = Upper 95 percentile confidence interval as a proportion of average
- $N$ = Total number of homogeneous sections on road network
- $p_k$ = Proportion of homogeneous sections in road class $k$
- $s_k$ = Standard deviation for the Lognormal Distribution for road class $k$

The required sample sizes were determined using the data obtained from the 4500 counting stations. Typical proportions or roads in the different classes of roads were used (rural roads only). The following sample sizes were determined for different population sizes $N$ (number of homogeneous sections in the road network) and the required confidence interval $C$:

<table>
<thead>
<tr>
<th>Population Size $N$</th>
<th>Confidence interval $C$ as % of the mean AADT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10.0%</td>
</tr>
<tr>
<td>10 000</td>
<td>1 250</td>
</tr>
<tr>
<td>20 000</td>
<td>1 350</td>
</tr>
<tr>
<td>50 000</td>
<td>1 400</td>
</tr>
</tbody>
</table>

The above table shows that significant increases in sample sizes are required in order to improve the confidence intervals. A confidence interval of 7.5% appears to be a reasonable compromise and cost and is therefore recommended for the determination of travel statistics.
8 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.

8.1 Project-level monitoring

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 economic analysis.

The data required by the different applications on a project level may vary significantly and are determined by the specific requirements of each application. In this chapter it is not possible to address the requirements of each application and only guidelines of a broad general nature are provided.

8.2 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.

8.3 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 7 or 14 days. The counts are undertaken on normal days and expanded to reflect annual traffic characteristics.
The following monitoring durations should be adequate for most projects:

a) 7-Day count when the AADT is 25 000 pcu/day or lower.

b) 14-Day count when the AADT is more than 25 000 pcu/day.

The above thresholds are provided in units of pcu (passenger car units) per day. A heavy vehicle is taken as equivalent to three (3) passenger car units.

In situations where more accurate counts are required than the 7- or 14-day counts, consideration will have to be given to a monitoring over a full year.

### 8.4 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 are required depend 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):

a) *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).

b) *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.
9 NORMAL, ABNORMAL AND EXCEPTIONAL DAYS

9.1 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. Definitions of the different types of days are provided in this chapter.

9.2 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.
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 the data verification procedures provided in 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.
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 applicable to the normal days of the year, excluding 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. The traffic counts must also be adjusted for growth and seasonal variation during the year before expansion factors can be derived.

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 12-, 18- or 24-hour counts (for different classes of vehicles and days of the week):

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

b) Annual Average Daily Traffic (AADT) from 48-hour counts (for different classes of vehicles and days of the week):

\[
AADT = \frac{\text{Day 1 Count}}{\text{Expansion Factor}} + \frac{\text{Day 2 Count}}{\text{Expansion Factor}} \right] / 2
\]

c) Annual Average Daily Traffic (AADT) from 7 or 14 day counts (for different classes of vehicles):

\[
AADT = \frac{\text{Average daily count}}{\text{Expansion Factor}}
\]
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d) Highest hour volumes (15th and 30th) from 12-, 18- or 24-hour counts (for total traffic only but for different days of the week):

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

e) Highest hour volumes (15th and 30th) from 48-hour counts (for total traffic only but for different days of the week):

\[
\text{Highest hour volume} = \left( \frac{\text{Day 1 Count}}{\text{Expansion Factor}} + \frac{\text{Day 2 Count}}{\text{Expansion Factor}} \right) / 2
\]

f) Highest hour volumes (15th and 30th) from 7 or 14 day counts (total traffic only):

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

The maximum hourly count required in the above formula is the highest hourly count that was obtained during the short-term observations.

The above methods for estimating the highest hour volumes were found to be the most accurate by Van As (2016).

The counts required for estimating the AADT are as follows:

- For 12- or 18-hour counts, the total count during the period.
- For 48-hour counts, the total counts during the 24 hours of each day.
- 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 Expansion factors: Single stratification methods

Formulae are provided in this section for the derivation of expansion factors from long-term traffic counts. These formulae are only applicable in situations where only the trip-purpose or the holiday stratification method is used (but not both). Formulae that are required for dual stratification methods are provided in the next section.

The 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
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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 12-, 18- or 24-hour counts for different classes of vehicles and days of the week (for 48-hour counts the average of the two 24-hour counts is used):

\[ f_e = \frac{\sum \text{Total short term counts for n normal days of the year}}{n \cdot \text{AADT}} \]

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

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

c) Expansion factor for the determination of the 15th and 30th Highest hour volumes from 12-, 18- or 24-hour counts for different days of the week (for 48-hour counts the average of the two 24-hour counts is used):

\[ f_e = \frac{\sum \text{Total short term counts for n normal days of the year}}{n \cdot \text{Highest hour volume over year}} \]

d) Expansion factor for the determination of the 15th and 30th Highest hour volumes from 7-day counts:

\[ f_e = \frac{\sum \text{Maximum hourly counts from n sets of observations}}{n \cdot \text{Highest hour volume over the year}} \]

The short term counts that are used in the above formulae must be selected from normal days without exceptional events. The AADT and the highest hour volumes, however, must be determined for both normal and abnormal days as well as exceptional days, but not extreme exceptional days. The counts must be adjusted for growth and seasonal variation that may occur during the year.
10.4 Expansion factors: Dual stratification methods

The formulae provided in the previous section are applicable to single stratification systems and cannot be used in systems where a dual stratification is applied. Formulae for such dual-stratification systems are provided in this method. The dual stratification method would involve application of both the holiday traffic and trip-purpose stratification methods.

