Development of a knowledge base for low-volume roads using a Geographic Information System

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Abstract

Currently each State Jurisdiction holds significant expenditure and road section activity data which are in varying formats and classifications. A Knowledge Management technique can extract differing data sets across multi-criteria in order to build up comprehensive data sets. Potentially this sound knowledge base can make more precise analysis and strategic decisions for low-volume roads.

Geographic Information System (GIS) has been used in this research as the platform of this knowledge base due to its powerful data integration ability. One GIS software (TransCAD) has been chosen to combine all the existing data and also to estimate the traffic data as the available data is insufficient on building up such a knowledge base.

Using traffic assignment and matrix estimation techniques, traffic volume data can be estimated from limited data source to produce a more comprehensive database. Nevertheless, not all the traffic assignment techniques have been tested and matrix estimation result cannot be validated until real data are acquired. It provides an approach when developing such a knowledge base, and with more input, results can be improved and a sound knowledge base is ready to be built.
Declaration

This is to certify that:

1. the thesis comprises only my original work towards the Master;

2. due acknowledgement has been made in the text to all other material used; and

3. the thesis is less than 40,000 words in length, exclusive of tables, maps, bibliographies and appendices.

Ran Sun
Preface

In the course of this study, 1 conference paper has been produced:

Acknowledgements

I take this opportunity to thank the support from my supervisors, Russell Thompson and Colin Duffield, for their kind support in focusing my research and also for their constructive feedback through my entire candidature. Their selfless help enabled me to get through difficult times in the past two years. I also would like to appreciate the structured and frank feedback from Marcus Wigan and Kim Hassall, for the discussions and support provided by them.

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I’ve enjoyed the kind support from my friend – Ming Xu, for all the intellectual discussions and experiences he provided, both academically and personally. My office mates and colleague Putu Mandiartha, I appreciate all the constructive discussions we have. There are also many others from with the Department of Civil and Environmental Engineering that have made every life at the University of Melbourne enriching and entertaining.

Finally, I would like to sincerely thank my parents for their endless support and encouragement towards my research. I could not thank them enough.
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<th>Description</th>
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<tbody>
<tr>
<td>AADT</td>
<td>Annual Average Daily Traffic</td>
</tr>
<tr>
<td>ADT</td>
<td>Average Daily Traffic</td>
</tr>
<tr>
<td>AGF</td>
<td>Annual Growth Factor</td>
</tr>
<tr>
<td>COAD</td>
<td>Council of Australian Governments</td>
</tr>
<tr>
<td>CV</td>
<td>Commercial Vehicle</td>
</tr>
<tr>
<td>DOT</td>
<td>Department of Transport</td>
</tr>
<tr>
<td>DOTARS</td>
<td>Department of Transport and Regional Services</td>
</tr>
<tr>
<td>ESAL</td>
<td>Equivalent Single Axle Load</td>
</tr>
<tr>
<td>ESAs</td>
<td>Equivalent Standard Axle Loads</td>
</tr>
<tr>
<td>GIS</td>
<td>Geographic Information System</td>
</tr>
<tr>
<td>GVM</td>
<td>Gross Vehicle Mass</td>
</tr>
<tr>
<td>I-O</td>
<td>Input-Output</td>
</tr>
<tr>
<td>IRI</td>
<td>International Roughness Index</td>
</tr>
<tr>
<td>KM</td>
<td>Knowledge Management</td>
</tr>
<tr>
<td>LEF</td>
<td>Load Equivalency Factor</td>
</tr>
<tr>
<td>LGA</td>
<td>Local Government Areas</td>
</tr>
<tr>
<td>LRS</td>
<td>Linear Referencing System</td>
</tr>
<tr>
<td>M&amp;R</td>
<td>Maintenance and Rehabilitation</td>
</tr>
<tr>
<td>NTC</td>
<td>National Transport Commission</td>
</tr>
<tr>
<td>O-D</td>
<td>Origin-Destination</td>
</tr>
<tr>
<td>PBS</td>
<td>Performance Based Standards</td>
</tr>
<tr>
<td>PCU</td>
<td>Passenger Car Unit</td>
</tr>
<tr>
<td>PM</td>
<td>Pavement Management</td>
</tr>
<tr>
<td>PMS</td>
<td>Pavement Management System</td>
</tr>
<tr>
<td>QDMR</td>
<td>Queensland Department of Main Roads</td>
</tr>
<tr>
<td>TMC</td>
<td>Turning Movement Count</td>
</tr>
<tr>
<td>VKT</td>
<td>Vehicle Kilometres Travelled</td>
</tr>
<tr>
<td>VPD</td>
<td>Vehicle per Day</td>
</tr>
<tr>
<td>WIM</td>
<td>Weigh-In-Motion</td>
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</tbody>
</table>
Glossary of Terms

Geographic Information System
A system designed to capture, store, manipulate, analyse, manage, and present all types of geographically referenced data.

Knowledge Management
It comprises a range of strategies and practices used in an organization to identify, create, represent, distribute, and enable adoption of insights and experiences.

Low-volume Roads
Roads that have lower level than other roads, either in its volume or its function. In this research, volume and function as well as location were taken into consideration to determine the most appropriate definition.

Matrix Estimation
A method used to estimate traffic counts using origin-destination matrix set.

Traffic Assignment
It concerns the selection of routes (alternative called paths) between origins and destinations in transport networks. It is the fourth step in the conventional transportation forecasting model, following trip generation, trip distribution, and mode choice.

TransCAD
TransCAD is software for transportation planning developed by Caliper Corporation. In addition to the standard point, line, area, and image layers in a GIS map, TransCAD supports route system layers and has tools for creating, manipulating and displaying routes.
Chapter 1. Introduction

1.1 Importance of Low-volume Roads Knowledge Base

In 2005, a study was performed by the Department of Civil and Environmental Engineering at The University of Melbourne to find the pavement maintenance cost relationships of low-volume road pavement. This research found that national data for road sector expenditures could be vastly improved with a “knowledge Management” approach to data capture and the use of data warehouse management systems. This system is able to:

- develop more accurate pavement maintenance cost;
- assist strategic road authority program budget construction;
- examine the specific road sector activity (possibly maintenance requirements) which could be benchmarked with similar activity across States and regions for arterial and local low-volume roads.

Currently each State Jurisdiction holds significant expenditure and road section activity data, which are in varying formats and classifications. A Knowledge Management technique can extract differing data sets across multi-criteria in order to build up comprehensive data sets. Potentially this sound knowledge base can make more precise analysis and strategic decisions for low-volume roads.

1.2 Background

At the Special Council of Australian Governments (COAG) Meeting in February 2006, high productivity vehicles were cited as being exceptionally important for Australia and each State was to develop an action plan for their introduction. However, infrastructure concerns exist for thin pavements, many of which will be actual low-volume roads sectors. Recent analysis undertaken for the National Transport Commission has identified that up to 45% of linehaul articulated transport could move
over to B-Triples and Super B-Doubles within a medium term time frame. For jurisdictions that maintain low-volume roads this prospect may cause considerable angst as the significant increases in both Gross Vehicle Mass (GVM) and Equivalent Standard Axle Loads (ESAs) by these articulated Performance Based Standards (PBS), vehicles will have an impact on pavement infrastructure. Further to this end road segment data must be collected and analysed so that better cost relationships are determined and newer maintenance optimisation techniques are advanced especially for thin pavements, many of which will be low-volume arterial and local roads.

A new project commenced in 2007 between The University of Melbourne and Swinburne University of Technology commissioned by Department of Transport and Regional Services (DOTARS) to produce a unique algorithm for analysing road deterioration and develop new models for assessing maintenance. The project will examine the existing data from Vicroads and Queensland Department of Main Roads (QDMR) including road profilometre data, maintenance records, structural details, traffic volume records, etc. This project will greatly assist the Special COAG agenda of balancing the introduction of long distance PBS articulated vehicles with asset infrastructure protection.

1.3 Statement of Problem

From the above information, a knowledge base is essential to integrate all the necessary data for decision-making process. However, problems exist in multiple areas. These problems include:

- various data formats and sources;
- unavailable data;
- no universal definition of low-volume roads;
- complexity in developing a Geographic Information System (GIS).
1.4 Research Objectives

Pavement management has had an ongoing need for a comprehensive knowledge base, which is capable of integrating, analysing and displaying different data for decision-making. These data include maps, tables, text descriptions, pictures and normally contain a large amount of information. However, it is not only data related to pavement management need to be taken into consideration. Generally these data are stored separately in their respective database, which are hard to match, integrate and analyse. The demand for efficient tools for managing and analysing such information is necessary. In a low-volume road project undertaken by The University of Melbourne and Swinburne University of Technology, and being commissioned by the Department of Transport and Regional Services, a GIS being used as a computer-based spatial system has been adopted as the platform to build such a knowledge base.

The aim of this research was to investigate the capability of GIS as a knowledge base for low-volume roads in Australia. The knowledge related to this research put the focuses on the nature of low-volume roads, features of GIS and functions of GIS, methods of building this knowledge base and the expected outcomes.

In order to achieve this, questions on whether GIS can provide sufficient support will be discussed via following perspectives: data integration, data fusion and transport modelling in Victoria so that the capability of the GIS in implementing this task can be tested.

The key objectives of this research are to

- define low-volume roads;
- select the most appropriate GIS software;
- integrate transport networks, current and predicted freight vehicle demand and land-use data;
- examine transport modelling approach; and
- build a knowledge base.
1.5 Scope

This research will focus on the development of the database from the perspective of traffic demand, especially freight activity. This involves data collection, processing and integration as well as transport modelling applications to estimate traffic volumes.

This thesis focuses on the use of GIS in the development of a low-volume roads knowledge base. These include the integration of data with various formats to form a consolidated database, which can estimate traffic volume data to identify the potential low-volume roads even if traffic volume data are sparse or not available.

In this research, because of the insufficient data input, the knowledge base was not fully validated. However, as a subset of a sound road network, the robustness of this knowledge base has been discussed should all the necessary data be available. This knowledge base can also be linked with other databases to further extend its function, for example pavement maintenance strategies. Furthermore, the method used in this research will help the road authority to identify the potential low-volume road to better improve the data collection in a more economical way.

During this research, the selection of GIS software and the choice of traffic assignment techniques were considered based on the available data to achieve the optimal outcomes. With more data input, the outcomes would be further improved with the entire process being better refined.

1.6 Summary of Thesis Structure

The thesis consists of six chapters:

- Chapter 1 has background information of this research, the focus of my work and the overall outcome of this whole project.
- Chapter 2 outlines the key literature related to low-volume roads, pavement management, as well as GIS and transport modelling.
• Chapter 3 and 4 present a detailed methodology to explain how the research was conducted.
• Chapter 5 includes analytical results of this research directly obtained from the model. Discussion of these research results together with the final outcomes and findings are also included in this chapter.
• Chapter 6 summarises key contents and limitations of this research, and provides recommendations for further research.
Chapter 2. Literature Review

2.1 Chapter Overview

This chapter summarises key literature relating to this project. In order to build up a knowledge base for low-volume roads, it is essential to understand the environment of this project.

Since this project aims to develop a knowledge base for low-volume roads for better pavement management, it is important to understand the features of low-volume roads by varied definitions from previous experiences. Currently there is no universal definition for low-volume roads; still it is essential to review some cases to summarise in order to find the most appropriate features for low-volume road in this project.

The second part will be knowledge which is related with pavement management, in order to build a knowledge base for low-volume roads, it is significant to summarise what should be integrated into this knowledge base. Pavement maintenance is initiated by pavement damage, and one way of deciding the damage caused by vehicles is Equivalent Single Axle Loads.

