

University of Southern Queensland
Faculty of Engineering and Surveying

**GPS Usage and Infrastructure Needs for Machine Guidance
and Control in the Construction Projects Associated with
QDMR**

A dissertation submitted by
Mr. Nawanandana Chandrasiri Liyanawaduge

In fulfillment of the requirements of
Courses ENG4111 and 4112 Research Project

Towards the degree of
Graduate Diploma in Geomatic Studies

November 2007

Certification

I certify that the ideas, designs and experimental work, results, analysis and Conclusions set out in this dissertation are entirely my own effort, except where otherwise acknowledged.

I further certify the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

Nawanandana Chandrasiri Liyanawaduge

Student Number: 0050020542

Signature

Date

ABSTRACT

This dissertation analyzed the GPS usage and infrastructure needs for machine guidance and control, in the construction projects associated with QDMR, in order to provide recommendations for future infrastructure needs. Research studies have confirmed that, GPS usage on machine guidance and control in the construction industry, within a VRS CORS environment increase the productivity of the projects. Investigation about the GPS usage on machine guidance and control, for construction projects, associated with QDMR was selected, as the limit of this study, in order to make recommendations for future infrastructure needs, with respect to a possible VRS expansion.

Three main research approaches were designed in the project, and the results were further investigated. Geographical locations, spread and density, budget allocations and the durations of the projects were analyzed, to find out a clear suite of evidence, to prove the argument. The business case and the associated cost /benefit analysis, confirmed that, it is beneficial to expand VRS coverage to allow QDMR, to use machine guidance and control on construction projects in south east Queensland. Results not only demonstrated that, the VRS expansion is possible in the south east region, but also, suggested that multiple strategies should be adopted, when establishing GPS infrastructure in Queensland, as a whole. VRS expansion is suitable for the locations, with high density of construction projects, while other districts may provide with either, independent GPS networks or should still use, stand alone systems. Recommendations on future GPS infrastructure developments in Queensland based on the above findings and further possible research avenues were also included in this dissertation.

Recommendations on future GPS infrastructure developments have been prepared for the first time in Queensland, from a research study, considering a situation applied to a major government organization in Queensland. These recommendations may be used by DNRW, QDMR and other potential GPS users, to develop strategies, for designing future GPS infrastructure in Queensland, at government level.

University of Southern Queensland
Faculty of Engineering and Surveying

ENG4111 & ENG4112 *Research Project*

Limitations of Use

The Council of the University of Southern Queensland, its Faculty of Engineering and Surveying, and the staff of the University of Southern Queensland, does not accept any responsibility for the truth, accuracy or completeness of material contained within or associated with dissertation.

Persons using all or any part of this material do so at their own risk, and not at risk of the University of Southern Queensland, its Faculty of Engineering and Surveying or the staff of the University of Southern Queensland.

This dissertation reports an educational exercise and has no purpose or validity beyond this exercise. The sole purpose of the course pair entitled “Research Project” is to contribute to the overall education within the student’s chosen degree program. This document, the associated hardware, software, drawings, and other material set out in the associated appendices should not be used for any other purpose: if they are so used, it is entirely at the risk of the user.

Professor Frank Bullen

Dean

Faculty of Engineering and Surveying

ACKNOWLEDGEMENTS

This research was carried out under the principal supervision of Mr. Peter Gibbings, Senior Lecturer, in Engineering and Surveying Department at University of Southern Queensland. I would like to thank the staff at the University of Southern Queensland, in particular Mr. Peter Gibbings for providing the helpful advices.

I also would like to thank the staff at Department of Main Roads, ABC Lasers Ltd, and the Department of Natural Resources and Water. Without the information regarding the road construction projects, from the Department of Main Roads, and the data provided by the Department of Natural Resources and Water, this project would not have been possible.

Finally, I would like to thank my family and friends for providing support and advice for the duration of this research project.

TABLE OF CONTENTS

Contents	Page
CERTIFICATION.....	ii
ABSTRACT.....	iii
ACKNOWLEDGEMENTS.....	v
TABLE OF CONTENTS.....	vi
LIST OF FIGURES.....	iii
LIST OF TABLES.....	iii
LIST OF APPENDICES.....	ix
ABBREVIATIONS.....	x
CHAPTER 1: INTRODUCTION.....	1
1.1 OUTLINE OF THE STUDY.....	1
1.2 RESEARCH AIM AND OBJECTIVES.....	3
1.3 OUTLINE OF RESEARCH METHOD.....	3
1.4 JUSTIFICATION.....	5
1.5 LIMITATIONS OF RESEARCH.....	5
1.6 CONCLUSIONS: CHAPTER1.....	6
CHAPTER 2: LITERATURE REVIEW.....	7
2.1 INTRODUCTION.....	7
2.2 GNSS GLONASS AND GALILEO SYSTEMS.....	8
2.3 VIRTUAL REFERENCE STATION CONCEPT.....	9
2.4 GPS NETWORK SYSTEMS IN THE WORLD	10
2.5 VRS SYSTEMS IN AUSTRALIA.....	11
2.5.1 VICTORIA.....	11
2.5.2 SYDNEY.....	11
2.5.3 PERTH.....	12
2.5.4 BRISBANE.....	13
2.6 MAIN ROADS IN QUEENSLAND (QDMR).....	14
2.7 GPS MACHINE GUIDANCE.....	16
2.7.1 APPLICATIONS OF THE GPS MACHINE GUIDANCE.....	17
2.7.2 AUSTRALIAN CONTEXT/USAGE OF THE GPS MACHINE GUIDANCE.....	17
2.7.3 BENIFITS OF GPS MACHINE GUIDANCE.....	18
2.7.4 ISSUES RELATED TO GPS USAGE ON MACHINE GUIDANCE.....	18
2.7.5 IMPORTANCE OF USING GPS MACHINE GUIDANCE.....	19
2.8 GPS INFRASTRUCTURE AND THE PRODUCTIVITY.....	20
2.8.1 EXISTING GPS INFRASTRUCTURE FOR MACHINE GUIDANCE.....	21
2.8.2 USAGE OF GPS INFRASTRUCTURE IN OTHER RELATED FIELDS.....	22
2.8.3 GPS INFRASTRUCTURE DEMANDS.....	22
2.9 CONCLUSION/SUMMARY: CHAPTER2.....	23

CHAPTER 3: RESEARCH DESIGN & METHODOLOGY.....	24
3.1 INTRODUCTION.....	24
3.2 EXPERIMENTAL METHODS.....	25
3.3 DATA COLLECTION.....	26
3.4 DATA ANALYSIS.....	28
3.5 CONCLUSION OF CHAPTER 3.....	30
CHAPTER 4: RESULTS.....	31
4.1 INTRODUCTION.....	31
4.2 GEOGRAPHICAL LOCATIONS OF QDMR PROJECTS.....	32
4.3 DENSITY AND THE SPREAD OF QDMR PROJECTS.....	33
4.4 LOCATIONS AND THE SUBSIDY ALLOCATIONS.....	35
4.5 DURATIONS OF THE QDMR PROJECTS.....	38
4.6 CASE STUDY – BUSINESS CASE, OPTION B, IPSWICH MOTOR WAY.....	38
4.6.1 CASE STUDY – BACKGROUND.....	39
4.6.2 CASE STUDY – SUMMARY.....	40
4.7 BUSINESS CASE.....	41
4.7.1 COST/BENEFIT ANALYSIS.....	41
4.8 CONCLUSION: CHAPTER 4.....	46
CHAPTER 5: DISCUSSION.....	47
5.1 INTRODUCTION.....	47
5.2 DISSCUSSION.....	47
5.2.1 RESULTS/ INTERPRETATION.....	49
5.2.2 ALTERNATIVE SOLUTIONS.....	50
5.3 IMPLICATIONS.....	52
5.3.1 CATEGORIES OF GPS NETWORK DEVELOPMENTS IN QUEENSLAND.....	53
5.4 FURTHER RESEARCH AND RECOMMENDATIONS.....	54
5.5 CONCLUSIONS: CHAPTER 5.....	56
CHAPTER 6: CONCLUSIONS.....	57
6.1 INTRODUCTION.....	57
6.2 CONCLUSIONS.....	57
6.3 POSSIBLE FURTHER RESEARCH.....	58
6.4 SUMMARY.....	59
BIBLIOGRAPHY.....	60
APPENDICES.....	63

LIST OF FIGURES

<i>Figure 2.1: Main Road Districts.....</i>	<i>15</i>
<i>Figure 2.2: Visual Indicator at a Grader.....</i>	<i>20</i>
<i>Figure 4.1: Locations of QDMR Projects in Queensland.....</i>	<i>34</i>
<i>Figure 4.2: State Roads in Each Main Road District.....</i>	<i>37</i>
<i>Figure 4.3: Project Subsidy Allocations.....</i>	<i>37</i>
<i>Figure 4.4: Comparison of Subsidy Allocations.....</i>	<i>39</i>
<i>Figure 5.1: Proposed Australian National Network (ANN).....</i>	<i>52</i>

LIST OF TABLES

<i>Table 4.1: Subsidy Allocations.....</i>	<i>36</i>
<i>Table 4.2: Construction Costs of a Typical Road Project.....</i>	<i>40</i>
<i>Table 5.1: Recommendations on Future GPS Infrastructure Developments in Queensland.....</i>	<i>55</i>

LIST OF APPENDICES

APPENDIX A.	PROJECT SPECIFICATION.....	63
APPENDIX B.	QDMR PROJECTS AND MAPS.....	65
APPENDIX C.	GRAPHICAL RESULTS.....	93

ABBREVIATIONS

The following abbreviations have been used throughout the dissertation and appendices.