The expansion factor that is required for the dual stratification method is the following:

$$f_e = f_h \cdot f_t$$

In which:

- $f_e$ = Expansion factor for dual stratification
- $f_h$ = Expansion factor for the holiday stratification (stratum h)
- $f_t$ = Expansion factor for the trip purpose stratification (stratum t)

Since the expansion involves the multiplication of two sets of factors ($f_h$ and $f_t$), it is necessary to set one of the factors to a constant value. By convention, the rural trip purpose stratum has been selected for this purpose and is set as follows:

$$f_{t_{\text{rural}}} = 1$$

The derivation of the expansion factors $f_h$ and $f_t$ is based on the same principles used for establishing the single-stratification expansion factors discussed in the previous section. It is, however, not possible to derive formulae for the direct calculation of the expansion factors and an iteration process is required.

For the iteration process, the following data must first be collected:

$$Y_{ht} = \sum y_{hti}$$

$$X_{ht} = \sum x_{hti}$$

In which:

- $y_{hti}$ = Individual traffic observations obtained from the subset of data
- $x_{hti}$ = Individual characteristic obtained from the long-term count

At the start of the iteration process, all expansion factors are set to 1:

$$f_h = 1$$

$$f_t = 1$$

During the iteration process, the expansion factors are repeatedly recalculated by means of the following formulae:

$$f_h = \frac{\sum_t f_t \cdot Y_{ht}}{\sum_t f_t \cdot X_{ht}}$$

$$f_t = \frac{\sum_h f_h \cdot Y_{ht}}{\sum_h f_h^2 \cdot X_{ht}}$$

The iteration process is then repeatedly undertaken until no change in any of the expansion factors is detected.
10.5 Adjustment for traffic growth and seasonal variation

The formulae provided in the previous sections for the determination of expansion factors 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 from a long-term counting station.

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 derived as described in the previous sections.

The adjustment factors are derived using daily traffic volumes (24-hour counts). Differentiation is made between light and heavy vehicles. Only normal days (excluding exceptional 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 counts.

The following formula is used in the model:

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

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 index of the day (applicable to both normal and abnormal days). However, only traffic data collected during normal days (without exceptional events) are used to fit the model (abnormal or exceptional days are excluded).

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:

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

The above adjustment factor is calculated for each day 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.

10.6 Stratum averages

Annual traffic characteristics cannot always be estimated by applying expansion factors to short-term counts in which case stratum averages must be used. This can occur when the observations required for estimating the characteristics have not been undertaken as part of the short-term count (such as classified counts) or when the annual characteristics that must be derived becomes very complex (such as the annual hourly distribution of traffic).

In situations where expansion factors cannot be used, stratum averages must be used for the estimation of the expansion factors. For this purpose, it is recommended that the holiday stratification method be used and stratum averages determined for each of the strata provided for by the method.

An important issue with the determination of the stratum averages is the possible impact of outliers. The data should be inspected and when outliers are identified, such outliers must either be removed or the median used as a robust measure of the average in the presence of outliers.
Figure 10.1: Examples of traffic growth and seasonal variation during a year
11 ANNUAL AVERAGE DAILY TRAFFIC

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 of annual average daily traffic and other related traffic characteristics.

11.2 Annual Average Daily Traffic (AADT)

Annual Average Daily Traffic (AADT) is perhaps the most important of all 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 usually assumed for annual traffic (but not for hourly volumes).

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.

The vehicle classes that can be used are described elsewhere in 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.

11.6 **Growth rates**

Growth rate is the year-to-year growth in the AADT expressed in units of percentage. Growth rates can be established from long-term counts that are undertaken as part of the system-level monitoring. The accuracy of short-term counts undertaken as part of network-level monitoring is not adequate and growth rates derived from such counts cannot be expected to be accurate.

The year-to-year growth rate at a long-term counting station can be determined by means of the following formula:

\[
\text{Growth rate (proportion)} = \frac{\text{AADT}_2 - \text{AADT}_1}{\text{AADT}_1}
\]

In which:

- \(\text{AADT}_1\) = AADT in first year
- \(\text{AADT}_2\) = AADT in second year
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 as well as 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 during a year is an important parameter in the design of roads and other transportation facilities. Annual hourly flow distributions are used in cost-benefit analyses of roads to establish operating costs for a full year while design hour volumes are used in the capacity analysis of roads and related facilities.

The purpose of this chapter is to describe the methods for derivation of hourly traffic distributions as well as design hour volumes. Methods are also provided for the derivation of related parameters such as directional split and peak hour factors.

12.2 Annual hourly flow distributions

The annual distribution of hourly flows is typically studied by plotting hourly flows against the number of hours a particular flow is exceeded during the year. Examples of such distributions are shown in Figures 12.1a and 12.1b. These distributions have traditionally been used in both economic analysis as well as for the establishment of design hour volumes.

The distributions shown in the two figures apply to different holiday traffic strata. Two distributions are shown in each of the figures, one for all days of the year and the other that is only applicable to the normal days of the year. The distributions shown in Figure 12.1a are typical of a road which carries low volumes of holiday traffic while the distributions shown in Figure 12.1b are typical of a road that carries a high volume of holiday traffic.

Traffic peaking on roads with high volumes of holiday traffic tends to be higher than on roads that carry low volumes of holiday traffic (as shown in the figures). On holiday routes, there is a significant difference between the distributions for all days and normal days but on non-holiday routes the two distributions tend to be similar for the highest hours of the year (the highest 2000 hours for the example shown in Figure 12.1a).
Figure 12.1a: Traffic-flow peaking over a year - Negative holiday traffic

Figure 12.1b: Traffic-flow peaking over a year - High holiday traffic
12.3 Annual hourly directional distributions

A disadvantage of using distributions such as shown in Figures 12.1a and 12.1b is that they do not account for the directional distribution or split of traffic during the different hours of the year. Directional split is an important parameter in the analysis of a road.