The next section focuses on vehicle classification. Some background information of traffic demand and modelling are the major contents for the next part, followed by a review of freight demand and forecasting.

The last section introduces GIS, which is the platform used for the knowledge base for low-volume roads in this project. The advantages and applications of using GIS will be shown.
2.2 Low-volume Roads

The definition of low-volume roads has never been determined due to its respective environment. However, knowledge of previous experience is essential to summarise the most appropriate features of low-volume roads in this project. When talking about low-volume road, it is obvious that it should be determined by traffic volume.

In the journal of *Survey of Low-Volume Urban Streets and Rural Roads* in 1994, Swanson (1994) discussed several features of low-volume roads:

- **Low-volume urban streets**: Travel speed is typically below 50kmh. About half of the places are allowed to park on the boulevard area. The design volume averaged 3,200 vehicles, ranging from 1,000 to 5,000 per day.

- **Low-volume rural roads**: Average vehicles per day is 1,700. Typical design speed is 70kmh, from 40 to 110kmh. Average maximum roadway grade is 8.3% from 3% to 11%. Minimum is 0.7%.

Table 1: Low-Volume Rural Roads Cross-Section Design Elements (Swanson 1994)

<table>
<thead>
<tr>
<th>Cross-section element</th>
<th>Average (m)</th>
<th>Range (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lane width</td>
<td>3.0</td>
<td>2.00-3.50</td>
</tr>
<tr>
<td>Shoulder</td>
<td>1.0</td>
<td>0.25-2.00</td>
</tr>
<tr>
<td>Right of way</td>
<td>17.9</td>
<td>8.60-30.0</td>
</tr>
<tr>
<td>Cross-fall</td>
<td>2.5</td>
<td>2.00-3.00</td>
</tr>
</tbody>
</table>

Swanson’s definition contains both urban and rural low-volumes based on vehicle per day (VPD), it also contains some design elements such as speed and lane widths, which leads to some more specific features of low-volumes roads and functions defined by Giummarra (2001). According to Giummarra, low volume roads have certain geometric standards in Australia:
<table>
<thead>
<tr>
<th>Road Classification</th>
<th>District</th>
<th>Average Daily Traffic (ADT)</th>
<th>Recommended Road Design</th>
<th>Road Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residences, farms</td>
<td></td>
<td>1000</td>
<td>10000</td>
<td>Residential roads</td>
</tr>
<tr>
<td>Road to residential</td>
<td></td>
<td>2000</td>
<td>20000</td>
<td>Residential roads</td>
</tr>
<tr>
<td>Road to commercial</td>
<td></td>
<td>3000</td>
<td>30000</td>
<td>Commercial roads</td>
</tr>
<tr>
<td>Road to industrial</td>
<td></td>
<td>4000</td>
<td>40000</td>
<td>Industrial roads</td>
</tr>
<tr>
<td>Road to institutional</td>
<td></td>
<td>5000</td>
<td>50000</td>
<td>Institutional roads</td>
</tr>
</tbody>
</table>

Table 2: Road Classification and Design Standard for Low-Volume Roads (Giummarra 2001)
Giummarra also proposed a classification system for low-volume roads (2003):

**Rural Areas – Arterial Roads**

- Class 1 – Those roads that form the principal avenue for communication between major regions of Australia, including direct connections between capital cities.
- Class 2 – Those roads, not being Class 1, whose main function is to form the principal avenue of communication for movements between:
  1. A capital city and adjoining states and their capital cities; or
  2. A capital city and key towns; or
  3. Key towns.
- Class 3 – Those roads, not being Class 1 or 2, whose main function is to form an avenue of communication for movements:
  1. Between important centres and Class 1 and Class 2 roads and/or key towns; or
  2. Between important centres; or
  3. Of an arterial nature within a rural area.

**Rural Areas – Local Roads**

- Class 4 – Those roads, not being Class 1, 2 or 3, whose main function is to provide access to abutting property (including property within a town in a rural area).
- Class 5 – Those roads that provide almost exclusively for one activity or function and that cannot be assigned to Classes 1 to 4.

**Urban Areas – Arterial Roads**

- Class 6 – Those roads whose main function is to perform the principal avenue of communication for massive traffic movements.
• Class 7 – Those roads, not being Class 6, whose main function is to supplement the Class 6 roads in providing for traffic movements or to distribute traffic to local street systems.

Urban Areas – Local Roads

• Class 8 – Those roads, not being Class 6 or 7, whose main function is to provide access to abutting property
• Class 9 – Those roads that providing almost exclusively for one activity or function and that cannot be assigned to Classes 6, 7 or 8.

Table 3: Road Classifications

<table>
<thead>
<tr>
<th>ROAD CLASS</th>
<th>CLASS TYPE</th>
<th>FIGURE</th>
</tr>
</thead>
<tbody>
<tr>
<td>5A</td>
<td>Primary</td>
<td>1</td>
</tr>
<tr>
<td>5B</td>
<td>Secondary</td>
<td>2</td>
</tr>
<tr>
<td>5C</td>
<td>Minor</td>
<td>3</td>
</tr>
<tr>
<td>5D</td>
<td>Access</td>
<td>4</td>
</tr>
<tr>
<td>5E</td>
<td>Tracks</td>
<td>5</td>
</tr>
</tbody>
</table>

From the functions of the roads, the Melbourne Hierarchy of Roads Study (Alan et al 1981) adopted the following definitions, and urged that they be adopted by “all relevant agencies” to improve communications:

• Freeways – Those roads with full access control and grade separated intersections that primary function is to service large traffic movements.
• Primary Arterial Roads – Those arterial roads whose function is to form the principal avenue of communication for metropolitan traffic movements not catered for by freeways.
• Secondary Arterial Roads – Those roads which supplement the Primary Arterial Roads in providing for through traffic movement, to an individually determined limit that is sensitive to both roadway characteristics and abutting land uses.
• Collector Roads – Those non-arterial roads which distribute traffic between the arterial roads and the local street system, which provide local connection between arterial roads and which provide access to abutting property.

• Local Access Streets – Those streets not being arterial or collectors, who’s main function is to provide access to abutting property.

From these different views on low-volume roads, it is noticeable that the definition of low-volume road is not only about volume but also incorporate the function of the road and other features as well.

2.3 Pavement Management

After reviewing some literature based on low-volume roads, it is necessary to examine what is the key focus for this research on low-volume roads. The reason why this project was initiated was to build a knowledge base for pavement maintenance and management. Therefore, understanding the nature of pavement management and what knowledge about pavement should be included in this knowledge base will be the next issue.

Pavement management is a business process that allows Department of Transport personnel to make cost-effective decisions about the pavements (TRB 2004). Pavement Management Systems (PMS) have been defined as “a system which involves the identification of optimum strategies at various management levels and maintains pavements at an adequate level of serviceability. These include, but are not limited to, systematic procedures for scheduling maintenance and rehabilitation (M&R) activities based on optimization of benefits and minimization of costs.” The major benefit of PMS is to help decision makers to be concerned about what, where and when to take M&R actions (Fred 1998). There are four general types of data included in a database for the foundation of all PMS:

• inventory (including pavement structure, geometrics, and environment);

• road usage (traffic volume and loading, usually measured in equivalent single-axle loads);
• pavement condition (ride quality, surface distresses, friction, and/or structural capacity); and
• pavement construction, maintenance, and rehabilitation history (TRB 2004).

2.3.1 Pavement Damage

The reason why pavements need to be maintained is due to pavement damage or deterioration. Pavement damage or deterioration is the degradation of pavement quality due to loading by traffic and/or climate (NVF 2008). Here, in this project, investigations have been made on traffic.

The damage of pavement includes: cracking, rutting and other distress, detailed pavement damage modes will not be discussed here. The damage also depends on the pavement materials (asphalt or concrete), vehicle mass etc. Despite the reason and modes of road damage. With time the pavement will develop distress in various degrees until the pavement reaches an unacceptable condition and will be rehabilitated by resurfacing. Therefore road wear is a very important parameter to focus at for design and maintenance of road pavement (NVF 2008). As a result, it is important to review a basic parameter: axle load.

2.3.2 Equivalent Standard Axles

It is quite complicated to determine the number of different types of wheel/axle loads that a pavement will support over its design life. From the perspective of maintenance, the damage caused by the wheel’s load is the primary concern. The most common historical way is to convert damage from the wheel loads of various traffic to damage from equivalent number of ‘standard’ or ‘equivalent’ loads. The most commonly used equivalent load is the 80kN equivalent single axle load (ESAL).
Generally this is described by a Load Equivalency Factor (LEF), where an axle load is said to be equivalent to a number of applications of a standard axle load. Fourth Power Law is the most widely used LEF which can be expressed as follows:

\[
\frac{N_{\text{ref}}}{N_x} = \left( \frac{W_x}{W_{\text{ref}}} \right)^4
\]

where: \(W_x\) and \(W_{\text{ref}}\) are axle loads and \(N_x\) and \(N_{\text{ref}}\) are the corresponding number of load applications (NVF 2008).

The relationship between axle weight and inflicted pavement damage is not linear but exponential. Thus, heavy trucks are responsible for a majority of pavement damage. Determining the LEF for each axle load combination on a particular roadway is possible through the use of weigh-in-motion equipment. This method allows for ESAL estimations without detailed traffic measurements, which is often appropriate for low volume roads.

A basic element in pavement design is estimating the ESALs a specific pavement will encounter over its design life. This is done by forecasting the traffic the pavement will carry then converting the traffic to the number of ESALs based on its makeup. A typical ESAL estimate consists of:

1. Traffic counts: A traffic count is used as a starting point for ESAL estimation. Also, simple traffic tube counts are relatively inexpensive and quick.
2. Heavy vehicle numbers: This usually requires some sort of vehicle classification within the traffic count. The simplest classifications divide vehicles into two categories: (1) heavy trucks and (2) others. Other, more elaborate schemes can also be used such as the FHWA’s vehicle classification.
3. An estimated traffic (and heavy vehicle) growth rate over the design life of the pavement. A growth rate estimate is required to convert a single year’s traffic count into the total traffic experienced over the pavement’s design life.
4. LEFs selection and convert truck traffic to ESALs.
5. An ESAL estimate.
NTC developed equations for converting GVM to ESA directly for some common types of trucks when based on the results from six jurisdictions during 1998, 1999 and 2000 by Weigh-In-Motion system. The equations are:

**Table 4: Conversion Equations by NTC (ARRB 2005)**

<table>
<thead>
<tr>
<th>Vehicle type</th>
<th>Predictive Equation</th>
<th>GVM range (t)</th>
<th>$r^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1-1</td>
<td>Predicted ESA = (0.0461 x GVM) - (0.0156 x GVM²) + (0.0018 x GVM³)</td>
<td>2.5 - 16.4</td>
<td>0.88</td>
</tr>
<tr>
<td>R1-2</td>
<td>Predicted ESA = (0.0657 x GVM) - (0.0096 x GVM²) + (0.00059 x GVM³)</td>
<td>8.3 - 25.8 (≤ up to 8 tonne steer)</td>
<td>0.93</td>
</tr>
<tr>
<td>R2-2</td>
<td>Predicted ESA = (0.1010 x GVM) - (0.0120 x GVM²) + (0.00052 x GVM³)</td>
<td>8.2 - 36.3</td>
<td>0.94</td>
</tr>
<tr>
<td>A122</td>
<td>Predicted ESA = (0.0900 x GVM) - (0.0051 x GVM²) + (0.00018 x GVM³)</td>
<td>9.3 - 41.6 (≤ up to 8 tonne steer)</td>
<td>0.95</td>
</tr>
<tr>
<td>A123</td>
<td>Predicted ESA = (0.1190 x GVM) - (0.0098 x GVM²) + (0.00016 x GVM³)</td>
<td>12.9 - 50.6</td>
<td>0.92</td>
</tr>
<tr>
<td>B1232</td>
<td>Predicted ESA = (0.0677 x GVM) - (0.0024 x GVM²) + (0.000098 x GVM³)</td>
<td>15.2 - 66.4</td>
<td>0.89</td>
</tr>
<tr>
<td>B1233</td>
<td>Predicted ESA = (0.1050 x GVM) - (0.0041 x GVM²) + (0.000066 x GVM³)</td>
<td>18.8 - 73.1</td>
<td>0.97</td>
</tr>
<tr>
<td>A123-T23</td>
<td>Predicted ESA = (0.0480 x GVM) - (0.0008 x GVM²) + (0.000023 x GVM³)</td>
<td>18.1 - 82.8</td>
<td>0.91</td>
</tr>
<tr>
<td>A123-T23-T23</td>
<td>Predicted ESA = (0.1030 x GVM) - (0.0021 x GVM²) + (0.000019 x GVM³)</td>
<td>28.4 - 137.7</td>
<td>0.98</td>
</tr>
</tbody>
</table>

(Where $r^2$ is adjusting factor)

A relationship between GVM and ESA proposed by Austroads (2009) is shown below:

$$ESA = aGVM + bGVM^2 + cGVM^3 + d$$

It is obvious that traffic volume and heavy vehicle numbers as well as the growth rate will be key factors in determining pavement maintenance. Within each heavy vehicle range, the number of axle groups and the number of axles within group are the parameters to calculate ESAL. Therefore, a vehicle classification system needs to be introduced.

**2.4 Vehicle Classification**

In order to understand the damage caused by the traffic on road infrastructure, we need to understand the movement of heavy vehicles. Thus, a vehicle classification system is necessary to classify the heavy trucks from all types of vehicles and calculate the damage caused by them from their different characters.
Table 5: Current Austroads Vehicle Classification Systems (Austroads 2004)

<table>
<thead>
<tr>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
<th>Austroads Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Length</strong> (indicative)</td>
<td><strong>Axles and Axle Groups</strong></td>
<td><strong>Vehicle Type</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Type</strong></td>
<td><strong>Axle</strong></td>
<td><strong>Groups</strong></td>
<td><strong>Description</strong></td>
</tr>
<tr>
<td>Short</td>
<td>Up to 5.5m</td>
<td>2</td>
<td>1 or 2</td>
</tr>
<tr>
<td>Medium</td>
<td>5.5m to 14.5m</td>
<td>3,4 or 5</td>
<td>3</td>
</tr>
<tr>
<td>Heavy</td>
<td>11.5m to 19.0m</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Long</td>
<td>&gt;2</td>
<td>4</td>
<td>&gt;2</td>
</tr>
<tr>
<td>Groups &gt; 2</td>
<td>Axles: number of axles (maximum axle spacing of 10 m)</td>
<td>D1: distance between first and second axle</td>
<td>D2: distance between second and third axle</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>5 &gt;2</td>
<td>Five Axle Articulated or Rigid vehicle &amp; trailer</td>
<td>8</td>
<td>(d2 \leq 2.1, \text{m, } 2.1, \text{m} \leq d1 \leq 3.2, \text{m} ) Axles = 5 and Groups &gt; 2</td>
</tr>
<tr>
<td>6 &gt;2</td>
<td>Six Axle (or more) Articulated or Rigid vehicle &amp; trailer</td>
<td>9</td>
<td>Axle = 6 and Groups &gt; 2 or Axles &gt; 6 and Groups = 3</td>
</tr>
<tr>
<td>&gt;6 &gt;2 &gt;3</td>
<td>'B' Double or Heavy truck trailer</td>
<td>10</td>
<td>Groups=4 and Axles &gt;6</td>
</tr>
<tr>
<td>&gt;6 &gt;6</td>
<td>Double Road Train or Heavy truck and trailers</td>
<td>11</td>
<td>Groups = 5 or 6 and Axles &gt; 6</td>
</tr>
<tr>
<td>&gt;6 &gt;6</td>
<td>Triple Road Train or Heavy truck and three trailers</td>
<td>12</td>
<td>Groups &gt; 6 and Axles &gt; 6</td>
</tr>
</tbody>
</table>

**Definitions:**
- **Group:** (axle group) - where adjacent axles are less than 2.1m apart
- **Groups:** number of axle groups
- **Axles:** number of axles

The actual classification of vehicles by Austroads is not only involves vehicle type, but also axle numbers and axle group numbers. A more visualised demonstration is shown in Figure 1 below.
Figure 1 shows a more visualised explanation on each vehicle class. As it is shown, Class 1 and Class 2 are passenger vehicles that normally do not have a large gross vehicle mass. Class 3 to Class 12 are normally identified as trucks in Australia. The reason why this classification system been introduced is due to the definition of low-volume roads. Moreover, in terms of data availability, national level data currently used in this project has a similar classification regarding traffic volume data.
2.5 Traffic Volume and Data Collection

From the perspective of low-volume roads and pavement maintenance, traffic volume and traffic counts are always key indicators and important input data. Therefore, some background information about traffic volume is necessary to introduce.

For road traffic, the most commonly used unit is the Annual Average Daily Traffic (AADT). This is the total volume of traffic passing a roadside observation location over the period of a calendar year, divided by the number of days in that year. Sometimes with the type of vehicle more precisely defined, for example Commercial Vehicles (CV), normally trucks (Austroads 2004).

Another important unit is Vehicle Kilometres Travelled (VKT). This is also classified by vehicle type. VKT provides a measure of the total level of usage of a road or road system.

There are different ways of collecting these data, Austroads in its report “Guide to Traffic Engineering Practice” summarises these methods (Austroads 2004)

- Manual Traffic Counting
- Automatic Axle Counts

Manual traffic counting is usually undertaken at an intersection to observe not only the traffic counts but turning movements as well. Automatic axle counts use pneumatic rubber tubes stretched across the road surface. Traffic counts are collected by an embedded sensor. By collecting the time of traffic travelling between two tubes can be used to estimate the speed and wheelbase. Other methods including inductive loops, microwave or radar scanning, infrared, acoustic, magnetic and video imaging devices are used in some situations.

Data collection is not always a long-term action, especially in rural areas when traffic volumes are not very high. The cost of installing automatic devices along a road network can be very high and hard to maintain such as loop detectors or manual counting. AADT is estimated by making short-term counts, usually on a rotational
basis, at selected sites. Collected data can be used in conjunction with an adjustment factor. For instance, after estimating the Average Daily Traffic (ADT), which is a sample of the AADT and is the traffic counts averaged over a time period, from a few days to a month. This is combined with an adjustment factor which is derived from a seasonal count on the potentially interest road to estimate AADT. VKT is predicted by measuring AADT on selected links and making an estimate of the total network travel.

There are different types of adjustment factors accounting for daily and seasonal variations. There are a number of ways of collecting traffic volume data depending on the type of collecting method used and the time period.

Traffic Loading data are normally collected by a Weigh-In-Motion (WIM) method which are referred to as, “A device that measures the dynamic axle weight of a moving vehicle to estimate the corresponding static axle mass” (Koniditsiotis 2000). It has a controller, computer and associated electronics, and roadway sensors for all lanes for which traffic data are being processed by the controller and at least one lane is instrumented with weigh-in-motion sensors (Cohen et al 2008).

### 2.6 Freight Demand and Forecasting

Traffic volume data, as mentioned above, is normally sparse and difficult to secure. Although there are some methods of collecting traffic volume data, these devices cannot be installed on every road to collect the necessary information. Therefore, traffic modelling, especially freight forecast is a way of using limited data input to get more information for a road network. Freight movements are important for transport infrastructure. This is not only within road transport for better road networks but also in a strategic sense to provide for commodity flows over the nation.

The Forecasting Statewide Freight Toolkit (Cohen et al 2008) summarises five basic model classes and six modelling components, as shown in Table 6. All of the classes, except the direct facility flow factoring model class, assign one or more modal tables
The origin-destination (O-D) factoring, four-step commodity, and economic activity models all have mode split components. The truck, four-step commodity, and economic activity model classes all have trip generation and trip distribution components.

- **The Direct Factoring:** This method uses basic information about existing flows and forecasts of economic data or trends that would affect the facility, which involves estimating a growth factor from current and past truck count data and applying the resulting factor to future years using a conventional compound interest formula.
- **Trip Generation:** Estimate of trips produced in and attracted to the study zones (Thomas 1991). Basically means how many trips will start in one zone.
- **Trip Distribution:** This method uses Gravity models to calculate distribution for each Origin-Destination (OD) pair by purpose and adjust the calculations iteratively based on the calculations of all other pairs of the same trip purpose.
- **Mode Split:** The mode split model component uses a freight trip table, obtained either from the trip distribution or the commodity flow model components, to forecast tables of freight flows between all geographic zones for individual freight modes
- **Traffic Assignment:** This method uses a table or matrix of traffic flows by mode between all zones.
- **Economic/Land Use Modelling:** Economic/land use modelling components in state-wide freight forecasting include modelling techniques known as a spatial input-output (I-O) or econometric models. The land use considerations in these models consider state and national economic activity are generally far less developed than in metropolitan land use models and typically only forecast household and economic activity across county-level zones based on basic supply, demand, and cost relationships for the state and national economy. These models may be used to develop the forecast socioeconomic variables that will be used by the freight model.
### Table 6: Model Class and Component (Cohen et al 2008)

<table>
<thead>
<tr>
<th>MODEL CLASS</th>
<th>MODEL COMPONENT</th>
<th>Direct Factoring</th>
<th>Trip Generation</th>
<th>Trip Distribution</th>
<th>Mode Split</th>
<th>Traffic Assignment</th>
<th>Economic/L and Use Modelling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct Facility Flow Factoring Method</td>
<td>Of Facility flows</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>O-D Factoring Method</td>
<td>Of O-D tables</td>
<td></td>
<td></td>
<td></td>
<td>Included</td>
<td>Included</td>
<td></td>
</tr>
<tr>
<td>Truck Model</td>
<td>Based on exogenously supplied zonal activity</td>
<td>Included</td>
<td>Not Applicable</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Four-Step commodity Model</td>
<td>Based on exogenously supplied zonal activity</td>
<td>Included</td>
<td>Included</td>
<td>Included</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Economic Activity Model</td>
<td>Based on outputs of economic model</td>
<td>Included</td>
<td>Included</td>
<td>Included</td>
<td>Included</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Growth factor method**

The growth factor method is a simple but effective way to estimate the future trends of traffic volume data when historic data is available. As demonstrated in *Quick Response Freight Manual-Final Report* (Cambridge Systematics 1996).