AFN	Australian Fiducial Network
AGRN	Australian Regional Reference Network
ANN	Australian National Network
A\$	Australian Dollar
BMA	BHP Billiton Mitsubishi Alliance Company
CORS	Continually Operating Reference Stations
DGPS	Differential Global Positioning System
DNRW	Queensland Department of Natural Resources and Water
GIS	Geographical Information System
GNS	Institute of Geological and Nuclear Sciences in New Zealand
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
MIN/DOT	Minnesota Department of Transportation
NSW	New South Wales
QDMR	Queensland Department of Main Roads
QR	Queensland Railway
RIP	Road Implementation Program
RS	Reference Station
RTK	Real Time Kinematic
USQ	University of Southern Queensland
VRS	Virtual reference Station
2D	Two Dimensions
3D	Three Dimensions

CHAPTER 1

INTRODUCTION

The VRS (Virtual Reference Station) concept from Trimble is an extension of the real-time kinematic (RTK) technique developed for GPS surveying and other forms of high precision positioning.

Higgins & Cislowski (2007)

Regional GPS network of Continuously Operating Reference Stations (CORS) are now being routinely established as the primary infrastructure to support user needs for real-time, centimeter level positioning.

Gordini *et al.* (2006)

Setting up GPS infrastructure reduces time, labor and the need for a GPS base station (Reference station) for its users making high-accuracy data more viable and affordable.

(Technology & More 2006, p.13)

1.1 Out Line of the Study

The above statements suggest the importance of Global Positioning System (GPS) usage and infrastructure in the surveying discipline. Research studies have shown that VRS RTK method is suitable for traditional surveying applications as well as the real-time dynamic applications such as GPS machine guidance and precision agriculture (Reynolds, unpub). GPS machine guidance instruments are being used by various organizations in the construction industry, around the world, in order to expedite the productivity and efficiency of their work (Baker 2002).

Department of Natural Resources and Water (DNRW) in Queensland have established a VRS CORS (Continuously Operating Reference System) network called SunPoz, currently restricted to five stations around the city of Brisbane. Construction projects using GPS machine guidance control, and other surveying applications performed, within this coverage, are benefited by the VRS network (Higgins & Cislowski 2007).

However, most of the major construction projects, mining activities, and other forms of engineering tasks take place outside the VRS CORS coverage at present. The Queensland Department of Main Roads (QDMR) and the Queensland Railway (QR) are among the government organizations that supervise and undertake the large scale construction projects in Queensland (QDMR 2007).

QDMR has \$13 billion worth of road construction projects to be completed within next five years (QDMR 2007). Providing continuous control for construction projects is a significant issue that needs to be addressed, because it is the base for all the other construction work that follows. Expansion of the VRS CORS network from its present coverage to other potential areas or establishing the new areas of Nodes (Independent GPS Networks) will address this problem. Expansion of VRS CORS network is the establishment of new stations connecting to the existing VRS stations, so that the full coverage for the particular areas is achieved. The other option is to establish new stations as an independent VRS CORS network, running completely separate from the existing network. A specific business case designed for QDMR's current situation, with the estimated cost/benefit analysis may provide the possible answers to this study. Also, study of the spread and the geographic locations of the present and proposed future QDMR construction projects, might be another approach to address the recommendations for future GPS infrastructure needs in Queensland. The cost of the GPS machine guidance instruments, survey controls, and related activities of a construction project need to be compared to the total budget of the project in order to find out the significance of these activities in relation to this study.

1.2 Research Aim and Objectives

The aim of this research is to investigate GPS usage on machine guidance and control for construction projects associated with the QDMR in order to make recommendations on future infrastructure needs with respect to a possible VRS expansion.

Is it beneficial to expand VRS coverage to allow Main Roads Department in Queensland to use machine guidance and control on construction projects?

A comprehensive study of the road construction projects, carried out by the QDMR in relation to a possible expansion of the existing VRS coverage may provide answers to the above problem.

1.3 Outline of Research Method

A careful study of the major road construction projects including the locations and durations of the projects undertaken by the QDMR will be carried out. Locations of the projects will depict the limits of the study and further reveal the necessary GPS infrastructure requirements, while durations of the projects will state the importance of long term planning requirements. A case study will be selected in order to calculate the general construction costs associated with the projects. This case study will provide the base to estimate the general construction costs and assist to calculate the cost/benefit analysis. The issues such as uncertain accuracy, precision on machine guidance, latency issues will also be considered in this research study, generally.

If an extended VRS CORS system or series of Nodes (Independent cluster GPS network) are established to allow QDMR to use machine guidance and control on construction projects, significant time, cost and labor may be saved, in each project. However the project revelations may support the above argument, yet. Furthermore, this network system can be used by other potential users such as, mining companies, farmers, government organizations including local governments, companies, universities and general public etc, as part of their work. The expected outcome of the

project is an investigation of the possible VRS expansion in Queensland, which is directly related to the aim as set out above.

This project is mainly designed to research the information available about the construction projects, associated with the QDMR, within an eight month time frame, in order to achieve the research aim.

The research method is divided into six parts. The first three being the identification and investigation issues relate to GPS usages and infrastructure needs, while the next three sections assesses, the issue in depth and prepare recommendations for possible expansion of the existing VRS CORS network.

The research method is as follows,

- 1 Research the background information on different types of GPS systems. What they are being used for and where they are being used including, GPS machine guidance instruments for construction projects associated with the QDMR.
- 2 Identify the current issues with regard to the GPS usages on machine guidance. Issues such as data availability from the existing base stations, different type of GPS usages such as Conventional RTK, VRS RTK and etc, cost of data, latency, accuracy and the reliability of data. The use of VRS RTK as a fast, efficient and effective system of GPS machine guidance.
- 3 Establish past, present and projected future GPS usage on machine guidance and control in the construction projects associated with the QDMR.
- 4 Assess the importance of establishing infrastructure for future construction projects in the QDMR, by comparing, the construction projects using GPS networks, against the traditional non GPS usage environments. Extrapolate the QDMR situation to make assumptions on the general construction industry.
- 5 Prepare recommendations which will be useful for assisting the decision making for establishing infrastructure needs at government level.
- 6 Prepare a dissertation to suitable standard.

1.4 Justification

Currently, there are ample satellites in the orbit to choose from, and at least three suppliers of signals. There will be no need to concern about the satellite availability or dilution of precision having potentially 75 satellites available in the orbit all the time (Fairall 2003). GPS machine guidance usage in the construction industry, have been refined by the development of satellite systems and their continuous and constant availability.

GPS machine guidance technology has been used, in the construction projects associated with the QDMR during the past few years, at a low profile. Projects using the GPS machine guidance systems are barely reported or commended in QDMR, comparing to the vast majority of similar successful applications from the private sector companies, appearing in the construction journals.

Establishment of GPS networks around the world, to support the construction projects, indicate that the similar situations can be applied here in Queensland. Research the information about the current GPS machine guidance usage in QDMR, with comparison to a well established GPS infrastructure usage may reveal the recommendations of future needs.

1.5 Limitations of Research

The research is restricted to the information concerning the GPS usage and machine guidance and control use in the construction projects, associated with the QDMR and, its subcontractors. GPS usages by companies or any other parties are only considered generally, in this project when preparing the recommendations for GPS infrastructure as per the following reasons;

- (i) Available time does not allow searching the information about construction projects carried out by others.
- (ii) There is no access or permission granted to obtain the information about the GPS usage and machine guidance in other companies or organizations.

1.6 Conclusions: Chapter 1

This dissertation aims to investigate, GPS usages on machine guidance and control for construction projects associated with QDMR in order to make recommendations on future infrastructure needs. The research is expected to result in recommendations of future GPS infrastructure developments.

The literature review will provide information of past projects of similar nature and establish the current state of knowledge.

A review of literature for this research will identify the existing VRS networks, the other similar research projects and the expansion of the VRS CORS network from its present coverage to other potential areas or establishing the new areas of Nodes (Independent GPS Networks).

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Literature review will reveal the current and past research in the same arena, and the knowledge gained through these projects. Also, the past research projects will enhance, establishing the state of knowledge in the similar context, in relation to further investigations. In addition, literature review is an important part of this research project, because, a fresh attempt need to be a continuation to the past work, rather duplication of the same work. Further, background information is needed, to compare and contrast, the current research progress, with the work which is already been completed, elsewhere.

Therefore, literature review will provide information of past projects of similar nature and establish the current state of knowledge. The aim of literature review is to find the related activities, performed in the past, and the research taking place at present in the similar nature. Also, the critical review of the current problem in a broader perspective will be explained in this chapter.

The critical evaluations about the GPS usages and the existing GPS infrastructure developments in the world, including Australia are considered at the beginning of the literature review. This project is mainly designed to investigate, the GPS usages on machine guidance and control for construction projects, associated with QDMR, in order to make recommendations on future infrastructure needs as highlighted in Chapter 1. As such, the background information about QDMR, and the specific role of GPS machine guidance in the construction projects, associated with QDMR will also be reviewed. General understanding about the GPS machine guidance systems, usage, and present developments, along with the VRS CORS networks developments, benefits and the importance of established GPS infrastructure, will also be discussed.

2.2 GNSS, GLONASS, and Galileo Systems

Use of GPS, GIS, advanced communication systems and other technologies play a vital role in today's construction industry (Trimble 2007). Carrying out a detail survey in a large construction site with using the GPS instruments is no longer a major task, when comparing to traditional surveying techniques. As a simple navigation tool for finding a road location up to determination of high accuracy points on earth, GPS usage might be the easiest, fastest and the economical method in the modern world, provided that the proper infrastructure have been established.

What are the different types of Global Positioning Systems?