For the purposes of economic analyses, the annual hourly directional split can be studied by means of graphs such as shown in Figures 12.2a and 12.2b. These figures show the distribution of the hourly flows in the two directions of travel for all the hours of a year. The directional hourly flows are shown as the following ratios in the two directions:

\[ \text{Flow ratio} = \frac{\text{Hourly flow in direction}}{\text{AADT in direction}} \]

In an economic analysis, it is not practical to account for every hour of the year. Use can, however, be made of intervals (or bins) in which the hourly flow/AADT ratios are subdivided into intervals for the two directions. For each interval combination, the percentage of hours that fall within each bin can then be determined and used in the economic analysis.

The heavy vehicle composition can be taken into account by determining the following average ratios for each of the bins:

\[ \text{Heavy vehicle ratio} = \frac{\text{Hourly heavy vehicle flow}}{\text{Heavy vehicle AADT}} \]

The distribution shown in Figure 12.2a is typical of a road with a high directional split during the peak hours while the distribution shown in Figure 12.2b is typical of a fairly even split during all hours of the year. However, note that both these figures were obtained for roads that have been stratified as high-holiday traffic. In general, directional splits do not appear to be dependent on the traffic stratum and the splits can vary from low (balanced) to high (unbalanced) for any traffic stratum.

Use can be made of a directional split classification for the expansion of short-term counts. Average distributions can then be determined using data obtained from permanent counting stations for each of the split classes and used in an analysis when only a short-term count is available (using the binned approach). The classification system provides for the following three split classes:

a) Low directional split during peak hours.
b) Medium directional split during peak hours.
c) High directional split during peak hours.

The directional split classes may be derived from annual and short-term counts by means of the threshold splits provided in the table below. For an annual count, the class is derived using the average of the directional splits during the 1% highest hours of the year. For a short-term count, the class is derived from the split during the highest peak hour on a weekday. The directional split is defined as the hourly flow in the high flow direction divided by the total flow in the two travel directions (with a value between 0.5 and 1.0).

The following threshold values may be used for determining the split classes:

<table>
<thead>
<tr>
<th>Threshold average split values</th>
<th>Low split class</th>
<th>Medium split class</th>
<th>High split class</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.50 – 0.55</td>
<td>0.55 – 0.67</td>
<td>0.67 – 1.00</td>
</tr>
</tbody>
</table>

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Figure 12.2a: Directional flow characteristics – High directional split

Figure 12.2b: Directional flow characteristics – Low directional split
12.4 Design hour volumes

Design hour volumes are used in the capacity analysis of a road with the purpose of determining the required width or size of the road. Such analysis can also be used to establish the need for passing or climbing lanes on two-lane roads.

A road cannot be designed to accommodate only the average hourly volume since it would be overloaded for long periods during the year. On the other hand, however, it would also not be economical to design the road for the highest flow that can be expected in a year, as it would be underutilised for most hours of the year. The selection of the design hour volume 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 highway design on a design hour between the 30th and the 100th highest hour of the year. AASHTO (2011) recommends that the 30th highest hour volume should generally be used as the design hour.

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 12.3a. Designing a road for the 30th highest hour volume on such a road would mean that the poor level of service is only 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 12.3b. Designing this road for the 30th highest hour volume would mean that a poor level of service would be experienced during a relatively large number of hours of the year. Roads with a low traffic peaking should generally be designed for a better level of service than those with a high traffic peaking.

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 (abnormal days excluded). 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. These design hours have been prescribed in TMH 16 (COTO 2012) for traffic impact assessments. The two design hours are as follows:

a) 30th Highest hour volume measured on all days of the year.

b) 15th Highest hour volume measured on the normal days of the year.

This approach allows a road to be designed for a relatively poor level of service during the 30th highest hour and a better level of service during the 15th highest normal day hour (as required by TMH 16). This approach would prevent a road from operating at very poor levels of service for a large number of hours of the year.
Figure 12.3a: Traffic flow peaking - High peaking on a rural road

Figure 12.3b: Traffic flow peaking - Low peaking on a rural road
The peaking characteristics shown in Figures 12.3a and 12.3b are for roads in rural areas. Roads in urban areas normally have a very low level of traffic peaking as shown in Figure 12.3c. On these roads, traffic volumes tend to be similar for a relatively large number of hours of the year. These hours would normally be the morning (or afternoon) peak hours of the year. Due to the flat distribution, any of the higher peaks can be selected for design purposes. The 15th highest hour approach can also be adopted for urban roads, although a lower level of services would normally be acceptable for these roads compared to rural roads.

### 12.5 Two-directional design hour volume

The design hour volumes are determined for the two directions of travel combined. Traffic volumes in the two directions are added together for each hour of the year and the hours ranked on the basis of this two-directional volume. The hour with the 30th (or 15th) highest two-directional volume is then selected as the two-directional design hour volume.

A method is provided below for the determination of the design hour volume that makes provision for roads with an unequal split in the AADT. Where this occurs, it is assumed that the traffic in the one direction has diverted to other routes and that the same proportion of traffic has diverted in all hours of the year.
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The methodology consists of the following steps:

a) For each hour of the year determine the following directional flow ratios:

\[ K_1 = \frac{Q_1}{AADT_1} \quad K_2 = \frac{Q_2}{AADT_2} \]

In which:

- \( K_1, K_2 \) = Directional flow ratios for two travel directions
- \( Q_1, Q_2 \) = Hourly flows (vph) in the two travel directions
- \( AADT \) = AADTs in the two travel directions

b) Determine for each hour the following two-directional flow ratio:

\[ K = \frac{1}{2} \cdot (K_1 + K_2) \]

c) Rank the two-directional flow ratios from small to large and select the 30th (or 15th) highest ratio \( K \).

For an equal split in the AADT, the two-directional design volume \( Q \) can be estimated by means of the following formula:

\[ Q = K \cdot AADT \]

A directional split must be applied to this two-directional design volume to determine the design volume per direction of travel.

12.6 Directional split

The directional split during the design hour is an important factor in the capacity analysis of a road. 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 over the different hours of the year, particularly during the peak hours. During these hours, the traffic volume in one direction could be significantly higher than in the other direction.