Using two years of historical data, an annual growth factor (AGF) is calculated as follows:

$$AGF = (T2/T1)^{1/(Y2-Y1)}$$

Where:

T1 is freight demand in year Y1 and,
T2 is freight demand in year Y2.
The annual growth factor can then be applied to predict future demand (T3) for some future year (Y3) as follows:
T3 = T2 AGF^{Y3-Y2}

2.6.1 Intermodal and Freight Forecast

Intermodal freight deals with the movement of commodities using various modes of transport. Its function is to estimate value to shippers which has given them greater choice of routings and a technique to lower costs by enabling them to select carrier combination and vehicles which offer most efficient service at least expense. “Intermodal freight transportation is the concept of transporting freight using more than one mode of travel in such a way that all parts of the transportation process are effectively connected and coordinated, safe, environmentally sound and offering flexibility” (Muller 1995). Wisconsin DOT developed a freight forecasting model as shown below:
Base-year 1992 data were used to develop forecasts for year 2020 and for five intermediate target years. Industrial employment and productivity were used for the freight forecast. A projection of employment was prepared for each year between 1992 and 2020 by using economic indicators of 92 separate classes of industry, equivalent to two digital SIC codes. Employment was calibrated to the official population projection in the State of Wisconsin, embracing all forms of economic activities. Finally, the base-year freight forecast of flows was generated. Beginning with the 1992 base-year volumes by commodity and origin, tonnage was multiplied with the combined ratio of change for employment and productivity to that origin and relevant industry. This was done for each target year assuming the same rate of change for all modes carrying a given commodity from a single origin. Adjustments
in the primary freight forecast were made for certain commodities (e.g., farm outputs, fuels, waste, and non-metallic minerals) and for export and air forecasts, which were judged to grow either faster or slower than the average for all freight. However, results could be improved due to the data elements that could not be readily obtained but would have been useful:

- Truck counts by vehicle class on selected facilities;
- Truck counts on a greater variety of facilities, including roads not designated as state trunk highways;
- Lists of major truck trip generators, their commodity and employment characteristics, and their location;
- Lists of truck routes or truck-restricted road segments;
- A state-wide, base-year truck forecast that is well calibrated to traffic counts on road segments serving as external stations for regional forecasting purposes; and
- Diurnal variation of truck trips by vehicle class and road functional class.

2.6.2 Traffic Assignment

Of all these techniques, traffic assignment techniques is the method used to estimate traffic volume data in this project, combined with growth factor to predict current and future traffic volumes and specific truck volumes. Thomas (1991) put the aim of traffic assignment in “to reproduce on the transport system, the pattern of vehicular movements which would be observed when the travel demand represented by the trip matrix, or matrices, to be assigned is satisfied. In the four phase traffic estimation process of the traditional travel demand model, the two major aims of traffic assignment procedures are:

- to estimate the volume of traffic on the links of the network and, possibly, the turning movements at intersections; and
- to furnish estimates of travel costs between trip origins and destinations for use in trip distribution and modal choice models.”

Highway network models generally contain two or three subsets of nodes:
• Centroids, of which there is one for each zone, representing the point within the zone at which all trips are assumed to start and finish;
• Intersections, located wherever links intersect and also wherever there is a marked change in the physical nature of a modelling road, e.g. an increase in the number of lanes;
• And, in some models, gateways or cordon stations, representing the points on the study area’s external cordon where trips enter and leave the area.

After the road network has been defined, the route which traffic will take has to be determined as well, generally defined by lowest cost among all routes. A more detailed description of traffic assignment techniques is presented in Appendix 3.

2.6.3 Auslink

Auslink is the vehicle to address Australian land transport challenges for developing an integrated network of strategic importance including road and rail links and intermodal connections to ports and airport. Within these networks, road freight took 72% of domestic freight shares by tonnes and 37% by tonne kilometres. From which it is clear to say that road infrastructure is in a long-term strategic importance for Australian transport demand.
Figure 3: Victorian Major Road Network

From Figure 3, the major road network in Victoria provides transport access to freight and passenger movements. As some of which become part of Auslink, helping to improve the freight movement capability. In national wide, Auslink tries to include range of corridors and links under its government better fund allocation and management, primary roads linking major cities, for example Sydney to Melbourne, Sydney to Brisbane.

Auslink will promote sustainable national and regional economic growth, developing and connectivity by contributing to an integrated land transport network.
2.7 Geographic Information Systems

After the review of traffic related topics, it is good to look at the tool, which has been used to put all these information together. Geographic Information Systems (GIS) integrate computer hardware, software, personnel, organizations, and business processes designed to support the capture, management, manipulation, analysis, modelling, and display of spatially referenced data for solving complex planning and management problems which enabled database management systems, and middleware applications. GIS provides an effective means for developing PMS tools.

Visual information allows complex spatial relationships to be identified and integrate various types of data, which allows them to be undertaken easily and visually (Taniguchi & Thompson 2003). GIS as a computer-based spatial data management system has been used in different research areas for years. Its capability of integrating, displaying spatial data has been proven to be strong. A specific designed GIS for transport research, known as GIS-T in general provides one approach to solve the problem when there is no or limited traffic data on a road. Another advantage of GIS is its data sharing ability while data formats from other software can be directly imported and provide a platform for data fusion.

Since such large amount of data is needed to collect in order to build a database of PMS, it is important to use a powerful technology, which is capable of this. A comprehensive GIS includes procedures for data input, either from maps, aerial photographs, satellites, surveys or other sources; data storage, retrieval, and querying; data transformation, analysis, and modelling; and output generation, including maps, reports, and plans. Under this kind of integration, a GIS is more considered as a “process” rather than a specific GIS technology (TRB 2004).

In order to use GIS to build a knowledge base, it is essential to consider them as an integrated system. Information in the database can be stored using location and attributes in GIS, where the information in PMS must be stored in a database and data is retrieved from the database according to the user’s needs. Moreover, GIS can show
the information visually generating maps that answer the questions that will be asked in PMS (Albitres 2003).

2.7.1 Transport Network Management

The graphical, map-based interface provided by GIS enhances data input and management capabilities. The data combination can also be used to easily assign demand characteristics to nodes on a transport network. The other use is transportation network generation. When zones define areas that exhibit homogenous household and land use characteristics, transportation demand can be more effectively predicted. Moreover, the network design capabilities of GIS assist in transportation network preparation (Sanchez et al 2002).

2.7.2 Rural Transport

In the report, *Rural Public Transportation: Using Geographic Information Systems to Guide Service Planning* (Sanchez et al 2002), GIS can be used to analyse transit service and develop a model to get quantifiable measurements that could be used to assess transportation accessibility improvements in rural areas. With this model, rural transportation planners and social service providers can be better equipped to coordinate, evaluate, improve and monitor transit services in rural communities. The capabilities of a GIS in planning applications are huge and can be used more specifically, for coordinating social services and rural transportation planning a GIS can be used to:

1. Visualise the spatial mismatch between welfare-to-work participants and potential employment opportunities
2. Help to determine a person’s access to appropriate transit services
3. Estimate the predicted number of transit users in a specific area
4. The methods to implement new transit services or modify existing routes by identifying possible riders and likely destinations (Multisystems 2000).
The application of GIS for rural low-volume roads starts with the collection of data. These include: cross section (travelled way and shoulder width), bridge width, horizontal alignment, stopping sight distance, intersection sight distance, roadside design, unpaved roads and two-way single lane roads.

A case study involving the Scientist, Central Road Research Institute, New Delhi was made to develop a scientific rural road network planning. Three different sets of data had been collected which were: village data, rural road data and map data. A base map with all features had been prepared with the scale of 1:50,000 in GIS environment which the location of all the village settlement and existing road network had been prepared with the help of toposheets, census maps and PWD road maps. These maps were digitized with number of layers: boundary layer, village location as point layer, the existing road network as line layer and waterway layer. With these data, using the GIS software, they could get the shortest route from an unconnected village to the nearest major centre along existing routes and as well as other information (Rao et al 2003).

Furthermore, in the case study for Lisbon, ArcView GIS was used with all resources required for exploring the PMS system (Santos et al 2004). The road network database could be analysed, queried and modified. In order to build a Pavement Management System, the most important phase was to define the data to be included in the road network database such as type, amount, relevance, reliability and ease of acquisition. Here information was stored for:

1. Position of each segment in the road network;
2. Road geometry;
3. Pavement structure characteristics and pavement history;
4. Node and segment localisation on the road network model;
5. Pavement condition;
6. Maintenance and Rehabilitation average costs; and
7. Complementary data.

A great amount of scenarios, individual or grouped data, stored or produced in the road network database could be visualised and analysed so that it was very
straightforward when managing these data which can be integrated into Pavement Management System (Santos et al 2004).

### 2.7.3 Pavement Condition

Pavement condition data is used to monitor the performance of the system, to help in the selection of projects, and identify pavements that need future maintenance and/or rehabilitation. The data usually includes pavement roughness and surface distress (cracks, ruts, faults, etc.) are collected by a specific tool (a sophisticated digital inspection vehicle in the Minnesota) (MnDOT 2007).

These data can be put into a GIS. The Virginia Department of Transportation has used GIS to display the general pavement conditions for its road network by country, as well as illustrating sections that are above, near, or below established condition threshold (Schmitt et al 2008). It is based on the periodic functional and structural evaluations to assess the level of service being provided to the user.

### 2.7.4 Freight Modelling

GIS is also a perfect platform to create freight transportation network. It can be used to contain information relating to freight transportation infrastructure, such as highways, railroads, ports, airports, and intermodal transfer facilities. The freight flows, obtained from the system inventory connected to the infrastructure elements as attribute data, the GIS freight database becomes a powerful analysis tool to support statewide freight transportation planning. The data of a freight transportation system inventory in GIS format would be useful.

GIS freight database can investigate possible changes to the freight transportation system to view their effects on future and current situations. The GIS can also store and management geographic and attribute information necessary for the system.
inventory and assist in freight modelling computations. The organization of data in GIS form would allow the effects of transportation infrastructure changes to be viewed quickly for a “what if “analysis (Eatough et al 1998).

2.7.5 Traffic Volume

Traffic volume data can be integrated into GIS as well. A case study, made by Texas Transportation Institute (Quiroga et al 2003), involved traffic volume data stations collecting traffic volume counts. They used two types of locations: segment count stations and intersection count stations while intersection count stations logically involve all the approaches to an intersection. A geodatabase handles traffic volume data stations in the GIS, which included five different data: traffic volume data, station types (Average daily Traffic—ADT, turning movement count—TMC), station status types (mobile, permanent), ADT data and TMC data.

After creating traffic volume data stations in the GIS, they integrated the metadata associated with those features into the database. These include: a unique identifier, shape, volume data station, latitude, longitude, status type, station type, route, mile, name, location description and street name. The final step was to integrate supporting document data, which can be stored in the document.

When queried through the map interface, GIS features display all related data associated with the features, including attribute data as well as metadata and a copy of the original document.

2.7.6 GIS on Low-volume Roads

As it reviewed in the previous sections, GIS is useful in data integration and analysis and it is mostly used in the management of larger highway systems such as entire state highway networks. Low-volume roads are not always included in this system
especially in rural areas due to sparse data source, cost and time consumption. Despite the fact that low-volume roads are not the main concern of road agencies regarding maintenance, these roads are still need to be monitored and properly maintained.

In the journal of Transportation Research Record in (Ebeling and Bittner 2007), it was stated that management of low-volume roads have numerous challenges including budgeting, maintenance decision making and development. Wisconsin state assisted their local officials by using Wisconsin Information System for Local Roads (WISLR) that will benefit their asset management capabilities. A web-based GIS was created that could provide both the state agency and the local government with accurate tracking of roadway mileage and pavement conditions and also to help making management decisions. WISLR combines GIS technology with database application tools based on the Pavement Surface Evaluation Rating system, allowing municipalities to perform long-range planning.

Traffic count data are useful in many ways, but not always available in all road networks, especially for low-volume roads. The traditional data collection sensor cannot be placed in every road section. In case where traffic volumes are needed but unavailable, Zhong and Hanson (2009) provided a solution by using travel demand models (TDMs) to estimate such information. The previous research relies heavily on available traffic counts to develop, calibrate and validate regression models, but on low-volume roads, this becomes a major problem. GIS-based TDMs using census data and Quick Response Method produced forecasted traffic for road network previously without any traffic information and limit the errors to less than 40%. Their study results showed TDM is a practical, useful, cost-effective way for estimating traffic parameters on low-class roads.