For the past 20 years, the term GNSS (Global Navigation Satellite System) has nearly been synonymous with the US NAVSTAR global positioning system (GPS). GPS was not the only GNSS available. Russia's GLONASS system was also fully operational during part of this period. Glonass utility remained low as its development generally lacked and adequate number of satellites reliable for general application. Probably, the highest profile development in 2005-2006 was the inauguration of Galileo constellation. The space vehicle sent into the orbit on 28 December 2005 transmitted its first signal on January 12, 2006. The introduction of Galileo constellation, by the European Union, and the planned introduction of regional positioning system by China, India and Japan will create new opportunities for users. Presently, only one system is fully operational. The GPS some Glonass satellites are currently in orbit. The system will reach its full complement by 2010. The first Galileo test satellites are currently in space. Galileo should be fully operational by 2008, as scheduled by the Europeans. The latest incarnation of Japanese QZSS will have three GPS-like satellites in orbit. Sherman *et al.* (2006)

History of the satellite constellation developments in the past recent years indicate that the GPS usage deliver better results at present as well as in the future.

If any, GPS infrastructure can be developed to establish a VRS CORS network within the next couple of years; it has the full potential of gaining the maximum benefit of

the GPS constellation developments. This is another positive approach, towards the GPS usage on the machine guidance in the construction industry.

2.3 Virtual Reference Station Concept

The VRS concept from Trimble is an extension of the real time kinematic (RTK) technique developed for GPS surveying and other forms of high precision positioning. With RTK, established reference (base) station at a known point broadcast the data to one or more roving receivers. RTK enables the roving receiver to be positioned with accuracy better than a few centimeters reliable to the reference station. VRS increases productivity by overcoming limitation of the current real-time GPS surveys. VRS has three major advantageous.

- 1) The use of mobile phone technology overcomes the limitations of the radio link communication.
- 2) Operators no longer need to set up a base station
- 3) Multiple reference stations increases confidence in results.

Additional benefits of VRS

There are other inherent advantageous in a VRS system.

- Reliability- If a base station breaks down the operations stop. But with VRS if one station goes down, operations can be carried out with other VRS stations.
- Negate interference factors - A network has more capacity to negate interferences than a single station set up.
- Errors eliminated due to possible simple surveying mistakes. In a traditional surveying system this will carry forward in the subsequent observations.
- Problems of accidental or malicious damage to an unattended base station.

(Higgins & Cislowski 2007)

The VRS concept involves permanently running Global Navigation Satellite Systems (GNSS) reference station at spacing up to 70 km. If several construction projects are falling within a 70km radius, all of these projects can be utilized a VRS CORS network instead of setting up individual base stations of their own, which reduces time, labor and the cost.

2.4 GPS Network Systems in the world

New Zealand is already entirely covered by a VRS system of national network of about twenty stations feeding data into one central computer. GeoNet is the first comprehensive nation wide monitoring system in New Zealand. GeoNet has been designed and built by the Institute of Geological and Nuclear Science (GNS) with the bulk of funding coming from the Earth Quake commissions (Thomas 2003).

Minnesota is the 12th largest state in US. Currently, VRS is predominantly being used by MIN/DOT (Department of Transportation). Access to this network is free to everyone. Most of the countries already have the equipment and need only a license, cellular modem, and the VRS software to gain 1-2cm, horizontal accuracy, that has been constantly gained with the new system. In addition, DOT users have used the system to gain good solution at up to 18miles (29km) from the nearest reference station. The new goal is to seed the state with the clusters or pods of four to six VRS stations (Dave, Don & Craig 2003).

The above information shows that, the VRS concept has been used by others around the world, successfully, and there are ongoing developments in this field. Also, there are many other examples, which can be used to guide the situation, when establishing a VRS network in Queensland.

2.5 VRS Systems in Australia

To be useful in many new applications, data need to be current in both space and time. The older data is the less useful it is. The new regime depends on a new generation of data creation technologies that centre on the individual in the field.

(Finner 2003).

The following sections briefly explain the existing GPS network augmentation system networks in Australian perspective. This information reveals that establishment of GPS infrastructure is not a new concept for Australians, anymore. What is relevant is the expansion of existing GPS VRS networks to suit the individual circumstances, on state by state basis. Although the current GPS infrastructure networks in all the Australian states are stated here for information, Queensland Sunpoz network is mostly emphasized in this section, as the base of this research study.

2.5.1 Victoria

The Department of sustainability and Environment in Victoria has developed a GPS continually operating reference station infrastructure called GPSnet. Continuously operating reference stations (CORS) has been enthusiastically greeted by the surveying profession. Victoria's cooperative Global positioning system base station network. The first GPSNet reference to use a combination of Glonass and GPS came into operation in September 2006. Victoria's Department of sustainability and Environment switched on the station at Robinvale on the River Murray, near Mildura to use the above combination.

2.5.2 Sydney

Sydnet is the CORS system established in Sydney. This network is maturing rapidly and extending its coverage rapidly. Sydnet is a project to establish a permanent real-time GPS network in the Sydney metropolitan area to provide GPS data for post

processing and a Network- RTK service for users in the region. Sydnet is being developed by NSW Department of Lands in partnership with the School of Surveying & SIS at the University of New South Wales. The first Sydnet is only to service basin region, but it is planned for expansion over time to cover other areas in NSW. The Sydnet network may be considered a 'second generation' CORS network, as it will be established with net-work based positioning capability from the very start. The physical infrastructure, the communication links and the database are controlled by one agency, the NSW Department of Lands. (Kinlyside & Tan 2005)

2.5.3 Perth

A continuously operating reference station (CORS) network began its operation in 29th June 2006 in metropolitan Perth. It is the first to be operated by a private enterprise. The network is called GPS Network Perth. It is based on Trimble R5 reference stations. It is the first VRS network to support both GPS L2C and L5 signals and Glonass signals. It provides professional users of GPS equipment around the city with corrected GPS data in real time. It means that, there is now no need to establish a GPS base station in the immediate vicinity of a project. Once, people start using it and experiencing the benefit, it will become the future for GNSS surveying and positioning in the Perth area. The network is likely to be expanded beyond the five reference stations. (Clucas 2005)

While the similar networks operating in Melbourne, Sydney and Brisbane are all managed or administrated by the state government departments this is the only system network established by a privately owned and managed GNSS augmentation Network.

Already, GPS network Perth's five reference stations provide 4550m² of coverage over Perth's metropolitan area. The new Perth Network is based on Trimble Net R5. GNSS receivers making it the first in Australia with full GNSS capabilities.

2.5.4. Brisbane

In South East Queensland, Natural Resources and Water (DNRW) has established a network of continuously operating reference stations (CORS) using the Trimble Virtual Reference (VRS) technology. Sunpoz offers both real-time and post processed products. The real time service has delivered field productivity increases, between 30% to 50% depending on the applications (Higgins & Cislowski 2007). The VRS technology uses CORS and mobile phone to determine real-time centimeter positions. A network of continuously operating reference stations (CORS) was established in the corridor between Brisbane and Gold Coast. The network corrections were delivered using the VRS technology.

At present, Victoria's GPSNet and Sydney's Sydnet stations use mixture manufacturers' base stations. Brisbane Sunpoz and GPS network Perth both use the proprietary VRS standard from Trimble Navigation.

At present, there are only few reference stations located in Brisbane in on the roof of DNRW office buildings. DNRW is a decentralized organization with more than 30 offices located across the state. This offers significant benefits in the establishment of a CORS network that is suitable for VRS operations as suggested by the DNRW officials recently.

However, it is debatable that simply selecting these locations as the VRS reference station locations does fulfill the requirement of the national demands. More focus should be drawn towards the use and the users of GPS data rather than an administrative preferences approach.

The existing stations are more benefited by Main Roads and RoadTek and other private companies operating around Brisbane, where the VRS coverage available for their work. It is revealed recently that QASCO has successfully used the Sunpoz CORS network to produce preplanned photogrammetric control for the "cut and cover" tunnels called for in the QASCO Bus way Project Plan.

Anyone operating within the Network coverage, which are hundred of square kilometers, now obtaining in the same accuracy available to them? However as

mentioned earlier, major new road projects, precision agriculture and mining industry still has demand on establishing base stations for their work. If Sunpoz CORS network is extended beyond the areas where it operates at present, these organizations will most definitely be benefited.

2.6 Main Roads in Queensland (QDMR)

QDMR is one of the major organizations empowered by the Government legislations to build, Queensland's major roads which will eventually benefit our future lifestyles. Planning, surveying, designing, constructing and maintaining the new roads for tomorrow, are some of the important tasks undertaken by the QDMR. From planning up to construction stage of new roads, in Main Roads, engineering and surveying involve at various levels.

QDMR plan, design, build and maintain 34,000 km state-controlled road network, highways and other main connecting roads in Queensland (QDMR 2007). It is about 20% of the states total road network and carries about 70% of the state traffic (QDMR 2007). In addition, Main Roads manages National Highways in Queensland on behalf of the federal government. That means, QDMR plans, designs and supervises work on the national highway but the federal government provide funding. The South East Queensland region has responsibility for approximately 2868km of the state controlled roads, including 427km of Auslink national network roads.

QDMR has recently released the Road Implementation Program (RIP), for the 2007-08 to 2011-12. RIP, marks a record A\$13.3 billion spend on Queensland roads. Data collection about the construction projects under the Road Implementation Program (RIP) is required to identify the requirements of establishing the GPS Infrastructure. As outlined in chapter 2.5.4, there is an established GPS network coverage, already emplaced by the DNRW in Queensland. However, this network only covers and provides the controls for the construction projects, within and closer to the Brisbane area. Details of the projects planned under RIP will undoubtedly, clarify the relevance of the existing coverage, and further demands in the future.