Designing a road that can only accommodate a high volume in one direction can be expected to result in poor operating conditions in the other direction during other hours of the year. Road designs can therefore not only be based on the directional split obtained during the 30th or 15th highest hours. A design approach is therefore required in which an analysis is first performed with a high directional split applied in the one direction and then a second analysis with the high split applied in the other direction.

Directional split is less of an issue on two-lane road sections where overtaking opportunities are provided. On such sections, the level of service in the two travel directions tend to be similar (although not exactly the same), even if traffic volumes are different in the two directions. The reason for this is that platoon formation depends on both catching up and overtaking. The catching is higher when traffic volumes are higher in a direction while overtaking is easier when traffic volumes are lower in the opposite direction. The catching-up/overtaking rate ratio therefore tends to be the same in the two directions of travel, irrespective of the directional split. Note, however, that this does not mean that the ratios are exactly equal and that directional split must still be taken into account.
account in the capacity analysis of such roads. It only means that the capacity analysis of such road sections are less sensitive to the directional split.

The directional split, however, becomes an important issue on two-lane road sections on which no overtaking opportunities are provided (due to a no-overtaking line or a median). On such road sections, level of service is only dependent on the catching-up rate since overtaking is not allowed. A similar situation also occurs on multilane roads on which level of service only depends on the traffic volume in one direction of travel and not on the opposing traffic flow.

The above issue with directional split can be addressed by selecting a relatively high directional split for design purposes. The directional splits obtained during the 30th and 15th highest hours are not taken into account. A method is described below which is based on a ranking method similar to that for determining the design hour volume, but in which hours are not ranked on the basis of two-directional volumes but on one-directional volumes.

The method consists of the following steps:

a) For each hour of the year determine the following directional flow ratios (the same ratios used for the determination of the design hour volumes):

\[ K_1 = \frac{Q_1}{AADT_1}, \quad K_2 = \frac{Q_2}{AADT_2} \]

In which:
- \( K_1, K_2 \) = Directional flow ratios for two travel directions
- \( Q_1, Q_2 \) = Hourly flows (vph) in the two travel directions
- \( AADT \) = AADTs in the two travel directions

b) Determine for each the following one-directional flow ratio:

\[ K_{\text{Dir}} = \text{Max}(K_1, K_2) \]

c) Rank the one-directional flow ratios from small to large and select the 30th (or 15th) highest ratio \( K_{\text{Dir}} \).

d) Determine the directional split as follows (with a value between 0.5 and 1.0):

\[ p = \frac{K_{\text{Dir}}}{K} \]

in which:
- \( p \) = Directional split (as a proportion)
- \( K_{\text{Dir}} \) = One-directional flow ratio for the design hour
- \( K \) = Two-directional flow ratio determined for the design hour

The capacity analysis must then be undertaken for the two directions of travel. For the capacity analysis in direction 1, the analysis is undertaken for the following flows and opposing flows (both in units of veh/hour):

Flow = \( 2 \cdot p \cdot K \cdot AADT_1 \)

Opposing flow = \( 2 \cdot (1 - p) \cdot K \cdot AADT_2 \)
For the capacity analysis in direction 2, the analysis is undertaken for the following flows and opposing flows (veh/hour):

Flow = 2 \cdot p \cdot K \cdot AADT_2
Opposing flow = 2 \cdot (1 - p) \cdot K \cdot AADT_1

An example of directional splits obtained for different hours of the year is shown in Figure 12.4. This figure shows the directional splits obtained for the travel direction with the highest flow and the split values are therefore all larger than 0.5. In this example, the split is high during the higher hours of the year and decreases for the lower hours of the year. The figure, however, is not necessarily typical of all roads and there are roads on which the directional split is nearly 50 for a large proportion of hours of the year.

The figure also shows the design directional split that was obtained by means of the method described above (for the 30th highest hour). For the example, the directional split is near to the median of the directional splits determined for the highest hours of the year but again this is not necessarily typical of all roads. There are roads on which the design directional split is either lower or higher than the median of the splits.

Figure 12.4: Example of directional splits over different hours
12.7 Traffic congestion and traffic peaking

Traffic congestion is a major issue in many cities throughout the world. Such congestion can lead to traffic diverting to alternative roads or to peak hour spreading that is caused by road users having to travel earlier in the mornings and later in the evenings to avoid peak hour traffic. Such congestion can significantly affect the design traffic volumes on a road.

The impact of traffic congestion on traffic peaking is shown in Figure 12.5. This figure shows the one-directional traffic peaking ratio (flow/AADT ratio) for the 15th highest normal hour for a number of roads in urban areas over a number of years of observations. The figure shows that the ratio has steadily been reducing for some roads since the first year for which data were available. For other roads, the ratio was initially fairly constant but started to decline at a later stage. In general it appears that peak-hour spreading may be occurring on roads with a peaking ratio of less than 0.125 (in the peak flow direction).

The above one-directional traffic peaking ratio can be used as an indicator that peak-hour spreading has occurred on a road. This indication cannot be used to indicate whether diversion has occurred, but diversion is more likely when there is peak-hour spreading.

On roads where traffic volumes may be affected by congestion, traffic demand should rather be estimated by means of a traffic demand model than determined from traffic counts. Traffic counts under congested conditions usually either under- or overestimate traffic demand depending on whether traffic has been diverted away or to a road.

Figure 12.5: Changes in traffic peaking over time
12.8 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 12.6 for the highest hours based on total traffic (and not only heavy vehicle traffic). In this figure, the two-directional heavy vehicle flow is expressed as a proportion of the heavy vehicle AADT (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. 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 1% highest hours of the year. The proportion of heavy vehicles is determined as the average for these hours. All days of the year are used for determining the proportion during the 30th highest hour while only normal days are used for the 15th highest hour.