2.8 Chapter Summary

In this chapter, literature has been reviewed on low-volume roads, features and different definitions of low-volume roads have been given. Background information regarding pavement management and maintenance has been reviewed and combined
with a vehicle classification system. As traffic volume and truck volume are the main concerns in this research, a review of traffic-modelling and freight forecast techniques are necessary to include in this section.

The next chapter contains an explanation of the methodology, as well details based on the literature reviewed to give a better understanding on the process of this research.
Chapter 3. Methodology

3.1 Chapter Overview

This chapter will cover the methodology used in this research. Linking the literature review, a logic procedure of how the methods were implemented will be demonstrated.

This chapter presents a flow chart (Fig. 4) to provide more visualised information regarding the structure of this thesis. Each section in the flow chart will be explained. As mentioned earlier, this research aims to develop a knowledge base for low-volume roads, for this project. Another important aspect for The University of Melbourne is to develop algorithms for pavement maintenance. The algorithms are based on traffic volume; therefore, cross-reference and interface between our independent works have taken place through the whole process of this project.

Due to the availability of data, and resources, there are limitations of this research. However, improvements can be made with more data and time.

3.2 Data

In this project, limits were found where some data was identified as important to the development of the knowledge base which was not available. This section will summarise the available data in this project.

To build up a knowledge base, the key role of GIS is to integrate all the data, whether it is spatial data, in other words, maps; or attributes data, which is text data. For the spatial data, VicRoads provided a Victorian road data which contain road name, IDs, types etc. This data contains the Victorian road map as well as embedded attribute data, for example, names, road ID and road type. (See Appendix 1)
One data source is VicRoads traffic data, which contains traffic volume and truck proportion data from year 1988 to year 2001. Traffic data including pavement condition, ESA, Gross Vehicle Mass (GVM) data are all stored in Excel format for over 3,500 road segments. Another one is SMVU data which is on a state level was also provided by relevant people involved in this research. This data separates traffic data into vehicle categories from motorcycle to the biggest road train. Each category has its own traffic data on a location base, whether it is in metropolitan areas or in rural areas. The number of different vehicles in areas was classified as well.

### 3.3 Research Process

Since the purpose of this research is to build a knowledge base for low-volume roads, the process of this research starts with a summary and comparison of different literature, incorporating with the current situation in Australia, and other researcher’s work, in order to get a reasonable definition on low-volume roads. After defining low-volume roads, focus has been made on what knowledge is needed in this knowledge base.
The next step is data collection. Two types of data were collected, one is map data, which is in GIS format, to be used as the base map for this knowledge base; another type of data is traffic data, including AADT data and truck proportion data on a national level. These data can produce a traffic volume data, which contains not only the total traffic volume but also truck counts in order to get the loadings on pavements. Other data such as pavement condition data are only can be obtained through survey and cannot be estimated like traffic data. In this research, the available AADT dataset contains information of pavement condition in the selected road network, as long as a road is defined as a low-volume road, these data can be integrated into knowledge base naturally. However, when identifying potential low-volume roads, pavement condition data cannot be estimated.
With the process of this model, we are able to compare and select the most appropriate tools, which can be used in this project. After evaluating different tools, we selected GIS as our platform as well as the use of data fusion technology and data observatories to be implemented with GIS to build a suitable model for this project.

The basic and most important advantage for using GIS is its powerful data integration ability. Different types of data will be input into GIS to build a data module. These data are mainly are two types: spatial data and attributes data. Spatial data is the geographic referenced data, which are mainly maps, containing coordinates embedded inside. Normally these data can be not modified and they can be matched by locations. Attribute data can be translated to text data since they contain numbers or words, to show the characteristics of a place, for example the population of a small town or pavement condition of a road segment.

As we can see from Figure 5, spatial data may contain borders, roads, land-use which is mainly map-based information. These data have their geographic referenced code and each of them can be a single layer in the GIS.

**Figure 5: Input and Output Using GIS as a Platform for Road Management (Osman & Hayashi 1994)**

As we can see from Figure 5, spatial data may contain borders, roads, land-use which is mainly map-based information. These data have their geographic referenced code and each of them can be a single layer in the GIS.
Data fusion technologies combine data from different sources, which raises concerns about quality and comparability of the resulting fused data. It combine data from multiple sources and gathers that information in order to achieve inferences, which will be more efficient and potentially more accurate than if they were achieved by means of a single source. Data fusion is a low-level fusion process. Fusion processes are often categorized as low, intermediate or high, depending on the processing stage at which fusion takes place (Casavant & Jessup 2007).

In the Lisbon case study conducted by Santos et al. (2004), GIS was used with all resources required for exploring the PMS. The road network database could be analysed, queried and modified. In order to build a PMS, the most important phase was to define the data to be included in the road network database such as type, amount, relevance, reliability and ease of acquisition.

Base map and traffic volume were integrated to produce a road data map, which contains a spatial map data, and also road attributes data. Remembering that base map is in digital format while traffic volume data normally comes in table format such as Excel, the way of integrating them is by matching its location. Problems here are that GIS road maps contain coordinates embedded inside, but attributes data do not. Attribute data are normally stored in table format and uses different ways of expressing its location for each road, for example collecting location in Local Government Areas (LGA), its region and milepost. Linear referencing is a way of matching road map data with attribute data provides a solution when integrating data.

The model here also includes the selection of the most appropriate GIS software for this research. A comparison has been made to evaluate GIS software in the current market to choose the one most suitable for this research. With the integration of road map data and traffic volume data, it is possible to use traffic modelling techniques in GIS software to estimate the traffic volume in a potentially interest area to find out whether the road is low-volume road or not. With more traffic volume on the road network being determined, data can be used as input for traffic modelling processes to refine the results and become more accurate. Estimated traffic volume data can also produce truck volume data by combining this with truck proportions to get a more
detailed traffic loading data as well. More importantly, it will provide information on the sustainability of road infrastructure, such as bridges.

This process then can be validated to see if improvements are needed and how it is able to test the accuracy. The maintenance model produced then can be integrated into this knowledge base to provide not only the pavement maintenance strategy to be applied in a specific road network, but also the exact location of each maintenance work conducted, as shown in the Figure 6 below.

![Figure 6: Maintenance Strategy in Chosen Area](image)

The final outcome will be a comprehensive knowledge base for low-volume roads in Australia containing all the necessary information. In this research, the knowledge base for low-volume roads may only be a subset of a more comprehensive one due to the insufficient data input, and resource limits. However, it should be noted that it provides an effective and sustainable way is of managing pavement data. This knowledge base will also be easy to update once it is complete.
3.4 Chapter Summary

This chapter introduced the methodology used in this thesis based on the flow chart. These include introduction of available data source, methodology of integrating data, evaluation of potential GIS software and the expected outcome. The next chapter will provide a more detailed explanation of each step taken in this research to better understand the research process.
Chapter 4. Research System Development

4.1 Chapter Overview

This chapter provides detailed information for the whole process of this research. Criteria are made for low-volume road in this project. The main focus of this chapter will be the use of GIS to integrate, model and display both data from the available database or from the estimation of freight demand.

4.2 Low-volume Roads

Based on the data we have and a review of the literature, an definition of low-volume roads has been made as: the volume of commercial vehicles (freight vehicles) whose gross vehicle mass is over 4.5 tonnes excluding buses is no more than 250 vehicles per day (vpd) in rural areas (100 kilometres away from metropolitan areas), road type is highway with normally one lane in each direction. The function of it is to provide transport corridor between major towns and cities, especially for freight purposes.

These roads are distributed in different rural regions and thus make the data difficult to collect and sometimes it is not available. After the acquisition of road network data (map) and partial road usage data, the next step is to input the road usage data into the map data and pick the low-volume roads out of the database. Under this hypothesis, data analysis and filtering has been made to select the potential low-volume roads, which fall into this definition from available data. For all the data to be integrated, GIS was chosen as the platform to build up this knowledge base.

4.3 Software Evaluation

GIS is a very important tool in a decision support system by facilitating preparation, analysis, display, and management of data in a geographical platform. In particular,
pavement management is a decision process that could benefit from the use of a geographical platform provided by GIS. It is not only essential in analysing the different road related activities, but also can vastly improve the quality of the decision-making process.

After determining that GIS is the most appropriate tool to use in this project, another thing is to choose the most appropriate software to be used in this project. In the current market, there are several GIS packages which are aimed at different levels. For instance, the basic entry-level GIS system such as MapInfo, ArcGIS are capable of data management, visualisation, and linkage to external data as mentioned here. Nevertheless, in this project, the transport planning and modelling capabilities of GIS are the key elements in developing pavement database.

In the current market, two readily available software systems were compared, these were MapInfo (Basic) and TransCAD. The reason why ArcGIS was not included in this research is because there was no available software at the time and its similarity with MapInfo. However, it should be noted that ArcGIS carries various functions in different versions and can be assessed in further research. At this stage, based on the requirements and how to select the software, it is best to introduce an evaluation framework. It is essential that we should use both functional evaluation and benefit-cost analysis together. In some scenarios, functional requirements of software are more important and significant than benefit-cost analysis when some functions are needed and unable to be replaced. Thus we need to identify the functions of the two different software systems respectively and find out the applications that need to be undertaken.

Before we start to decide what software we will use in this project, we had to identify which functions were going to be needed. Functions include:

1. Data
   • geometry/capacity;
   • transport network;
   • surface type and condition; and
• current and predicted freight vehicle demand.

Does this software have the capability of containing all these kinds of data and can they be managed easily? How many formats of data are supported? TransCAD 5.0 contains Australian road map data used in this research; however, this road map data is not as specific as the VicRoads map data.

2. Mapping and Visualisation

Both software systems are able to modify the map and make the map visible. The information included in maps should be able to be modified and updated.

3. Geographic Analysis Tool

Is a basic analysis tool available as well as some queries including distance, travel time analysis and other analysis methods?

4. Planning Tool

In order to establish a rural area low-volume roads system, several planning tools are needed; these include traffic assignment, and matrix estimation.

5. Application Model

Network analysis, involves transport planning and travel demand model, transit analysis, vehicle routing and logistics, territory management and site location model. With all these needs, we still have to do a function analysis to compare their different and similar functions, (see Appendix 2).

Based on these evaluation criteria, we decided to use TransCAD as the software system. It is more suitable to apply in transport problems and provide completely integrated GIS and transport analysis than MapInfo. Several planning and modelling systems can deal with the problem, among these software, TransCAD was found to be
specially designed to address transport especially freight modelling and analysis. With its embedded traffic assignment procedures and matrix estimation process, transport analysis can be undertaken. TransCAD developed by Caliper Corporation seems to be the appropriate GIS software since it provides transport-modelling functions, which are necessary in this research due to the insufficient traffic data in rural areas. The development of the database needs input from a GIS format road map, traffic volume data including AADT (total) and truck volume, while the data is not available, O-D estimation using various traffic assignment methods can be used combined with matrix estimation to create unavailable traffic data. After assigning truck proportions to estimate traffic volumes, it is possible to estimate the truck volumes travelling on each road section.

One thing worth mentioning is that in the development of this database, due to the need of these transport modelling functions, it was appropriate to use TransCAD as the knowledge base platform. However, after the database has been created, other software should be taken into consideration as mentioned previously with basic GIS features, for example Maptitude (Caliper) which is capable of managing the pavement data. MapInfo (Basic) is also capable of updating displaying map data after the knowledge base is built.