At present, QDMR has offices spreading through out Queensland. Figure 2.0 shows the locations of the, fourteen main roads districts in Queensland. There are quite a number of projects, currently supervised by the QDMR and many future projects are expected to be completed within the next five years.

GPS machine guidance usage, on these construction projects in QDMR are presently, at a low profile, possibly, due to non availability of proper infrastructure in the project areas. Current, GPS usage is only restricted to setting up a base station at the site, providing the controls for construction projects. However, the successful VRS developments in Brisbane and other capital cities in Australia by Government organizations and the private sector companies, pave the way to introduce, VRS CORS networks in to other areas where it is needed.

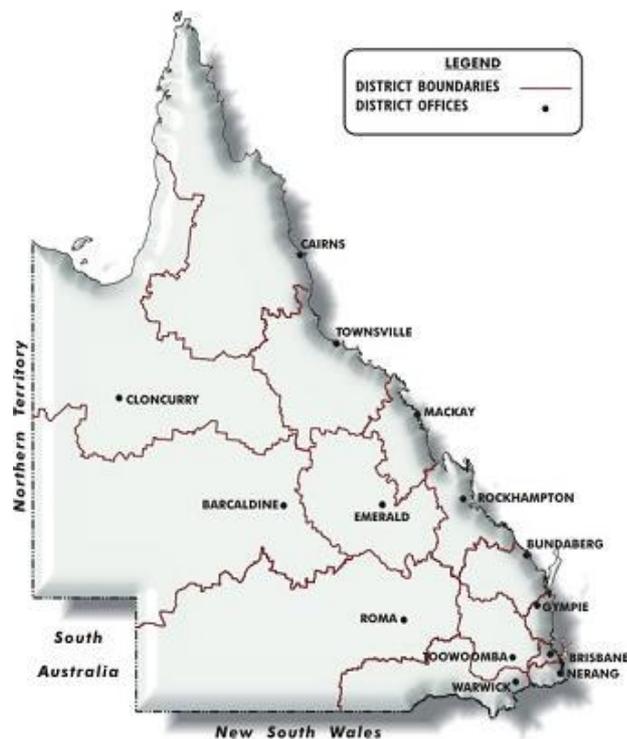


Figure 2.1
Main Roads Districts (QDMR 2007)

2.7 GPS Machine Guidance

The machine guidance or control alternatives may be simply, divided into three categories; 1) 2D guidance needing line of sight, 2) 3D guidance needing line of sight, and 3) GPS guidance systems. There are some important differences between the 3D systems, and that is the fact that, the 3D laser systems need a direct line of sight to the equipment, and the range of operation, depending on the total station used, is usually an area with a radius between 400m to 600m. Therefore, there is a need to move the base station more frequently, than for the GPS system, which covers an area with a radius around 4 km, depending on the radio used.

Another important factor, that should be considered, when selecting a machine guidance system is that, one base station for a GPS system can support an unlimited number of pieces of equipment, while the 3D-laser system needs one base station per machine. This results in a lower cost, for adding a piece of equipment to a GPS system than for the 3D-laser system. The owner and contractor should also note the increased quality of work that can be achieved by using a sophisticated 3D guidance system (Jonasson 2000). Also, the other benefits of a GPS machine guidance system can be listed as, excavate to design, productivity gains, productivity monitoring, and, control

Present developments of the GPS machine guidance technology were erupted about two decades ago. Efforts made during 1980s, to integrate the controls of the construction equipment with the available positioning systems were hindered, due to the expense and the limitations in accuracy. During the 1990s, with the introduction of automatic total stations and global positioning systems, the successful integration of surveying and machine control at construction sites became reality. Early successful automated control systems mostly have been based on 2D laser or ultrasonic technology. Subsequently, robotic total stations have afforded 3D control and most recently, manufacturers of GPS technology have emerged with off-the-shelf systems for machine guidance (Jonasson 2000).

AGTEKs Auto Pirate 3D Automatic Machine Control, (AGTEK 2007), Leica Geosystems Leica Dozer 2000, Trimble's GC900 Grade control system, 3DAutomatic control system are among the major 3D GPS machine guidance products in the

market. Present developments in the GPS machine guidance technology have enabled the construction companies to achieve a significant increase in their productivity levels (Leica 2007).

2.7.1 Applications of the GPS machine guidance

The Falkirk Mining Company has been a pioneer in the use of GPS technology, for machine guidance in land reclamation and mining applications (Leica 2007). The company has been using Leica's Dozer 2000 GPS machine guidance system at its lignite surface mine in North Dakota since 1998, resulting in substantial productivity improvements and cost savings. Similarly, there are many GPS machine guidance applications around the world.

2.7.2 Australian context/usage of the GPS machine guidance

In 1999, BMA (BHP Billiton Mitsubishi Alliance Company) approached Leica Geosystems, to investigate about the Leica 200 Dozer machine guidance package at their coal mine in Blackwater. For the past 7 years, Blackwater mine has been using Leica Local counterparts Fleet Management System, a communication network, that allows mine production to monitor machinery, throughout the whole mine by the use of GPS receivers. A single order of 15 Leica 200T GPS machine Guidance system to the Blackwater mine shows that, the importance of using this technology here in Queensland (Leica 2007).

The road construction projects associated with the QDMR have been using the GPS machine guidance for earth work during the past few years. The Burnett River Dam access road, constructed for Burnett Water Pty Ltd, was one of the projects carried out by QDMR, with using the GPS machine guidance systems (Brownjohn 2006).

2.7.3 Benefits of GPS machine guidance

Benefits of using a GPS machine guidance system can be listed as follows

- a) Productivity: - Cost savings
Productivity gains by reducing re-handling of overburden and subsoil
- b) Accuracy: - Near enough is not enough.
Doing accurately for the first time
Excavate to design.
- c) Monitoring: - Productivity monitoring
Operator feels more in control
- d) Safety: - Provide safety, especially at night when visibility is poor.
The operator needs not to get out of the cab to check the equipment or stakes.

The productivity gains and the cost savings through the GPS machine guidance systems are very important aspects, which will be adequately addressed, in this research project in the following sub chapters.

2.7.4 Issues related to GPS Usage on Machine Guidance

There are few reported setback in the usage of GPS machine guidance technology in Queensland. The main draw back is that, the unavailability of sufficient GPS coverage, to provide controls to the construction sites. Establishment of new GPS infrastructure in Queensland is the alternative way, to overcome this issue.

Despite the facts mentioned above, the other specific issues with regard to GPS usages on machine guidance are

- Data initialization issues
- Radio, GPRS and mobile link communication issues.
- Data availability from the exiting base stations
- Cost of data - comparison of data available through conventional survey methods such as Total stations, combination method of GPS+ Total stations and VRS only.

- Latency issues- Latency is the time it takes to receive the signal from the satellites, calculate the correction and transmit then to the receiver in the field.
- Issues such as tree coverage, tree types.
- Trained staff and reliable, hard ware and software.
- Continuous technical support and the effective communication between them.

2.7.5 Importance of using GPS machine guidance

One of the main importances of GPS technology is that, it is a fast growing technology. Accurate earth moving equipments have been developed, by the major equipment manufacturing companies by integrating, GPS, telecommunications, IT and other technologies. Trimble's Terramodel is one such total software solution for integrated survey, design and construction. With the powerful Terramodel, a wide range of processes can integrate into one operation and improve the construction workflow. Data can be easily moved between the field and the office and 3D machine control capabilities in Terramodel reduced setout activities (Trimble 2007).

Latest machine guidance equipments have been designed to use, for a person even with a little technical knowledge. The major advantage is that the surveyors do not have to be in the construction sites regularly, setting out the stakes rather engaged with other important tasks, which requires more technical expertise.

It is a challenging tasks to co-ordinate the many different aspects of road and site survey, design and constructions. With the advancement of new technologies, including the use of GPS technology, many hardware and software developers have developed methods to integrate the activities associated with bulk earthwork and volume calculations making it easier than ever before. The systems provide a visual indicator to the grader driver. The following figure 1.1 shows a picture of a typical visual indicator at a grader.

The indicator tells the driver, whether the blade is high or low, or to the left or the right of a line defined by the road design in the software. Also, with the use of GPS machine guidance and control, it has been far easier for the surveyor at the site, to carry out their work and volume calculations efficiently. Construction sites falling, within the coverage of VRS network now has the ability to use VRS data for real time processing, for grader operators. But the problem is that most of the major projects are falling outside the VRS CORS coverage and still has the necessity to engage another GPS controller as a base station which needs extra time, cost and effort.



Figure 2.2
Visual Indicator at a Grader
(Leica 2007).

2.8 GPS Infrastructure and the productivity

With the improvement of the GPS machine guidance systems, and the widespread GPS usage in Queensland, it is inevitable, finding alternatives to establish GPS infrastructure in the areas where it is badly needed. GPS machine guidance systems within the mining industry still operate as stand alone systems, due to unavailability of suitable GPS infrastructure in most of the parts in Queensland. If established GPS infrastructure is available, and the access to the network is affordable, then there will not be any other major reason for not using such a system, by these users.

The existing GPS infrastructure, either cover only a limited area or does not cover any area at all, in many circumstances. As such, productivity in the construction projects hinder, and therefore, the cost of each project will increase comparatively.

2.8.1 Existing GPS Infrastructure for machine guidance

The classic RTK methodology allows for an operational distance between the reference stations (RS) and the user of up to 10-15 kilometers (ICSM,2004), due to the correlation of some GNSS errors with distance. By adopting a Network RTK (NRTK) VRS approach, this operational range can be extended to 40-70 kilometers according to the recommendation of the author of GPSNet [trademark] software (Trimble 2001).