Figure 12.6: Example of heavy vehicle flow ratios over different hours
12.9 Peak-hour factors

The capacity analysis for a road is normally undertaken for the peak 15-minute flow rate during the design 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 also vary significantly during the different hours of the year as shown by the example provided in Figure 12.7. Generally, it appears that the PHF is approximately the same for the 1% highest hours and the PHF may therefore be determined as the average for these hours. All days of the year are used for determining the factor during the 30th highest hour while only normal days are used for the 15th highest hour. The peak hour factor is determined for the two travel directions combined.

![Figure 12.7: Example of peak hour factors over different hours](image-url)
13 AXLE LOAD MONITORING

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)

Axles are considered to be part of an axle group when the spacing between two axles is 2.2 m or less. For 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 for use in the HS WIM lanes while Type C1 systems are recommended for other lanes.

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 sensors

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.

The accuracy of WIM observations can be significantly affected by factors such as pavement smoothness, cross fall, gradient and horizontal curves. Detailed requirements are provided in TMH 3 (COTO 2014) that can be used for the selection of suitable WIM sites. It is important that these requirements are adhered to when undertaking WIM observations. 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 purpose. The conclusion of the research was that axle load statistics must be obtained from axle load observations on each road and that the statistics cannot be derived by means of some stratification system.

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 stratification 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 detail planning and design 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

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:

\[
E80 = \left( \frac{W}{8.2} \right)^n
\]

In which:

- \(E80\) = 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) 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 at least 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 ton

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.

The EMS procedure does require an estimate of the standard deviation of logarithms (Ln) of the “dynamic load ratio”. This ratio is defined as:

\[
\text{Dynamic load ratio} = \frac{\text{Total axle load}}{\text{Static axle load}}
\]

The above ratio depends on the roughness of the road at the time the WIM observations were undertaken. Research is required to establish values for the ratio but in the absence of such research, a value of 0.05 can generally be applied.

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.

This chapter provides information on the classification systems that must be used as part of a traffic monitoring programme. Due to limitations of different monitoring methods, it is not possible to adopt a uniform classification system for all traffic counts. In some cases, automatic monitoring may have to be supplemented with manual monitoring to obtain data on vehicle classes that cannot readily be identified by means of automatic methods.

Various definitions for vehicle classes for use in South Africa have been adopted in the TMH 14 South African Standard Automatic Traffic Data Collection Format (COTO, 2014). The TMH 14, however, provides for a wide range of vehicle classes which cannot always be identified during traffic monitoring (particularly automatic monitoring). Requirements are therefore provided in this chapter on the vehicle classes that must be implemented as part of a traffic monitoring programme by road authorities.

The TMH 14 provides definitions for both motorised and non-motorised traffic classes. The requirements of this chapter are applicable to motorised traffic while requirements for non-motorised traffic are provided in the next chapter of this document.

14.2 General definitions

A number of general definitions are provided in TMH 14 (COTO, 2014) for motorised 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.

The TMH 14 makes provision for a classification system that provides for all the above vehicle classes. 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. It is only possible to differentiate between all the vehicle classes by means of manual monitoring method.

14.3 Unclassified system

Classification of vehicles are not always required and there are situations in which it is not necessary to classify vehicles and where a simple count of the total traffic is sufficient. For the design of traffic signals, for example, vehicle classification is not required when the volume of heavy vehicles is low (which is typical of many urban streets).

For applications such as above, no classification system is required and only a count of the total traffic is needed. Any type of monitoring system (automatic or manual) can be used for monitoring the traffic.
14.4 Light/Heavy classification system

The simplest of classification systems is to only differentiate between light and heavy vehicles (using the definitions provided previously). This classification is usually adequate for many traffic engineering applications (e.g. capacity analysis). This system is mostly used in manual traffic monitoring since more advanced classification systems can readily be implemented in automatic traffic monitoring.

The following two vehicle classes are defined:

a) Light Vehicles
b) Heavy Vehicles

14.5 Length-based classification system

The length-based classification system is used most often in South Africa in automatic traffic monitoring systems. The classification system is particularly used for purposes of pavement management and design, but it can also be used for other purposes (such as economic analysis).

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 be used for this purpose. Type E1 and E2 monitoring systems can also be used but lengths are indirectly derived from axle spacing data (with a resultant loss in accuracy).

The following four vehicle classes are defined:

a) Light Vehicles
b) Heavy Vehicles
   i) Short Heavy Vehicles
   ii) Medium Heavy Vehicles
   iii) Long Heavy Vehicles

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

14.6 Axle-based classification system

It is not always possible to implement a length-based classification system and use must then be made of an axle-based classification system. The axle-based classification system can be used when manual monitoring as well as axle-based Types E1 and E2 automatic monitoring is undertaken. The classification system can be used for the same purposes as the length-based classification system.
The axle-based classification system provides for more classes than the length-based system but it remains a relatively simple system:

a) Light Vehicles
b) Heavy vehicles
   i) 2-Axle Heavy Vehicles
   ii) 3-Axle Heavy Vehicles
   iii) 4-Axle Heavy Vehicles
   iv) 5-Axle Heavy Vehicles
   v) 6-Axle Heavy Vehicles
   vi) 7-Axle Heavy Vehicles
   vii) 8+ Axle Heavy Vehicles (8 or more axles)

Alternatively, the following simpler classification system may also be used:

a) Light vehicles
b) Heavy Vehicles
   i) 2-Axle Heavy Vehicles
   ii) 3 or 4-Axle Heavy Vehicles
   iii) 5 or More Axle Heavy Vehicles

14.7 Vehicle utilisation classification system

A vehicle utilisation classification system is one in which vehicles are classified according to the purpose for which the vehicles are used. It is not possible to implement such systems by means of automatic monitoring, but the systems can readily be used in manual traffic monitoring. The system is used for purposes such as economic analysis of alternatives and for the planning of public transport facilities.