4.4 Process

The definition of low-volume roads has been provided and the most appropriate GIS software has been chosen. The next step is to integrate the data and estimate the traffic volume to identify potential low-volume roads. In order to achieve this goal, it is essential to find an appropriate approach to develop a sound database.

TransCAD developed by Caliper (US) has been used to provide a knowledge-based system to integrate, analyse, and display the road data. More importantly, its transport modelling capability can create the traffic data in the road network by using traffic assignment techniques when there is no traffic data at all. In addition, when there is limited traffic data, by using matrix estimation methods, traffic flow data in a
potentially interest areas can be predicted. Using marco-level traffic classification data, it is able to produce an estimation of truck activities on a link.

To integrate these data, data fusion techniques were used. This starts with data observatories, which need field work to be done to gather the real but raw data from different transportation facilities. These may include but is not limited to pavement condition, its roughness and surface distress, traffic light position, road direction and intersection, traffic volume during a period of time, public transport facility location (tram, train, bus) etc. After this step, the raw data can be processed by data fusion technology which combines several sources of raw data to produce new raw data. The fused data is more informative and synthetic than the original inputs which can provide more specific and detailed data to the GIS. Then we can use GIS to manage these data, modify the updated information or use the planning tools to solve real problems.

4.4.1 Data Integration

Geographic map and attribute data set can be integrated to form a comprehensive road data map. Although these may contain several layers, integrated map will display them in one map for easy manipulation and analysis. To have an overview of an area, these layers can be put together to form an overlay map and provide visual display, which is important to understand the whole picture of an area and the relationships between different data. As Figure 7 shows, an integrated map including major Victorian Roads, local government areas and town centres has been produced. This map then can be used as the base map for the next step modelling process.
Attributes databases are mainly numbers and descriptions. In pavement management, they are mainly traffic volumes, pavement conditions and maintenance plans. These data usually are in a table format (i.e. Excel format) and also can be input into TransCAD directly.

In this research, the base map, which contains roads in the Victoria region, can be obtained from related agencies or GIS software map package. These maps do not include traffic flow data and cannot be matched directly. The reason is that there is no Unique Identifier of the low-volume data. In order to combine them, we need to link the data of all Victorian roads and low-volume roads. Thus some characters of different segments are needed in order to connect them, and then we can isolate the irrelevant data and re-establish a new map with only the low-volume road information that we need and use this map as our base map to do further research. Without the unique identifier, it is not possible to connect them together.

From the other data sources, traffic flows for a specific segment can be combined with the road map data to form a database for further analysis. When there is no traffic data available, an O-D estimation procedure in GIS can help to build up a traffic flow table. The data we need to integrate includes road network data as well as road usage data.
However, road usage data often does not have coordinates and normally have their own unique characters to show the location of where these data was collected. Since different transport agencies or private companies collect data, the same road may have a different road ID, or name, the same road may have two different maintenance methods, and this introduces a new issue.

4.4.2 Data Fusion

Although in the Lisbon case, (Santos et al. 2004) comprehensive GIS-based road database had been produced, the situation is not the same in Australia as the focus of this study is on low-volume roads which mean the survey taken by Lisbon City Council is not appropriate or available due to the locations of low-volume roads are normally in rural areas and data collection needs the cooperation of different local councils. Since the way of storing data in regions may not be the same and each road segments normally do not share a unique name or ID, how to fuse these data becomes a challenging task.

When matching the attribute data with spatial road data, several attributes could be used to help us in identifying the location of the roads, including:

- Local government area (LGA)
- Road name
- Road length
- Road type

Although GIS can improve the integration of data, sometimes we may come across a situation where transport data are stored without geographic coordinates. These data use a measurement from a fixed reference point along a route. These may include pavement conditions, average daily traffic on a linear network such as a bridge, street intersection, or mileposts. This information can be stored using a Linear Referencing System, also known as Dynamic Segmentation in order to match with the spatial data.
Linear Referencing System (LRS) is a way to define a feature or location by its linear distance from a known point on a route such as highways, rail lines, runways, pipelines and waterways. Analysing linearly referenced data lets you identify trends, locate problems and search for causes.

![Figure 8: Linear Referencing System](image)

As Figure 8 shows, we want to match the existing traffic volume data (green line) along a road in red line connecting two towns from A to B, but we found there is no coordinates to indicate the spatial locations of the traffic volume data but with a start point in town A. In order to match them, a linear route in black line has been created from the town A to B where traffic volume data were collected. With the exact distance from the start point to the end point, data without coordinates can be integrated with road map data, to eliminate any misinterpretation.

After the data are matched, each segment will have their own information, which includes a unique identifier and attributes such as shape, volume data, latitude, longitude, name, location description and street name.
Despite this, some road usage data may not be able to be obtained in rural areas as the in this project, the next part will demonstrate a possible means of estimating these absent data using a Traffic Assignment method and the process of matrix estimation when only limited count data is available in order to get freight movements in interest areas.

4.4.3 Traffic Modelling

However, the road link attribute data does not often contain pavement related information. Here, pavement data was available partially from the data collected by Swinburne University and other data sources. Data such as IRI of pavements, budgets spent on each segments of roads can only be obtained through surveys, and normally these data are collected by road agencies. Road traffic volume data is often forecasted using models. Traffic volume data is normally collected in urban areas at certain point or high-volume roads with devices, for example loop detectors, cameras and weigh-in-motion technology. However, in rural areas on low-volume roads, these techniques are not always applied because of its cost. Traffic estimation techniques are a good way of estimating these traffic volumes using limited knowledge. In this study, traffic assignment and matrix estimation methods have been used to estimate these data in chosen areas to create a reasonable set of data.

An alternative method can be used to estimate freight volume. At first, we need to identify a small area in the Victorian road map in the rural area and export it in order to build a new map only display the selected area. In order to build a freight model, we need to know the traffic flow and travel time along each segment we choose. This data are not included in the Victorian map, which means we do not know the time and capacity of different segments. In order to use the traffic assignment method in TransCAD to do this, we need to make some assumptions and create this information and see if it is available so as long as we get those data, it is ready to build a real freight model. Then a new network is needed and this involves the field data in both map layer and node layer. The next step is to create an Origin-Destination (O-D)
matrix, which includes information from and to segments based on the length or travel time.

**Traffic Assignment**

In pavement management, traffic volume data especially freight movements is very important to provide support for road management. Nevertheless, comprehensive freight volume and loading data is not always available from road agencies or local councils. A possible solution is to use O-D estimation to provide the necessary information. In this research, the situation is not exactly the same as the situation in Queensland since the areas involved are rural areas and the roads are low-volume which means traditional data collection methods are not always possible or worth using. Since these data are unavailable, we need to find alternatives to obtain it. GIS provides us a potential way of doing so by using the O-D estimation method.

Before we start this procedure, the information needed includes:

- A base road network map in a selected area contains line layer and nodes;
- An origin-destination matrix defining the demand;
- Free-flow travel time along links; and
- Maximum flow that a link can carry over a given time (capacity)

There are several assignment methods that we can use in TransCAD including:

- User Equilibrium
- Stochastic User Equilibrium
- Origin User Equilibrium
- Path Based User Equilibrium
- System Equilibrium
- All or Nothing (No capacity data needed)
- STOCH
- Capacity Restraint
- Incremental

Detailed information of these methods can be found in Appendix 3
Table 7: Required Attributes

<table>
<thead>
<tr>
<th>ATTRIBUTE</th>
<th>TYPE</th>
<th>CONTENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time*</td>
<td>Numeric</td>
<td>Free-flow travel time</td>
</tr>
<tr>
<td>Capacity*</td>
<td>Numeric</td>
<td>Maximum flow that a link can carry over a given time period</td>
</tr>
</tbody>
</table>

In Table 7, the values of both time and capacity can vary by direction along each link. These fields are noted with an asterisk (*) and should be replaced by pairs of fields representing the relevant data in each direction. For example, the field Time* should read as a pair of fields named [Time AB] and [Time BA]. If you do not provide directional fields in the network, then it is assumed that the value in the field provided applies to both directions on the link. Only All-or-Nothing assignment does not need capacity to be specified.

Table 8: Required Settings

<table>
<thead>
<tr>
<th>SETTINGS</th>
<th>CONTENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iterations</td>
<td>Maximum number of iterations to be performed</td>
</tr>
<tr>
<td>Increments</td>
<td>A series of demand percentages (summing up to 1) to be assigned during each increment</td>
</tr>
<tr>
<td>Relative gap</td>
<td>Relative Gap convergence criterion value</td>
</tr>
<tr>
<td>Alpha</td>
<td>The global default value of the $\alpha$ parameter in the BPR function</td>
</tr>
<tr>
<td>Beta</td>
<td>The global default value of $\beta$ parameter in the BPR function</td>
</tr>
<tr>
<td>Function</td>
<td>Error term distribution function for stochastic user equilibrium</td>
</tr>
<tr>
<td>Error</td>
<td>Percentage error for the error term used in stochastic user equilibrium assignment</td>
</tr>
</tbody>
</table>
After selecting the appropriate method to use, a traffic assignment model can be constructed by assigning the estimated traffic flows in different links in a table file, and also a report file containing a summary of user inputs and model outputs.

**O-D Matrix Estimation**

In the urban areas, a traditional method of collecting information on the spatial pattern of trips is large-scale home interview surveys, which can produce accurate and up-to-date trip tables for transport planning.

The situation is no better in rural areas when collecting traffic data especially for freight movement. Fortunately, traffic counts on highway links are routinely collected in many areas. This section will discuss a flexible and effective procedures provided by TransCAD for estimating and/or updating O-D trip matrices. Here, the problem is low-volume roads in rural areas, which means, this method matches our need to create a comprehensive traffic database.

Traffic counts themselves are stochastic variables that are measured with error, and may be inconsistent with flow conservation. Methods that treat counts as deterministic may give unstable or unrealistic results.

Counts are usually available for a small area in a network, which will not reflect the overall network. A good sample will include measurements from widely spread parts of the network. The TransCAD method based on the work of Nielsen (1993, 1998), which treats counts as stochastic variables, as well as working with any traffic assignment method.

There are several considerations that need to be considered to implement this procedure:

- **Link Counts:** Annual Average Daily Traffic (AADT) count information is used to produce an accurate daily O-D trip matrix since this is the data which is available. A common estimate will be assigned to both directions although this is not always
the case. If there are too few counts, traffic assignment method will enrich the counts for the input.

- Base O-D Matrix: The base O-D matrix has two functions; one is to set the dimensions for the output matrix, and to provide initial values for the estimated trip table. If there is no prior information on flows, the base O-D matrix should be constructed to have a small positive value (e.g., 0.1 or 0.01) for every cell that is expected to have positive flow in the estimated matrix.

Following the Traffic Assignment, O-D estimation can be used to refine the results we get for more reasonable outcomes.

### 4.4.4 Case Study

This case study is based on available data and reasonable assumptions, until have further data, it is not possible to validate the reliability and make comparison between different assignment methods especially for larger scale. In this project, the truck trips and volumes are the focus, and with the available data, the All-or-Nothing is chosen to be the assignment method used. Detailed steps of this case study are shown below:

1. Firstly, a map of Victorian road is opened in TransCAD.
(2) Choose an area in the road system and create a network that contains all the
links and nodes in the line layer for further step.