GPS machine guidance is a real-time application, which needs continuous coverage of controls. Most viable method is to establish a base station at a close vicinity to the site, in order to carry out the earth moving operations. Stand alone systems are good enough to increase the productivity, when there is no coverage of VRS CORS network.

Currently, DNRWs Sunpoz is the only network operating in south-east Queensland, which provides the continuous VRS coverage for its users closer to the Brisbane Area. Apart from this network, there are two other Australian Regional GPS Network stations , (ARGN) available in Townville, and Alice Springs, which provide AUSPOS data for post processing GPS applications.

2.8.2 Usage of GPS Infrastructure in other related fields

Establishment of a GPS VRS Network, merely to sustain the earth work operations, in QDMR construction sites, may be an awkward idea, up to a certain extent, to many

users. The evidences provided, support and enhance the importance of immediate GPS Infrastructure needs, in Queensland. Although, QDMR road construction projects are only considered here to highlight the productivity, cost savings and the GPS Infrastructure needs, it is very important to consider about the other major potential GPS users, as well. Queensland Railway (QR) is one such large organization that could be benefited from a new VRS Network. Also, the other potential users can be identified as,

- 1) Mining companies.
- 2) Farmers, for precision agriculture, and forestry.
- 3) Navigation and location based services.
- 4) Local Government Organizations.
- 5) Surveyors, and other surveying related groups.
- 6) Research organizations and Universities.

These prospective users and their expected contribution to the usage of the GPS Infrastructure will be an enormous outcome to the program, in the long term. On the other hand, these users and their continuous and increasing demand, will eventually strengthen, the ultimate requirement of a National GPS VRS network in Queensland.

2.8.3. GPS Infrastructure demands

Queensland is one of the biggest states in Australia with a large area extents and widely spaced population distributions. Therefore, it seems that the idea of NRTK coverage is not economically viable for Queensland. As such, the establishment of sparse CORS networks over wide areas, in combination with higher density sub-networks in locations that, fully justify the investment is required. However, the careful considerations of the data available for road projects in the eastern side of Queensland may suggest that, there is a possibility to establish a VRS network throughout this region.

2.9 Conclusions/Summary: Chapter 2

Literature review exposed, the current and past research in the same arena, and the knowledge gained through these projects. As, discussed in length, literature review is an important part of this research project, because, it enabled, the new work to be started, as a continuation to the previous work, without duplicating the same work. Further, background information will be compared, with the results and findings at chapter 5.

Most of the construction projects, and the mining projects falling outside the VRS coverage, still need to spend more time, on establishing control at construction stages. If a new network similar to the existing VRS CORS system or, the current network can be expanded into the other areas, where it is needed, this will eventually increase the productivity, and therefore the efficiency in return. Identifying the general issues mentioned above in the construction industry, as a whole, is a massive task. However, carrying out a major study to investigate, GPS usage on machine guidance and control for construction projects, associated with the QDMR would be one of the best solutions to the above problem.

As, QDMR has already undertaken Road projects across the entire estate, study of GPS usage and infrastructure needs and control on the construction projects, associated with the Department, will generate a better understanding of designing an effective VRS CORS network in Queensland. In addition, this dissertation aims to make recommendations on future GPS infrastructure needs for the construction industry associated with the QDMR.

CHAPTER 3

RESEARCH DESIGN AND METHODOLOGY

3.1 Introduction

This chapter describes the research design and methodology, which was used in this project. Research design provided an overview of the entire project, while methodology was important as the basic plan, to achieve a successful outcome to the design, with available resources and within the allocated time. Experimental methods, data collection and data analysis are the core factors, or the key elements, which have been explained in this section as part of the research design and methodology.

Therefore, the aim of the research design was to follow an order of research approach to the issue, in order to obtain a successful outcome. Knowledge gained through the past researches, and their findings were utilized in the project, to develop an independent research method, in order to find a solution to the research topic. The research methodology already mentioned in chapter 1.3, is further explained here, as experimental methods, data collection, and data analysis.

Literature review in chapter two revealed that, GPS usage on machine guidance and control, in the construction industry, have been tested successfully, in Australia and around the world. Furthermore, Study also revealed, more cost savings, and productivity gains, can be obtained, by using the GPS machine guidance technique, in the construction industry, within an established VRS CORS Network environment. This VRS CORS network can be a completely new network, expansion of the existing network or a series of nodes (independent network) or a clustered network, depending upon the individual circumstances. Established GPS infrastructure in the world and other states of Australia indicated that, positive approach and further investigations can be made to recommend and design the infrastructure needs in Queensland. Apparently, the above findings suggested that, QDMR construction projects using the machine guidance may be benefited by the expansion of the existing network or

establishment of a new VRS CORS Network. Therefore, this research is mainly designed, to investigate the GPS usage and infrastructure needs for machine guidance and control in the construction projects associated with the QDMR.

3.2 Experimental Methods

As this research project was mainly focused, on the construction projects, associated with the QDMR, collection of detailed information about the present, and future road construction projects in Queensland, was required, as the foundation for this research. Detailed information such as the project name, location, budget of the project, road length, project duration, type of the construction etc; was collected at the initial phase of the research. Then, this information about the construction projects were grouped, into their geographical locations, with attribute data, such as estimated cost of the project, project duration etc; attached.

Collecting this information and sorting out these relevant data, was necessary, so that it can be easily marked on a relevant map. Marking the project locations approximately, on several maps in A4 and A3 sizes, was essential, to study the spread of the construction projects, in each geographical location of the main road districts. It also helped to identify the areas, where the constructions are planned, in the future. Plotted maps, was used to find out, the density of the existing projects, and to perform further data analysis in order to recommend future infrastructure needs.

A case study about a past construction project, was carried out, to find out the general construction costs, associated costs, and GPS machine guidance costs in a general construction environment. This information was later used as the approximate percentage values to calculate the cost/benefit analysis.

A business case was planned, to justify the conception of future possible VRS expansion, in order to assist QDMR construction projects in Queensland. General construction costs, earth work costs, instrument costs and other associated costs in a construction project, as well as the establishment costs, on going maintenance costs of

the existing VRS stations, and the annual fee for the license agreements with DNRW, were also acquired to calculate the cost/benefit analysis. This information was obtained from QDMR, DNRW and the equipment sales agents. Cost/Benefit analysis was prepared to calculate the cost savings, from the total budget allocations in QDMR, for the next 2 year period, by using the GPS machine guidance systems under an established VRS CORS network environment. For the calculation purposes only, an assumption was made, as the VRS expansion, beyond the existing stations have been established and these infrastructure have been used by QDMR, for the construction work. Cost/benefit analyses, based on the above results, represented sufficient evidences, to justify and recommend the GPS Infrastructure expansion in Queensland.

Present a business case to support the argument of establishing a new VRS CORS network, expansion of the existing network or planning a series of Nodes in Queensland, was the end result or the outcome, which was expected from this research approach. Preparation of recommendation for future GPS usage and Infrastructure developments based on the findings is the other major outcome, which will be accomplished in this research work. These recommendations will be adequately discussed in chapter five, for the benefit of the authorities and the interested parties, who would contribute, in the process of establishing future VRS expansion in Queensland. Designing a robust VRS CORS Network, is another task, which is beyond the scope of this work, to be continued, based on the recommendations from this research project.

3.3 Data Collection

As most of the information about the present and past major construction projects, are available through the QDMR website, during the process, it was decided, to collect all the necessary data, into a separate project directory. Plans, Maps and other relevant materials were printed, as hard copies, in order to identify and mark the project locations on the plans, manually. Collection of data was carried out mainly by the following sources;

- a) From the QDMR website in digital form, or as hard copy printouts. These information included the following;

- Current and proposed construction project details. Collected data is included under Appendix B, as QDMR Projects and Maps.
 - Past project details, Project reports, Feasibility studies, and business cases for road construction projects.
 - Construction projects and the budget allocations, planned under the RIP program.
 - Detailed information such as the area extents, population, state roads, federal roads, total length of roads, staff and other social and economical details about each main road districts.
 - Map of the main road districts.
 - Large scale plans, of each Main Road districts in A4 and A3 sizes.
 - Plans showing the main road district headquarters, QDMR road numbers, names and the local government boundaries.
 - Main Roads and RoadTek magazines and Newsletters.
- b) Contacting, individuals and relevant authorities or companies by various means.

Individuals, authorities and the companies were contacted, included:

- Senior Surveyor at DNRW in Brisbane.
- Principal Advisor, Research and development in QDMR.
- Senior Advisor in surveys in QDMR, at Eagle Farm and Nerang.
- Machine Guidance Instrument Specialist from ABC Lasers in Acacia Ridge.
- Project Managers and Civil Engineers for construction projects in QDMR in Brisbane.

These parties were contacted either by emails, telephone or organizing the meetings. Valuable information regarding the existing SunPoz network, were obtained from the Senior Surveyor at DNRW. Sunpoz VRS network, it's coverage, current usage, past projects, major projects carried out in the past by using the Sunpoz network, annual maintenance costs, license agreements, fees and other relevant topics such as, future developments were discussed during this conversation. Officers from the QDMR provided useful links to contact the project managers and the engineers, who were

responsible for managing the road construction projects using the machine guidance systems.

- c) Collecting the information through the relevant websites.

The background information for literature review was collected from various internet sites, as listed in the references. In addition, several other websites were visited, to study the past knowledge, relevant to the topic. Mainly, information regarding the VRS CORS Networks, GPS machine guidance instruments and their usage, and the GPS infrastructure developments in Australia and around the world were studied and the relevant data was collected.

- d) From the USQ Library, Books, Magazines and Journals.