The following vehicle utilisation classification system provides for the vehicle classes that are most often found on South African roads:

a) Light vehicles (vehicles with single-tyre wheels)
   i) Motor vehicles
   ii) Minibuses.
   iii) Light commercial vehicles.

b) Heavy vehicles (vehicles with at least one wheel with two or more tyres)
   i) Midi-buses.
   ii) Buses.
   iii) Trucks (rigid or articulated).

An issue with the above classification system is that it can only be implemented by means of manual short-term monitoring. It is therefore not possible to derive expansion factors for the vehicle classes from system-level monitoring and factors must be assumed. The accuracy of the expanded counts, however, can be expected to be poor and can only serve as an approximate indication of the annual traffic volumes.
14.8 Required classification systems

Requirements are provided in this section for the classification systems that must be implemented by road authorities in South Africa as part of their traffic counting programmes. The requirements are only applicable to system- and network-level monitoring but recommendations are provided for project-level monitoring.

System- and network-level monitoring

The most important purpose for which system- and network-level data are collected is the identification of road pavement maintenance and rehabilitation projects. This application is the main justification for undertaking traffic monitoring. Other purposes are also important, but if it was not for the need to preserve road pavements, it would be difficult to warrant an extensive network-monitoring programme.

Road pavements are significantly affected by heavy vehicles. The impact of heavy vehicles, however, can vary significantly depending on the number of axles on a vehicle and the loads carried by the vehicles. It is therefore important that counts should differentiate between different classes of heavy vehicles.

On a system-level, it is only necessary to differentiate between light and heavy vehicles provided that the network-level counts differentiate between different heavy vehicle classes. The minimum classification requirements for system- and network-level monitoring are therefore as follows:

a) System-level monitoring. Any classification system may be used provided that differentiation is made between light and heavy vehicles.

b) Network-level monitoring. Either of the following two classification systems may be used.
   i) Length-based classification system
   ii) Axle-based classification system.

The above are minimum requirements and additional vehicle classes may be counted in addition to the heavy vehicle classes.

Project-level monitoring

The vehicle classification system that is required at the project level depends on the particular application. Provision should therefore be made in a monitoring programme for a wide range of vehicle classification systems at the project level. The following systems would find most application:

a) Pavement design. Either of the following classification systems (as specified for network-level monitoring):
   iv) Length-based classification.
   v) Axle-based classification.

b) Road design (capacity analysis). A light/heavy classification is usually sufficient.

c) Intersection design (including traffic signal design):
   i) No classification when heavy vehicle volumes are low.
   ii) Light/heavy classification when heavy vehicle volumes are high.

The heavy vehicle volume is considered to be low when less than 10% of vehicles are heavy (TMH 16, COTO, 2012).
d) Toll monitoring at toll plazas: Axle-based classification.
e) Economic analysis of road improvement projects. An automatic as well as a manual traffic count will be required using the following classification systems:
   i) Either the length- or axle-based classification systems.
   ii) Vehicle utilisation classification.
15 NON-MOTORISED TRAFFIC

Non-motorised traffic typically includes pedestrians, cyclists and animal-drawn vehicles. Such traffic is usually monitored by means of manual counting methods. One of the 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.

15.1 Introduction

Non-motorised traffic typically includes pedestrians, cyclists and animal-drawn vehicles. Some guidance is provided in this chapter on the monitoring of non-motorised traffic on a project level. System- or network-level monitoring is usually not undertaken of non-motorised traffic and no such monitoring is prescribed in this document.

Non-motorised traffic is usually counted by means of manual counting methods although automatic equipment is available that can be used for this purpose. 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. The non-motorised traffic counts may, or may not be representative of annual characteristics and care must therefore be exercised in the use of such counts.

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 Non-motorised traffic classes

Provision is made in the TMH 14 South African Standard Automatic Traffic Data Collection Format (COTO, 2014) for the following non-motorised traffic classification system:

a) Any non-motorised traffic. Any non-motorised traffic which could not be categorised into one of the non-motorised categories.

b) Pedestrians. Any walking person, including those that make use of wheelchairs. Pedestrians may be further subdivided into the following (judgement may be used for this purpose):
   i) Adults (pedestrians older than 12 years).
   ii) Children (pedestrians 12 years or younger).

c) Cyclists. Any person travelling by means of bicycles. These include persons that are pushing a bicycle, even if the person is walking. Cyclists may be further subdivided into the following (based on judgement):
   i) Adults (cyclists older than 12 years).
   ii) Children (cyclists 12 years or younger).


Not all the above classes may be required for a particular application and classes must be selected as required for the application.

15.4 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 only undertaking a simple count and additional surveys may be required.
15.5 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. A possible issue with such counts is that the peak hours for non-motorised traffic may not coincide with those of vehicular traffic.

15.6 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 TRAFFIC INFORMATION SYSTEMS

Traffic monitoring programmes involves the collection, storage and analysis of vast amounts of traffic data and it is therefore essential that computer software must be available for this purpose.

16.1 Introduction

Traffic monitoring programmes involves the collection, storage and analysis of vast amounts of traffic data. It is therefore essential that computer software in the form of a traffic management system must be available that can be used for this purpose.

The development of a traffic information system is a complex and costly exercise which cannot be undertaken by every road authority in the country. It is therefore essential that road authorities should share existing resources where available and to co-operate in the development of the traffic information systems.

The South African Traffic Information System (SATIS) is available at the South African National Roads Agency Ltd (SANRAL) that can be used by other road authorities in the country. This system can accommodate various types of monitoring programmes and is suitable for all classes of roads, including rural and urban roads. A major advantage of using SATIS is that it provides an opportunity for different road authorities to share traffic data (which could lead to significant cost reductions).

This chapter provides an overview of the main components that are required in a traffic information system. It is not possible to provide a detailed specification for such a system and only the broader requirements can be addressed.