(3) An O-D matrix needs to be created from and to each node. Using the Multiple
Shortest Path function to minimize travel time. The travel time is based on the
length of each link and travel speed. In this map, the travel speeds on highway
and local road are 100 kilometres per hour and 60 kilometres per hour.
Centroid nodes are recommended to be included in the network since it will enable TransCAD to keep track of them and make sure that centroid connectors are only used at the beginning and end of any trip.

This step will create a matrix which contains the minimum travel time (in minutes).

(4) Perform Traffic Assignment function and choose All-or-Nothing method, as well as using shortest path travel time matrix. One thing need to remember is to choose centroid nodes in the network settings. As shown below, ID 184 and 248 are chosen as centroids of the area.
A table will be created to show the relevant information in each link through estimation. This table is a joint-view of the original table using the ID to match the information.

As it shows, all information is bi-direction. For example, traffic flow along link ID 78656 has two columns from A to B and B to A, when considering the Average Annual Daily Traffic, total flow (Tol_Flow) should be used.

The O-D estimation is the next step, as we get the traffic flow in each link, we can assign them as counts data to each link. In this case study, traffic counts in certain links are available, as it is shown in the following figure, thus these data are not the same as estimated flow data.
Counts* should be read as the half of the actual AADT going through this link since this when no direction considered, this applies to both directions. Thus the actual AADT is 750.

The matrix file is the same minimum travel time matrix.
There will be two files which are joint-view flow table and estimated OD matrix to refine the results. The matrix represents the estimated flow from and to each point.

By knowing the traffic flows on each link, we can distribute freight truck proportions to each of them to obtain freight volumes. However, it is not absolute to assume all kinds of freight vehicles are able to travel through links, especially in rural areas;
some roads may not be able to provide access for larger trucks like B-doubles or road trains.

The National Transport Commission (NTC) has released an interactive map portal, which allows truck drivers and operators to plan the journey of SMART trucks across the country (NTC 2010). It is based on the Performance Based Standards (PBS) program in July 2009. Four levels have been identified:

- Level 1: roughly equivalent to General Access (everywhere), and limited to 20 metres long and 50.5 tonnes
- Level 2: roughly equivalent to B double routes
- Level 3: roughly equivalent to Road Trains Type I
- Level 4: roughly equivalent to Road Trains Type II

According to the Austroads Vehicle Classification Scheme, there are 12 classes by their axles and lengths. Using this method, we can tell if a link provides access to what level and assign freight trucks to each of them in order to know the traffic loading on each link. In rural areas, truck proportions may not be the same as in urban area, in 2005 in rural area within Victoria, after reviewing the data from reliable source, removing trucks that their GVM are less than 4.5 tonnes and buses, different distribution of trucks were extracted from the analysis of available national level traffic data and were summarised below.

Table 9: Percentages of Trucks in Rural Areas of Victoria

<table>
<thead>
<tr>
<th>Percentage in Total Vehicles</th>
<th>RIGID TRUCKS(&gt;4.5 TONNES)</th>
<th>ARTICULATED TRUCKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.7%</td>
<td>1.0%</td>
<td></td>
</tr>
</tbody>
</table>

From step 7 in Appendix 4, ID 12043 is estimated to have total flow of approximate 1,363 vpd. According to Table 9 above, we can then calculate that the rigid trucks are 2.7% of 1,363 which is 37 vpd, and articulated trucks are 1.0% of 1,363 which is 14 vpd. By confirming with NTC interactive map to find the possibility of truck access on this road, it is available to assign more detailed truck volumes to each type of rigid
or articulated trucks (B-Double) in order to know the total GVM of the road in this year and also ESA.

4.5 Chapter Summary

This chapter has illustrated the methodology used in this study in detail. A definition of low-volume roads has been made in order to identify and select the appropriate data to integrate into the knowledge base. GIS software has been chosen as the platform for this knowledge base and its capability has been tested. In order to identify the potential low-volume roads when traffic data is not available, traffic modelling techniques have been used to estimate freight volumes, during this process, since it needs the input of traffic volume data, not only the traffic volume data on low-volume roads is needed to input into GIS but all the available data in this research is better to be integrated to get the best outcome. Although only one traffic assignment method was used, it shows this is a practical approach to get traffic volume data. Combining with national level freight proportion data, freight volumes can be estimated and future trends can be predicted to enhance this database. Moreover, this will create more data as the input of this process to refine the results.

GIS has been identified as an effective tool for data integration. It is used to combine information from disparate databases to provide information for PMS activities. Link/node bases tie roadway, structure, and rail crossing inventory systems and allow the use of multiple referencing schemes of route and milepost designations (State of Wisconsin/Department of Transportation 2007).

GIS played an important role in this study for the purpose of storing, integrating, modelling and displaying the data from varied database including GIS-format base map data, table format traffic data and maintenance data as well. With the help of GIS, it is possible to combine these data and obtain an integrated database with the maintenance strategy and different traffic factors in it to make the road management easy to handle and well-implemented.
Chapter 5. Findings and Discussions

5.1 Chapter Overview

Process for each step taken in this study has been presented in Chapter 4. In this chapter, some findings will be shown to verify the hypotheses and summarise the analysed data.

Definition of low-volume roads will be verified from the integrated map and other findings. Findings in the development of low-volume roads are given and discussed. Data has been analysed in order to get a better understandings and implications.

5.2 Low-volume Roads

Definition of low-volume roads has been made in Chapter 4 in terms of its volume of freight vehicles, its function. In this part, verification and comparisons will be made. Traffic data in Victoria were input and matched using the methods mentioned previously into the GIS to show freight volumes with compound annual growth rates in local government areas. Three different roads by volume are included:

- Low: Freight Truck volume lower than 250 per day
- Medium: Freight Truck volume between 250 to 1,000 per day
- High: Freight Truck volume higher than 1,000 per day
Figure 9: Annual Growth Rates in Local Government Areas

This map integrated not only spatial maps but also table format attributes data as shown below:

**Table 10: Road Attributes**

<table>
<thead>
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As shown in Figure 9, road sections are displayed in different local government areas in three different colours based on their freight volume. Most low-volume roads are in rural areas, over 100 kilometres away from metropolitan areas. Most high-volume roads however are in urban areas. Taking a close look at the information it contains, it can be seen that these roads are mainly highways to providing freight movement between towns and cities, which confirms the definition made previously.
Another supportive evidence is the algorithm developed by Mandiartha et al (2010), which separates roads into two categories: Total traffic volumes below 3,000 vpd are low-volume roads and over 3,000 vpd are high-volume roads. The definition in this research for low-volume roads for freight volume lowers than 250 per day, which is 8% of the total volume of Mandiartha’s definition. The data in this research were examined and analysed to find the proportion of freight vehicles on low-volume roads. The lowest proportion of freight vehicle on low-volume roads in this database is 4% of total volume, and the highest one is 20% of the total volume. However, the national level traffic data has a freight proportion of around 3% of the total volume. Therefore, a reasonable range between 6% and 12% can be drawn which also consistent with 8%.

The definition of low-volume roads has been made based on the integration of data and reasonable assumption, although this may not apply under other circumstances, this is currently a more comprehensive and acceptable one in this context.

### 5.3 GIS Knowledge Base

The development of low-volume roads knowledge base is a process that will need more input and data to enhance. However, during this stage, data to build up such a comprehensive knowledge base is not available. Nevertheless, the process of developing such knowledge base has been explained and the results show it is applicable. What this knowledge base should provide is all the necessary information for pavement management from traffic volumes to pavement conditions and maintenance strategies. The maintenance algorithm can even be integrated into a GIS for automatic calculations. The knowledge base itself should not contain too much information since the purpose of building such knowledge base is to manipulate the data more easily. Therefore, data such as historical records can be stored in other format such as Excel, and input into a GIS for analysis since the data will be matched directly based on their own unique identifier.

TransCAD in this study provide enough support for developing such a knowledge base not only because its capability of integrating data in various formats but also its
powerful modelling functions. Traffic modelling techniques embedded assist researcher modelling traffic volumes. The finding is that GIS provides a good platform for developing such a knowledge base for low-volume roads.

 Integrating data is a time consuming procedure due to the fact that there is no direct link between independent databases regarding one road section. Although the methods used here considered multiple conditions to link attribute data with map data, matching cannot be one hundred per cent accurate.

 As for the traffic modelling procedure, all-or-nothing assignment technique is the only one that can be applied in terms of available data. Other techniques require more data input despite the improved outcome. The results from the data needed for other techniques are presented in Appendix 3. An example of using other traffic assignment techniques is also given in Appendix 3 to show the result of capacity data input.

 The main problems of using GIS starts with the terms used in different scenarios and the principle of the software, still with other problems associated with the pavement management system come from institutional issues and the lack of a solid, long-term commitment to implement it as part of an overall infrastructure management that includes different information. However, systems cannot make decisions, only decision-makers can do that. The question is whether they are effectively using the best tools to assist themselves in making the best decisions (Fred 1998).

 5.4 Analysis of Data

 Analysis of the national level traffic data indicates that rigid trucks are still a large proportion of the freight vehicles in Victoria as shown in Figure 10 and Figure 11 below:
Figure 10: Freight Vehicle Shares in Victorian Rural Areas

In rural areas, freight volumes consist of four basic categories: rigid trucks comprise a large proportion of total freight vehicles (Fig. 10). Figure 11 shows the annual average growth rates, with B-Double having the biggest rate increase and this need to be taken into consideration when forecasting traffic volumes and road infrastructure.

Figure 11: Freight Vehicle Growth Rates in Victorian Rural Areas
When considering ESAs, the growth rate is one of the parameters needed to be taken into account. Furthermore, when deciding whether roads are still low-volumes, say next year does not have low-volume (>250CV), the maintenance plan will be altered.

### 5.5 Benefits of Matrix Estimation and Knowledge Base

As traditional traffic modelling and forecast techniques were not appropriate in this research due to the lack of data input, traffic assignment techniques using all-or-nothing method can produce traffic volume from minimum data input, matrix estimation can then be used to enhance the database. More importantly, this method was not limited to enhance the database, but to identify potential low-volume roads.

The O-D matrix set can be manipulated by changing traffic volume on each road section to see which road can make the biggest changes in the matrix and then determine as key roads. Even within a small area with limited data input, this method can still provide information on identification of key road sections.

Although in this research, validation undertaken due to the insufficiencies of rural traffic data, with the knowledge of the key road sections, the real data can then be collected in field surveys and then input into the database to perform the validation process. It will not only make the data collection more targetable, but also make it more economical since the data collection stations can be placed in more reasonable locations. As most data collection stations are placed in high traffic movement areas, low-volume roads traffic data are sparse and insufficient, this approach will improve the situation and provide more accurate traffic and freight forecasts.

It is estimated that non-bulk freight transport grows 1.25 times faster than the general economy (Gargett 2004). Nevertheless, freight data has traditionally been very difficult to secure, and even more difficult to use in transport demand forecasting. Recent research tried to overcome this problem in metropolitan Brisbane. The research conducted in Queensland aimed to use the EMME/2 method to combine existing traffic counts, roadside interview data and truck trip tables for Metropolitan

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Brisbane, to provide Queensland Transport with a current freight matrix and some measure of the confidence that may be placed in the results. This approach proved the feasibility of using a limited amount of freight data to estimate a freight vehicle demand (Pekol & Wigan 2005). By using count data including seven day classified automatic counts, 12-hour manual classified counts, three separate matrices for three truck classes were produced, rather than the usual single truck matrix. The weights were then assigned to each traffic count to control the degree of confidence. The three truck classes were small rigid, large rigid, articulated. A seed matrix needed to be prepared to that the fundamental the process. The results can also be improved by the input of estimated data. A series of heavy vehicle trip matrices were developed for metropolitan Brisbane by combining existing data, current and historic matrices, and a limited amount of new data.