USQ library on the internet was visited and the articles relevant to the topic were extracted. Books, magazines and other technical journals were examined and the data relevant to the research topic were copied with due recognition, as listed in the reference page.

3.4 Data Analysis

Data analysis was performed, to determine either stand alone or VRS CORS GPS Network systems are more suitable, for the areas concerned, in relation to the following questions.

- Spread of projects, with their geographical locations?
- Potential QDMR use?
- What are the other users?
- Is VRS suitable?
- Should VRS used or use stand alone bases?
- Who is responsible for expansion of the network?

Maps with the locations of QDMR construction projects marked were used to explore, whether expansion of the existing VRS network is possible or alternative methods are required. What are the alternatives, whether it is to establish series of nodes or to use stand alone GPS systems? The other important task was to investigate the potential

QDMR usage of a possible VRS network. What are the other users? Due to the nature of different kind of geographical locations, establishment of a VRS network, merely to support, QDMR projects may not be the best solution. Therefore, the other potential users such as mining, agriculture and the services and their support and the contributions were also regarded. Expected durations of the projects was one of the key points, that considered, when recommending the future GPS infrastructure, since, ongoing commitment is necessary, to use and maintain these infrastructures. Obviously, stand alone GPS systems are more suitable, for short term projects, where, implementation of mass GPS infrastructure is just a waste of time and energy. Therefore, long term construction projects were highly considered, when analyzing the data, as these projects strengthen the requirements of future GPS infrastructure demands.

Collected information about the construction projects, planned under RIP program was tabulated to various forms of graphical presentations, to explain and highlight the relevance of these data. These tables, graphs and charts are included and explained in chapter four, and Appendix C, to discuss the actual data analysis.

Although, the details about the road construction projects, budgets and durations of the projects are available through the QDMR website, there is no extensive detail, documented about the earth work or the earth work using the GPS machine guidance systems, in the construction projects. However, considerable amount of details are still available in the QDMR website to calculate the percentage of earth work, in a construction project. Feasibility studies and the cost estimates about the major projects as well as the project reports, also, provide significant contributions to find the details of the GPS machine guidance usage in the construction projects, associated with the QDMR. A report prepared by Project Support, for the Ipswich Motorway Alternative Northern Corridor, Alternative option, was used as the case study to obtain the costs for construction costs. These values were used as a guide, to calculate the cost/benefit analysis.

A business case was prepared with the cost/benefit analysis and the recommendations were given based on the findings /results from the above data analysis. The actual data analysis is extensively explained in chapter five.

3.5 Conclusions: Chapter 3

Established GPS infrastructure in the world, and other states of Australia indicated that, further investigations can be made to improve, develop and design the new GPS infrastructure in Queensland. Knowledge gained through the similar projects in the past, was utilized in this research, to develop an independent research method, in order to find a solution to the research topic.

Collection of data, about the current construction projects associated with QDMR mostly updated, and available through their website. Detailed information also available from the same website for each project, including the total budget of each project. However, a case study to find out the construction cost was carried out from a project report, prepared for QDMR. Establishment of VRS CORS network will be a challenging task, as it requires considerations to the main question of whether; it is the ideal network or the best solution. Finally, the recommendations about the GPS usage and infrastructure will be prepared, with all the knowledge and the information gathered during the course of the research project and included in the preceding chapters.

CHAPTER 4

RESULTS

4.1 Introduction

GPS usage and infrastructure needs, for machine guidance and control, in the construction projects, associated with the QDMR in Queensland, was selected and , set as the limit of the current research project. A research method was carefully developed, as adequately explained, in the previous chapter 3, in order to achieve a successful outcome to the main research topic. This research project was designed, and the method was developed, based on the past and present studies about the similar nature, in the world and Australian context. Also, the research was carried out in an orderly fashion, to obtain the optimum results out of the project, within the available time frame. This chapter includes the results from the above observations, as texts, graphs, tables and charts, and further includes the calculations based on the collected information. Results from the observation are presented here, to find out a clear suite of evidence to prove the argument of VRS expansion into other areas in Queensland. The results and findings are included in this section to discover, any supportive evidence to the main research topic.

The aim of this chapter is to state the results obtained, during the course of the research project. Establishment of VRS CORS network will be a challenging task, as it requires considerations to the main question of whether; it is the ideal network or the best solution. Therefore, results from the observations were included and explored in this chapter, for further data analysis.

Firstly, at the beginning of this chapter, the maps with plotted information such as project locations, total budgets and durations of the projects were included. Most of the above locations were again approximately plotted, on a small scale map to highlight the significance of the extracted information. All the other supportive documents about the QDMR projects were included in Appendix B, as QDMR

projects and Maps. Secondly, a case study about a typical construction project was carried out, and the results from the study were included in this chapter. This case study was important, because it provided the percentage of the construction costs in a road project which enabled to calculate the cost/benefit analysis, in relation to the proposed VRS expansion. Finally a business case was prepared, and the details were included, in this chapter, to highlight, the findings and the importance of the expansion of the existing VRS CORS Network in Queensland. Results of the data analysis, about the construction projects, associated with the QDMR in Queensland, are highlighted in this section, to discuss the clear suite of evidence for supporting the main research topic.

4.2 Geographical Locations of QDMR projects.

A current list of all the construction projects, associated with QDMR was prepared, as annexed in Appendix B under, QDMR projects and maps. Maps showing the main road districts were printed in A4 and A3 sizes and the locations of the projects were approximately marked, on the relevant maps. The main objective to mark these locations on the maps was to find any clear suite of evidence for future VRS expansion in Queensland.

The following observations were made from the above task;

1. During the study it was noted that, the projects to be marked, were only needed, in the districts with a large area extent. Therefore, maps for Cairns, Cloncurry, Barcaldine, Townsville, and Roma districts were marked, with the relevant project locations, and these details were later extracted into the figure 4.1.
2. Observations revealed that, all the other main road district headquarters are located within, 300 km radius to each other, at the eastern side of Queensland, as calculated from the map.
3. As identified from the detailed maps, the majority of the road construction projects fall, around the main center of the each main road administrative districts, in most instances.

4. Current and future road construction projects in Cairns, Cloncurry, Townsville and Roma are sporadic and scattered projects.
5. A\$40 million worth of construction projects are planned within 200km from Cloncurry, in the next 4 years, while another A\$10m project is planned far away from the center.
6. A\$31m road construction project is planned in Weipa, as shown on the map, while significant amount of road projects are planned in or closer to Cairns.
7. In Townsville, 6 out of 8 road construction projects are closer to the town, while the other two are located away from the town.
8. The 5 circles drawn in red on figure 4.1 are indicative locations to cover the whole area in south east Queensland, alongside the blue circles which was drawn from the center of the major towns. These red circles are approximately drawn from the center of the other minor townships, in the local government areas.

The figure 4.1 shows the locations of main road district boundaries and the projects, along with the extracted information from these individual maps. These individual areas were then compared with each other, in relation to the range of road constructions planned, budget allocations, total length of roads, population and the area extents etc. Mining areas, farming, commercial and other social environments were also, considered to give the recommendations about the future GPS infrastructure needs.

4.3 Density and the Spread of QDMR projects.

Dots and the lines highlighted in orange, in figure 4.1 shows, the approximate locations of the future QDMR projects in Queensland. Detailed information of all these projects is available in Appendix B under QDMR projects and maps. Three of the major projects in Cairns have been marked, with the budget allocations and the durations. Similarly, locations of the projects in Cloncurry, Roma and Townsville districts can be found in the figure 4.1. Locations and the details of projects in

Barcaldine are not available, through the QDMR website, at present. Approximate locations of the projects for the above three districts marked on the map, revealed that they are scattered in various parts of the districts. However, the construction projects, at the eastern side of Queensland, are close to each other with comparing to the projects at the northern and western sides of Queensland.

VRS expansion is not possible in the areas, with distant and scattered projects, because of the investment on establishing GPS infrastructure cannot be justified, whatsoever. Considering the facts, such as the budget allocations, durations of the projects, future developments and the other potential users, a series of nodes or an independent network may be implemented in these areas. Main road districts along the coastal line from Nerang up to Mackey including, Toowoomba, Warwick and Emerald are close to each other with comparing to the districts in northern and western sides of Queensland which, may have a potential of a VRS expansion in to these areas with the interpretation from the above map.

4.4 Locations and the subsidy allocations.

Subsidy allocations for the next five years for QDMR projects, under RIP program were extracted, and tabulated with other data as shown in Table 4.1. This information shows the immense amount of funds, already allocated into the road construction projects in the coming years. With the knowledge gained, through the previous chapters, it is apparent that more productivity gains, and cost savings can be obtained, from these QDMR projects, by using the GPS machine guidance technology, under GPS VRS environment. Subsidy allocations for road construction projects for 2007-2008 and 2008-2009 periods were depicted as different types of graph presentations, for easy reference and to explain the results/findings. Some of these graphs are available in Appendix C.

Figure 4.2 shows, the percentage of state roads in each district. It also reveals that the maximum percentage of state roads is in Roma district and then follows, Barcaldine, and Toowoomba. Cloncurry and Cairns while, the lowest percentage of state roads are in Brisbane and Nerang Districts. With comparing the details in figure 4.2 with the figure 4.3, the following observations were noticed.

- Brisbane with a lowest percentage of 3% roads in Queensland will receive the highest investment of nearly A\$ 43million, for the next 4 years, on road projects.
- Cairns will receive the second highest fund allocations with a percentage of 9% of roads in Queensland.