16.2 Road network definition

A traffic information system requires a definition of the road network on which traffic data are collected. The definition is required for each node or link at or on which traffic monitoring is undertaken.

The road network definition is mainly used as the access point through which data users can access the traffic database. It also serves as the access point through which other software packages can access the database. The road network definition is also required for the planning and design of a traffic monitoring programme (all monitoring levels).

The following data are required for the road network definition:

a) ID Numbers and names of each element in the road network.
b) Location data (e.g. GPS coordinates).
c) Element type definitions (type of node or link).

16.3 Counting station definition

The traffic information system also require a definition of counting stations at which traffic monitoring is undertaken. The station definition data that are required for this purpose is defined in TMH 14 (COTO, 2014). A format is provided in TMH 14 for the exchange of the station definition data between road authorities and monitoring service providers.

16.4 Counting programme

The traffic information system should make provision for the definition and management of the traffic monitoring programme for the road network. Provision should be made for the system, network as well as project monitoring levels.

The information system must also be capable of monitoring the progress of the monitoring service provider. The system must be capable of generating the various statistics that may be required for this purpose. It must also be capable of producing the statistics that are required for the payment of service providers for completed monitoring services (in accordance to the TMH 3 (COTO 2014) requirements).

16.5 Data authentication and verification

Data authentication and verification are very important elements of a traffic information system. Data authentication is required to prevent unauthorised changes of data while data verification is required to check data for errors. The system must check data for any unauthorised tampering of data or errors and must make reports available to the road authority as well as the service provider. Provision can be made for the service provider to correct data with the permission of the data owner.

The software must mark data as “suspect”, “good”, “bad” or “missing”. The service provider is required to investigate reasons for suspect data and make recommendations of whether the data must be marked as good or bad. Periods during which no data have been submitted must be marked as missing.

16.6 Traffic stratification

Provision should be made in the traffic information system for the trip purpose, holiday traffic and dual stratification systems. The software system should be capable of deriving the expansion factors from system-level observations for each traffic stratum as well as each traffic region (where more than one region is defined).

Expansion factors must be derived for all required annual traffic characteristics, including AADT, vehicle composition, design hour traffic, annual distribution of traffic, etc. The methods that must be used for this purpose are described in this document.
16.7 Axle load monitoring

The traffic information system should also provide for axle load monitoring. Provision should be made for the development of axle load monitoring programmes and for the collection, verification and analysis of the axle load data.

Important functions that should be provided in the traffic information system include the systematic calibration of axle loads as well as the determination of the static load components from the load observations. The methods required for this purpose are provided in this document.

16.8 Data summaries

The information system should provide for the production of a wide range of data summaries for various purposes and applications. All summaries should be automatically be adjusted by means of expansion factors and, where required, adjusted for growth and seasonable variation. Axle load data should also be automatically calibrated and converted to static load distributions.

Provision should be made to export the data summaries in various forms. Most of the exports should be in a format that will allow direct use of the data in spreadsheets. Provision should also be made for exporting the original data in the format specified in the TMH 14 document.
17 DATA AUTHENTICATION AND 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.

17.1 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 or extreme 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). An overview of the data authentication requirements are also provided. The data tests were developed on the basis of a study into the variability of traffic flows by Van As (2013b).

17.2 Site information records

According to the TMH 3 specifications, the service provider is responsible for the collection and submission of site information data and records. The data that must be collected are defined in TMH 3 and include information such as scaled sketches of the monitoring site, photographs, any assessments that were made of the road geometry and pavement as well as the site records specified in TMH 14 (COTO 2014).

Road authorities should implement quality control measures aimed at ensuring the site information data have been collected correctly. These measures can be implemented by the road authority, or the authority may employ the services of another service provider for this purpose (other than the service provider submitting the data). All data should be check as part of the process (sampling is not adequate).
17.3 Manual count quality control measures

The TMH 3 specifications make provision for the optional implementation of a quality control system by the employer of a service provider providing manual traffic monitoring services. The implementation of such a system is made obligatory in this document for all road authorities undertaking manual traffic monitoring.

The road authority will be responsible for implementing the quality control system and the service provider will not be involved with or responsible for this quality control. The road system may be implemented by the authority, or the authority may employ the services of another service provider for this purpose (other than the service provider submitting the data).

The required quality control measures are described in TMH 3. These measures include the following:

a) For Type M1 video-based monitoring, verification of whether vehicles and vehicle categories have been captured correctly from video recordings.

b) For Type M3 interval monitoring, verification of whether traffic data have been captured correctly from the data forms.

Note that no quality control measures are required for Type M2 traffic monitoring (except for the quality control required to verify site information records). This is a major advantage of Type M2 traffic monitoring compared to particularly the Type M1 monitoring, but also Typ3 M3 monitoring.

17.4 Data authentication

The TMH 3 specifications make provision for both data authentication and verification. Data verification is implemented with the purpose of testing data for possible errors. Data authentication is implemented with the aimed of preventing unauthorised amendments to data after data have been collected and before the data are submitted.

The TMH 3 requires that traffic data and other information be authenticated by means of software that will be made available to service providers. The following authentication is required:

a) Automatic monitoring. All data must be converted to the required TMH 14 format and authenticated within a specified period after extraction from data loggers.

b) Manual monitoring. Data authentication is only required for Type M2 manual monitoring but image authentication is required for the following purposes:
   i) Site photographs for all types of manual monitoring.
   ii) Data capturing forms used for Type M3 monitoring.

The data authentication software will require a connection to the Internet or a GPS unit to establish the date and time at which the authentication has been undertaken. The software will append or embed an encrypted code to or in the data file which will allow detection of any changes to the data after data have been authenticated.
17.5 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.

17.6 First-level verification 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 individual vehicle 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 lower and upper bound 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.