5.6 Chapter Summary

This chapter summarised findings on low-volume roads, GIS knowledge base and some implications of data analysis.

The definition of low-volume roads has been verified and the result shows it is reasonable assumption and should be used as a guideline for identifying potential low-volume roads.

GIS plays an important role by integrating data, despite the process being time consuming, once it is completed, the updates are easy and comprehensive. TransCAD is supportive software in the development of this knowledge base, but choice of software of managing this knowledge base should not be limited. Other software is also capable of implementing the management task.

The traffic assignment technique used in this research shows the possibility for estimating traffic volume. With more data input, improvements can be made to find the best techniques to be used for low-volume roads traffic forecasting.
Chapter 6. Conclusions and Future Recommendations

6.1 Conclusions

In decision-making processes associated with pavement management, traditional databases lack the ability of integrating, analysing and displaying data. This thesis has investigated the possibility of using GIS to fulfil this need from the perspectives of data integration, data fusion and transport modelling. This knowledge base has been developed for low-volume roads in Australia for better budget estimation, allocation and other associated decisions.

The definition of low-volume roads has been clarified to identify a reasonable categorisation of potential low-volume roads. During this process, due to the insufficient traffic data, traffic assignment technique has been used to estimate the traffic volume for assisting the identification roads consistent to such definition. This technique provides sufficient evidence to verify that this approach is reasonable and could be used as the basis for further updates of the knowledge base when more data input is available.

The establishment of this knowledge base will enhance the capability of pavement management system and provide more detailed and visualised information to relevant decision makers. Linked to GIS, the implementation of PMS with other systems using GIS as the core of the central database will allow sharing and contrasting information more easily, such approach is featured to be:

- avoiding conflicts among projects;
- saving money; and
- providing maximum economic and social benefits from the invested funds.

In regard to pavement management, the capability of GIS has been examined from perspectives of data integration, data fusion and transport modelling. GIS was used to implement these tasks, providing an easier approach to establishing a knowledge base.
for managing pavements and assisting with the development of pavement maintenance plans. With more data available, a more comprehensive and robust low-volume road database could be built.

Linear referencing provides a solution when integrating non-spatial data with map-based data. The traffic assignment and matrix estimation shows the transport modelling abilities of GIS to fill in unavailable data in a potential interest area. At this stage, there were insufficient data for areas to examine the accuracy of the use of these methods. Future research will focus on testing the reliability of these methods and exploring other means for the traffic forecast optimisation. Growth rates of freight trucks in each local government area have been created to explore the connection with pavement maintenance costs with this specific function, it is possible to produce forecasts of low-volume road activity.

The results indicate that GIS is fully capable of integrating various data to build up a visual, sound knowledge base. It is also able to provide a transport-modelling solution to assist with the development of a pavement maintenance plan. However, limitations exist in data collection and combination. More data types and formats have to be explored and integrated into the research model, expected fusion work will be more complex and time consuming. TransCAD including other GIS software approaches is a complex and unique tool that requires considerable time to learn in order to get familiar with it.

The achievement of objectives mentioned in Chapter 1 can be summarised as:

- Definition of Low-volume roads has been made and verified, and it has proven to be appropriate in this study;
- TransCAD has been selected as the most appropriate GIS software in the development of this knowledge base, other software can be also be used once the knowledge base developed, on achieving its management purposes;
- All relevant data have been integrated;
- Transport modelling approaches have been examined and considered as a practical means in the development of this knowledge base; and
• A subset of a comprehensive knowledge base has been built and can be further improved with more data.

6.2 Future Recommendations

At this moment, by inputting data in a macro level (national level), estimates of low-volume road segment activities can be produced by state, two types of data are needed including:

• Macro Commodity Growth Rates
• Truck Types Growth Rate

Figure 12: Marco Level Estimates

By using the data which contains macro level volume of vehicles by commodity carried in 8 years, growth rates in each commodity yearly can be calculated and input into GIS. Another input is truck type annual growth rates which can be classified into categories. These inputs could be used to create macro level traffic estimates on low-volume roads by state and provide support the development of pavement management strategies.
GIS for Future Commercial Truck Pricing

One of the most important future aspects of GIS will be to capture and store relevant cost, truck activity and basic design characteristics of road sections. Recently, the Australian Government recommended that mass-distance-location pricing be investigated. (Treasury 2010). This requires that:

- Truck type (axle groupings)
- Truck movements
- Area of operations
- Load tonnages

be collected or estimated at a regional level.

Also the costs of both routine and periodic maintenance will also need to be recorded and this is balanced against activity on the particular road section. From the activity data estimates are required for:

- Equivalent Standard Axle loads (ESAs)
- Passenger Car Units (PCUs), and
- Gross vehicle Mass (GVM)

These can be used to estimate attributable truck activity costs to road sections. PCU and GVM data were used, as opposed to ESAs, for activity based cost allocations was used by NTC (NTC 2005). However, further geographic data is also preferable for the large number of non-linear regressions to establish location cost/activity relationships. Additional data required are:

- Type of road seal
- The existence of a constructed road shoulder, and
- The local rainfall contour index

The Council of Australian Governments (COAG) has also recommended that the National Transport Commission investigate mass-distance-location pricing techniques. All these data types would be required for a future new mass-distance-location pricing system, which can be supported by a GIS database.
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Appendices
Appendix 1: Victorian Road Map

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[Map of Victorian Roads]

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## Appendix 2: Comparison of GIS Software

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Appendix 3: Traffic Assignment Techniques

Single-Class Traffic Assignment

In TransCAD, there are two types of assignment methods which are equilibrium and non-equilibrium.

Equilibrium Methods

User Equilibrium (UE)
This method uses an iterative process to get a convergent solution. It is assumed that no travellers can improve their travel time by shifting routes.

Stochastic User Equilibrium (SUE)
This method makes assumption that travellers do not have perfect information about network attributes and/or they perceive travel costs in different ways. Compared with UE, it permits use of less attractive as well as the most-attractive routes. The method built in TransCAD using the Method of Successive Averages (MSA), which is known to be a convergent method (Sheffi & Powell, 1982; Sheffi, 1985).

Origin User Equilibrium (OUE)
This method has been proposed by Bar-Gera (1999) and Dial (1999, 2006) which the equilibrium solution for each origin is an acyclic graph. It achieves equilibrium for each origin and prohibit flow from links that are part of cycles, giving greater computational efficiency.

Path-Based User Equilibrium Assignment
This method is based on saving all of the paths from an assignment and moving flow from longer to shorter paths as these are revealed in subsequent iterations.
System Optimum Assignment (SO)

This method computes an assignment that minimises total travel time on the network. It assumes no users can change routes without increasing their total travel time despite travellers could reduce their own travel times.

Non-Equilibrium Methods

All-or-Nothing Assignment (AON)
This method assumes all traffic flows between O-D pairs are assigned to the shortest paths connecting origins and destinations. Travel time is a fixed input and does not vary depending on the congestion on a link and used for assigning truck trips.

STOCH Assignment
STOCH distributes trips between O-D pairs among multiple alternative paths that connect the O-D pairs.

Incremental Assignment
It is a process in which fraction of traffic volumes are assigned in steps. A fixed proportion of total demand is assigned in each step based on AON assignment.

Capacity Restraint
This method tries to create an equilibrium solution by iterating between AON traffic loadings and recalculating link travel times based on a congestion function that reflects link capacity.

Required Network Attributes and Model Settings

In each of these assignments, the settings will be different (Table 1).
Table 1: Network Attributes and Model Settings for Assignment Methods

<table>
<thead>
<tr>
<th>Assignment Method</th>
<th>Required Attributes</th>
<th>Required Settings</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>User Equilibrium</strong></td>
<td>Time, Capacity</td>
<td>Iterations, Convergence, Alpha, Beta</td>
</tr>
<tr>
<td><strong>Stochastic User Equilibrium</strong></td>
<td>Time, Capacity</td>
<td>Iterations, Relative gap, Alpha, Beta, Function, Error</td>
</tr>
<tr>
<td><strong>Origin User Equilibrium</strong></td>
<td>Time, Capacity</td>
<td>Iterations, Relative gap, Alpha, Beta</td>
</tr>
<tr>
<td><strong>Path Based User Equilibrium</strong></td>
<td>Time, Capacity</td>
<td>Iterations, Relative gap, Alpha, Beta</td>
</tr>
<tr>
<td><strong>System Optimum</strong></td>
<td>Time, Capacity</td>
<td>Iterations, Relative Gap, Alpha, Beta</td>
</tr>
<tr>
<td><strong>All or Nothing</strong></td>
<td>Time</td>
<td>None</td>
</tr>
<tr>
<td><strong>STOCH</strong></td>
<td>Time, Capacity</td>
<td>Alpha, Beta, Error</td>
</tr>
<tr>
<td><strong>Capacity Restrain</strong></td>
<td>Time, Capacity</td>
<td>Iterations, Relative gap, Alpha, Beta</td>
</tr>
<tr>
<td><strong>Incremental</strong></td>
<td>Time, Capacity</td>
<td>Increments, Relative gap, Alpha, Beta</td>
</tr>
</tbody>
</table>

After we pick a small area (Fig. 1), two fields shown in the table which display the road data are needed to be added which are Time and Capacity mean the travel time
through each segment and the number of vehicle go through each segment. I make up this number based on the length of segment and its links with other segments. After this step, we need to modify their properties to index because it will be used for all the situation travel around from and to different segment and when use traffic assignment, it is needed to be index instead of a character without any help.

Figure 1: Chosen Area

Then a new network is needed and involves the field data in both map layer and node layer. The next step is to create a Production Attraction matrix (PA), which include the information from and to segments based on the length or travel time. Then convert this matrix to Original Destination (OD) matrix which can be used in traffic
assignment. Have these information, we can use the single class traffic assignment tool to create a map showing the traffic flow and V/C (volume, capacity) ratio in different segment. One thing is important is when create the flow map, there are several delay functions to calculate the flow and V/C ratio based on the formula and what kind of information included in the flow map. The one I choose is Generalized Cost Delay Function which is based on the Bureau of Public Roads (BPR) delay function, but also provides the ability to include a fixed cost on some of the links (tools) and an operating cost per unit of distance ($/mile)

\[ c_i(x) = k_i + \delta^* L_i + \Phi^* t_i [1 + \alpha_i (x_i/C_i)^{\beta_i}] \]

Where:
- \( c_i \) Generalized cost on link i
- \( k_i \) Dollar cost on link i
- \( \delta \) Constant such as the operating cost per unit of length
- \( L_i \) Length of link i
- \( \Phi \) Constant representing the value of time
- \( t_i \) Free-flow travel time on link i
- \( \alpha \) Constant
- \( x_i \) Flow on link i
- \( C_i \) Capacity of link i
- \( \beta \) Constant

It is assumed that all the constants are greater or equal to zero.

Using this function, we can get the result of traffic flow and V/C ratio through each segment; we still are able to change the constant in terms of different situations. After we define all these items, a new map with traffic flow and V/C ratio will be displayed, it will also include a new matrix table which contains the estimated link volumes and link costs, such as total volume on links in both directions, travel time on links in both directions etc.,. From this new map, we can easily see the condition of these links, and
with real data, it is ready to build a similar system which fit rural low-volume roads in Victoria.

Figure 2: Traffic Flow and Volume

With the help of other knowledge management tools, we are able to create more specific analysis based on the research of transportation, such as the population of the areas where the routes go through, after analyse the traffic flow, this will be a heath report to discuss where the noise pollution influent the residents most.
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