Table 4.1

**Current Road Projects in Queensland 2007-2009
Undertaken by the Department of Main Roads, Queensland**

District Offices	Projects	Projects	Road Length	Road Length	Road Length	Staff	Area Sq km
	Total Subsidy	Total Subsidy	km	km	km		
	2007-2008	2008-2009	State Roads	Other	Total		
	\$A	\$A					
Peninsula District (Cairns)	22,134,667	16,796,500	3066		3066	220	265250
Northern District (Townsville)	5,319,075	4,491,500	1506	717	2223	200	104000
North Western District (Cloncurry)	4,253,051	2,487,000	3076	520	3596	130	311270
Mackay District	3,844,491	2,714,000	1796		1796	59	38410
Central District (Rockhampton)	7,401,174	3,078,134	1699		1699	80	44538
Central Highlands District (Emerald)	1,719,683	1,671,833	2445		2445	44	N/A
Central Western District (Barcaldine)	7,045,652	5,753,033	4059		4059	75	370472
Wide Bay District (Bundaberg)	5,149,223	3,525,000	2000		2000	120	N/A
South Western District (Roma)	2,802,343	2,612,386	4198		4198	95	N/A
Southern District (Toowoomba)	4,429,232	4,184,000	3118		3118	86	N/A
Border District (Warwick)	3,049,710	2,643,269	2430	240	2670	150	N/A
North Coast Hinterland District (Gympie)	12,050,106	2,828,000	1158		1158	150	N/A
Metropolitan District (Brisbane)	29,964,906	12,904,390	1140		1140	280	N/A
South Coast Hinterland District (Nerang)	2,202,661	1,502,240	1000		1000	130	N/A
Total	111365974	67191285	32691	1477	34168	1819	N/A

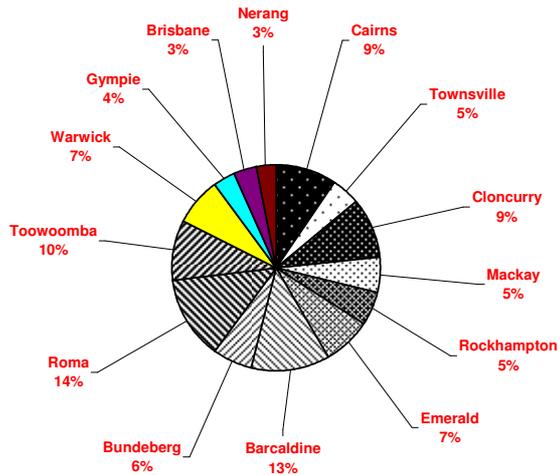
N/A - Not Available

Table 4.1

Subsidy Allocations

Figure 4.3 shows the QDMR subsidy allocations for periods of 2007-2008 and 2008-2009, in each district in dollar value, while figure 4.4 is a graphical presentation of the comparison of the above funds. As per the above graph, maximum amount of funds is allocated to Queensland capital city, Brisbane while the next allocation is to Cairns district for the 2007-2008 periods. In 2008-2009 periods, Cairns will receive the highest amount of funds for road construction projects. This information is very important when discussing the possible future VRS expansion in the chapter 5.

Figure 4.2
State Roads in Each Main Road District



Main Roads - Projects Susidy Allocations 2007-2008 & 2008-2009

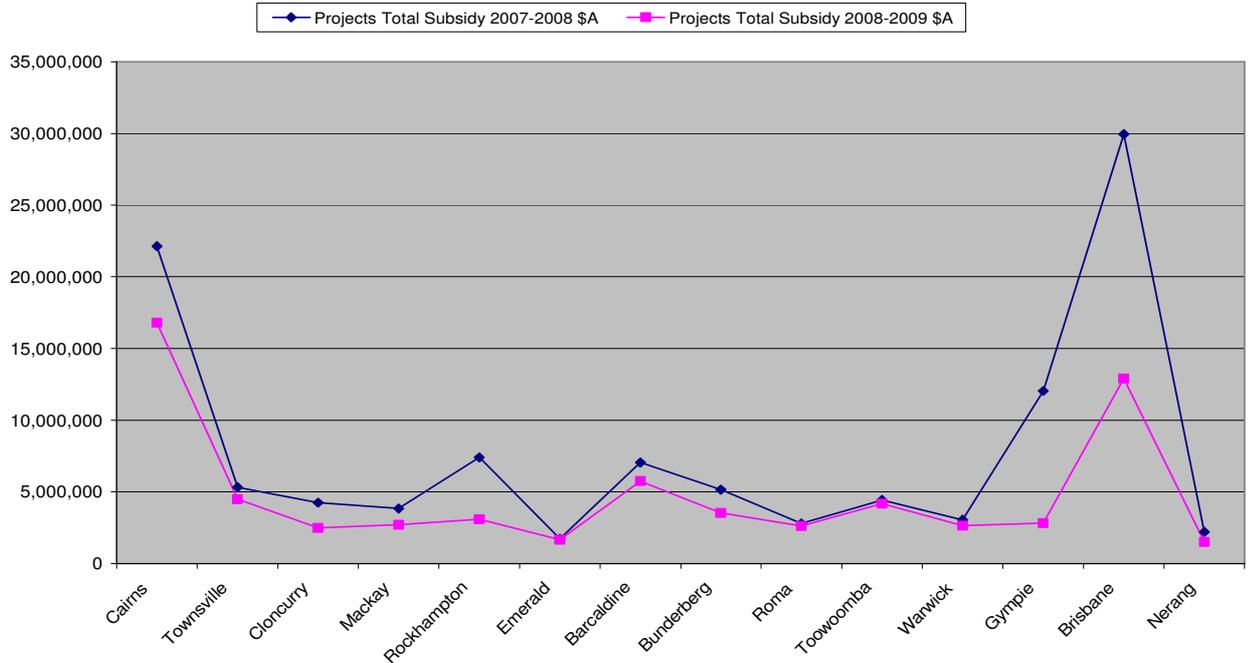


Figure 4.3
Project Subsidy Allocations

4.5 Durations of the QDMR projects.

Although, the subsidy allocations for 2007-2008 and 2008-2009 periods are considered here, to highlight and discuss the research topic, it is noted that, there are many other road projects, which extend beyond this time frame. Some of the projects are expected to be completed within this time limit, while the others will continue for few more years. The important fact here is that, most of the QDMR road projects are planned, at least for one or more years. For example, 28million budget, 180km long, Burke developmental road upgrade in north western district (Cloncurry) has to be completed in four years. Details in the figure 4.4 also reveal that 2007-2008 period is more important, than the 2008-2009 periods, because the majority of funds are allocated in the first period than the next, as per the graph.

With respect to the durations of the projects, it can be basically categorized into two major groups.

- Long term projects (1 year or more)
- Short term projects. (less than 1 year)

What is the significance of the durations of the projects, when establishing a VRS CORS network? Why do we have to consider long term as well as the short term projects when preparing the recommendations of future GPS infrastructure needs? Answers to these questions will be adequately discussed in chapter 5, with relevant to the research topic.

4.6 Case Study – Business Case, Option B, Ipswich Motorway, Alternative Northern Corridor

This project report was used as a guide, to obtain the costs for earth work, in a typical road construction project, in relation to the total budget. These values were then used, to calculate some potential benefits for VRS expansion under the business case. Project Support has been prepared this report for Maunsell Australia Pty Ltd, to provide the likely costs, for the Ipswich Motorway Alternative Northern Corridor,

option B, for inclusion, in the Business Report. This estimate has been prepared for 10.4 km long road section and the associated, earth works activities. Cost for each activity is listed, as per the following Table 4.2 (QDMR 2007).