17.7 Second-level verification 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 per traffic stream (direction of travel) using hourly traffic counts for all hours of the day. 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.

b) Daily traffic count tests (normal days). These tests are undertaken per traffic stream. The tests are undertaken for the total traffic and for each individual vehicle type. The tests can only be applied when data are available for at least two days. Counts at short-term stations are expanded before the tests are applied. At long-term stations, differentiation is made between normal and abnormal days as well as the seven days of the week (without application of expansion factors). The counts must, however, be adjusted for seasonal variation and growth before the tests can be applied. Statistical methods are then used to identify outlier counts. The outliers could be due to data errors or due to exceptional events.

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. These tests are undertaken separately for each lane of traffic.
### Thresholds for lower- and upper-bound tests

<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>1.5 m</td>
<td>25 m</td>
</tr>
<tr>
<td>2 axle vehicles</td>
<td>2.5 m</td>
<td>35 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>2N – 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

Threshold values for the failure rate tests are provided in the following table. 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.
Thresholds for failure-rate tests

<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>

Thresholds for calibration tests

<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>0.85t</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>

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. These tests are undertaken separately for each load sensor. 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.

vi) 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. These tests are undertaken separately for each load sensor.

17.8 Third-level verification 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. The tests are undertaken for each traffic stream (direction of travel) in the data.

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:

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

b) 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.

c) 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.

d) 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.

e) 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.

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

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

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

i) Percentage unclassified vehicles. Unclassified vehicles are those that could not be classified by the equipment.
17.9 Complete data sets

The TMH 3 Specifications for the Provision of Traffic and Weigh-in-Motion Monitoring Service (COTO 2014) defines a “complete” data set as one that does not contain any missing or bad or erroneous data (for a specific period). No data may be missing or bad for any of the lanes of a monitoring site.

The periods over which full data sets must be provided are specified as follows by TMH 3:

a) Automatic monitoring
   i) Traffic monitoring - 24 hours of the day (subject to grace periods).
   ii) Axle load monitoring (HS WIM) – Each hour of the day (no grace period).

b) Manual monitoring
   i) Full data sets for the specified time periods (no grace periods allowed).

The TMH 3 does not provide for grace periods for manual monitoring, but does make provision for situations in which a manual traffic monitoring service had to be interrupted due to circumstances outside the control of the Service Provider. Such circumstances may arise due to adverse weather, traffic accidents or other reasons. In such situations, the Service Provider will be allowed to complete the traffic monitoring on another suitable day within a specified time interval. More details of the requirements are provided in the TMH 3 document.

Provision is made for grace periods in TMH 3 for automatic traffic monitoring. The maximum number and duration are specified of periods during which automatic monitoring may be interrupted. Traffic counts undertaken during intervals in which missing or bad data occur, must be increased by means of the following formula:

\[ Q_a = \frac{T}{t} \cdot Q_c \]

in which:
- \( Q_a \) = Adjusted traffic count for interval
- \( Q_c \) = Traffic count during the \( t \) seconds of available data
- \( t \) = Duration in seconds of available data
- \( T \) = Duration of the interval in seconds

The above adjustment may be undertaken for time intervals of any duration not less than 30 minutes but not more than 60 minutes.
18 RSA DATA FORMAT

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).

18.1 Introduction

An overview is provided in this chapter of the data format that must be used in South Africa for the transfer of data between road authorities, service providers and other organisations. This format must be used for both manual and automatic traffic monitoring. The required format is specified in the TMH 14 South African Standard Automatic Traffic Data Collection Format (COTO 2014).

18.2 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 (Extensible Markup Language) 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
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.

18.3 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.

18.4 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.

18.5 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.
19 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.

19.1 Introduction

Recommendations are provided in this chapter for data summaries that should be produced and made available to users of traffic 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).

19.2 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.

19.3 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 systems and strata.
b) Annual average daily traffic count data (all days of the year)
   i) AADT (Annual average daily traffic).
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.

19.4 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).
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):

$$p_W(w) = \sum_{t=e}^{\infty} p_T(t) \cdot p_E(w-t, t)$$

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 therefore be 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.
' WIM Dynamic load correction: EMS Algorithm
'We strive for accurate and efficient load monitoring
Sub WimEMS()
Dim Iter1 As Integer 'First iteration counter
Dim Iter2 As Integer 'Second iteration counter
Dim jLde as Integer 'First load bin index
Dim sDynR As Double 'Std Dev of Ln(dynamic load ratios)
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 AA As Double 'Intermediate variable
Dim PP As Double 'Intermediate variable
Dim FF As Double 'Intermediate variable

'sDynR = Standard deviation of Ln(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
        '...
        Next Iter2
    Next Iter1
End Sub

'***********************************************
********************************
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### Expectation/Maximization Algorithm

```
'-- Perform expectation maximization algorithm ----------------------------------
For iLde = 1 To 200
  dCalW(iLde) = 0#
Next iLde
For jLde = 1 To 200
  FF = 0#
  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
  Next jLde
Next iLde
'-- Smoothing algorithm --------------------------------------------------------
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)) / 0.95
pAdjW(199) = (0.2 * dCalW(200) + 0.3 * dCalW(199) + 0.1 * dCalW(198)) / 0.85
pAdjW(200) = (0.3 * dCalW(200) + 0.2 * dCalW(199) + 0.1 * dCalW(198)) / 0.65
FF = FF + pAdjW(198) + pAdjW(199) + pAdjW(200)
If FF > 0# Then FF = 1# / FF
Next iLde
'-- Check convergence --------------------------------------------------------
For iLde = 1 To 200
  If Abs(pAdjW(iLde) - pConW(iLde)) > 0.000001 Then GoTo X9
Next iLde
Exit Sub
X9:
Next Iter1
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 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 hourly counts. The tests can only be performed when counts are available for all the hours of the day.

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

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

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.
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.

f) Missing patterns. These are patterns in which no data are available for the whole day.

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