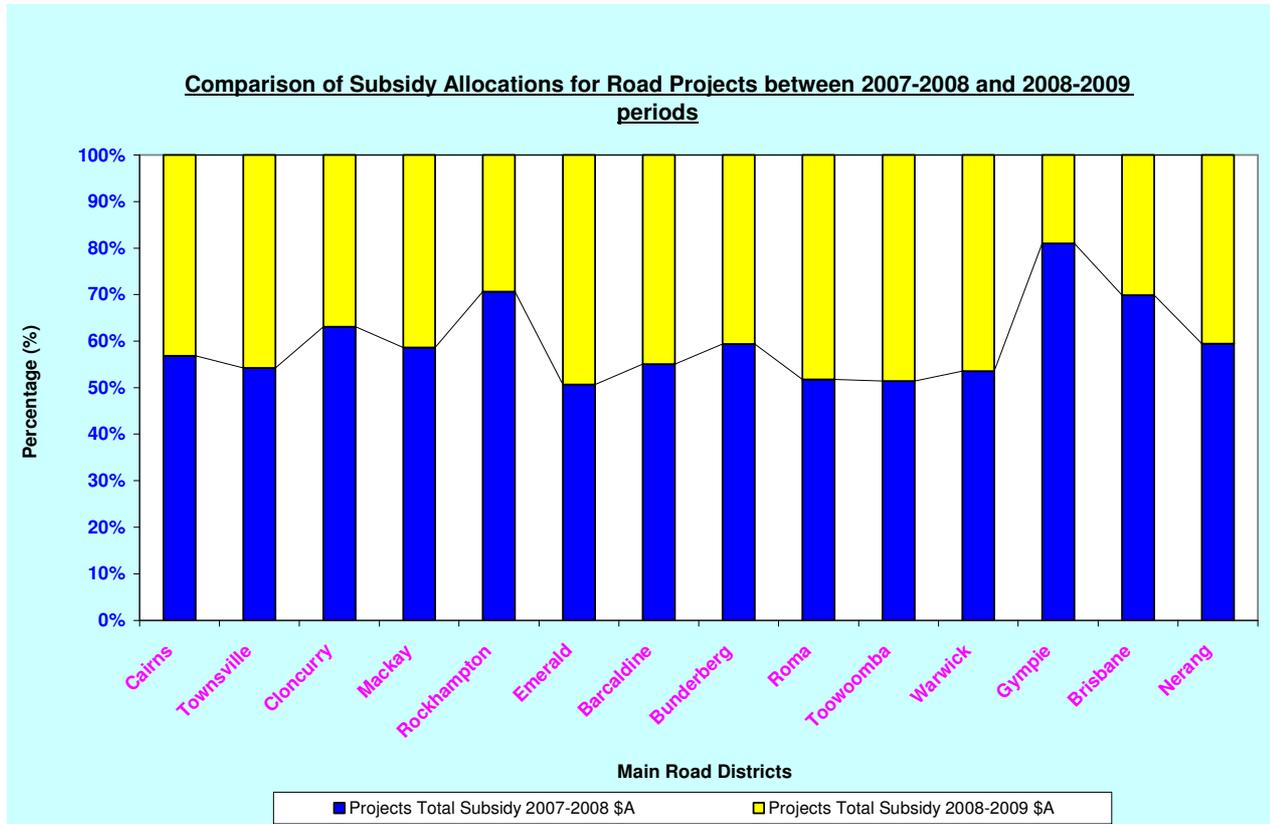


Figure 4.4
Comparison of Subsidy Allocations

4.6.1 Case Study - Back ground

As part of this project, one of the major research approaches was to prepare a business case, to highlight the importance of the GPS usage on machine guidance instruments. When preparing the business case, it was necessary to obtain the, realistic and current values, to calculate the general construction costs for earth work. If, there were several examples to choose, a mean value for construction costs and more reliable results could have been obtained.

Earthworks	Cost (\$)	Percentage (%)
Clearing	909,900	
Preparation of Natural	1,824,163	
Cut	8,419,761	
Fill	15,737,020	
Imported Fill	28,841,289	
Cut to Spoil	-	
Sub grade Trim	579,099	
Geotextile	-	
Rock Fill (Unsuitable)	-	
Landscape	19,479,158	
Ground Treatments	91,360,626	
Total	167,151,016	7.49%
Construction Total	1,086,234,292	48.68%
Total Project Cost	2,231,241,303	100.00%

Table 4.2
Construction Costs of a Typical Road Project
(QDMR 2007)

However, during this research work, it was decided to use a general value as an indication, from one of the construction projects. It was anticipated that, the values extracted, from the project report, as shown in the Table 4.2 was accurate enough to generate a suitable business case. There are many activities fall under earthworks, as listed in the following table. Although, the machine guidance technology may not be used in each and every activity, it is assumed that, majority of tasks can be undertaken by the method.

4.6.2 Case Study - Summary

The figures in Table 4.2 illustrated that, the cost of earthworks, in this particular job, was about 7.49% of the total budget of the Project. For calculation purposes, this value was rounded off and accepted as 7.5%, later in this project. The above costs

were estimated, assuming that the normal construction techniques are adhered. Further, the above values should be adjusted to match, the situations where, GPS machine guidance equipments have been used to carry out the earthworks.

4.7 Business Case

The above case study, verified the relationship between the costs of earthwork, to the total budget of a construction project. Recently, it is revealed that, the Road Implementation Program (RIP), marks a record of A\$13.3 billion spend on Queensland roads in the next 5 years. Based on the percentage of 48.68% for construction costs, in the above example, approximately A\$6.5 billion of funds to be spend as construction costs in the RIP program, while nearly, A\$1 billion is expected to be spend on earthworks only. These are massive amount of funds, planned to be spend on road construction projects, within the next five years. Also, results from the observations in Section 4.3 suggested that, VRS expansion may be possible in the coastal line from Nerang up to Mackey including, Toowoomba, Warwick and Emerald districts in Queensland, due to the density of the construction projects in these areas. Considering the above facts, it is paramount to generate a business case, to prove the cost/benefit analysis.

4.7.1 Cost/Benefit Analysis

This cost/benefit analysis has been prepared, to confirm the cost savings, from the total budget allocations in QDMR, from 2007 to 2009 period, provided that, new GPS infrastructure have been established, to support the existing stations. At first, it was assumed that another 20 new VRS CORS network stations have been established, to expand the current network, as explained in chapter 3.

Although, several assumptions have been made here, to emphasize the business case, the possible VRS expansion still need to be planned, and the new locations of the control stations yet to be decided. The values used here are approximate figures,

obtained from the various reliable sources of information, as explained in section 3.2. Also, the values shown in the calculation sheets are annual costs and charges.

Cost/Benefit analysis for GPS infrastructure expansion

At present, there are four VRS stations running under Sunpoz Net work in south east Queensland. Figure 4.1 indicated that, another 9 stations are required, if main road districts at south east Queensland, are considered as the locations for new stations. Out of these 9 stations, the VRS station at Brisbane is already established under Sunpoz Net work. That means another 8 stations have to be established just to serve these areas, despite the mathematical, distance, accuracy and other technical requirements of the network. The expected locations for balance 12 new stations can be selected as necessary to fulfill the above network requirements, after thorough investigations. The local government townships such as, St. Lawrence, Mariam Vale, Duaringa, Nandebbera and Dalby between the major towns can be considered as some of the other stations due to the full area coverage, as shown in red circles on the map. Australian Fiducial Network stations and the proposed Australian National Network stations should also be considered, when selecting the new locations for new GPS infrastructure.

Example 1;

Example 1, explain a situation where, earthwork costs only, is used to calculate the cost/benefit analysis.

This example illustrates a situation, where 20 new VRS stations have been established, to serve the GPS machine guidance instruments, in the construction projects associated with QDMR. It was expected that, at least 4 license agreements have been received, from the other users, annually.

As per the Table 4.1, the total value of the construction projects in the above 9 districts is A\$ 113,227,471, for 2007-2008 and 2008-2009 periods.

<u>Costs:</u>	<u>A\$</u>
Establishment costs / per station	
Base station equipment initial cost	125,000

(Note: This amount may vary depending upon various factors, such as instrument type, or the model etc ;)

On going costs

Rent/Lease, part of a building as the office space: -	13000
= (A\$250 x 52weeks)	
Station maintenance costs,	16000
(Computers, Electricity, Administrative costs etc :)	
Extra costs, (Security other issues etc :)	2000
Sub total	31,000
Depreciation value of the equipments/per year	12,500 = 125,000/10
(Assumed that instrument's lifetime is 10 years)	
Total estimated costs per station/per year	43,500
Total cost to run 20, VRS stations/per year	870,000
= (43,500 x 20)	

Benefits

Annual License for accessing a VRS CORS Network: -	600,000
= 7500 x 4 x 20	
(Assumed, at least 4 license agreements per station or area, are received)	
Cost savings by using GPS machine guidance instruments	424,603
Cost/Productivity gains from earth work	
(Refer to schedule A, Part A below)	
Total gains	1,024,603
<u>Cost/benefit ratio (using earth work costs savings)</u>	870,000: 1,024,603
(To establish and maintain, 20 VRS Network stations)	1: 1.17
Actual savings in \$ value	154,603
Savings per station/per year	7730 = 154,603/20

The cost/benefit analysis based on the above assumptions, confirm that there is a potential for VRS expansion in south east Queensland. Although, the GPS usage on machine guidance on construction projects associated with QDMR is considered here to demonstrate the above argument, there are many other users who could be benefited, with a new VRS network. These users and their usage will be adequately discussed in the chapter 5.

Example 2:

Example 2, explain a situation where, construction costs only, is used to calculate the cost/benefit analysis.

The calculations below indicate that, cost/ benefit ratio in this situation is 1: 3.85, which is about A\$ 124,297 savings per station.

Benefits

Annual License for accessing a VRS CORS Network: - 600,000
 = 7500 x 4 x 20

(Assume, at least 4 license agreement per station or area are received)

Cost savings by using GPS machine guidance instruments **2,755,956**

Cost/Productivity gains from construction work

(Refer to schedule A, Part B below)

Total gains 3,355,956

Cost/benefit ratio (using construction costs savings) 870,000: 3,355,956

(To establish and maintain, 42 VRS Network stations) **1: 3.85**

Actual savings in \$ value 2,485,956

Savings per station/per year 124,297

= 2,485,956/20

Schedule A

Part – A

Total budget for QDMR projects, 2007-2009 period 113,227,471

(Refer to Table 4.1)

Expected costs for earth work	8,492,060
<i>Refer to Table 4.2, (7.5%, for earth work)</i>	
Cost for earth work only/per year	4,246,030
Productivity gains by GPS machine guidance usage	424603
<i>Cost/Productivity gains from earth work (10% gain as minimum)</i>	

Part – B

Expected costs for construction work	55,119,132
<i>Refer to Table 1.1, (48.68%, for construction work)</i>	
Cost for construction work only/per year	27,559,566
Productivity gains by GPS machine guidance usage	2,755,956
<i>Cost/Productivity gains from construction work (At least 10% gain)</i>	

These results stated the minimum level of cost savings, calculated by using the 10% productivity gains from GPS machine guidance usage, for a possible VRS expansion. As mentioned in chapter 2.5.4, if 30% to 50% productivity gains can be obtained from the projects, by using GPS machine guidance in a VRS environment, the savings from the above examples will be increased, relatively.

The above calculations also revealed that, it is beneficial to expand the VRS CORS network from its current coverage, to provide control for, GPS machine guidance for the construction projects, associated with the QDMR in south east Queensland. In this calculation, it was assumed that, at least 4 licenses per station were obtained, from the other users. The other alternative is to recover the additional costs of \$30,000 per station, through national funds.

However, DNRM is responsible for establishing and maintaining, the GPS control network in Queensland. The above example is based on the construction projects associated with the QDMR, only. There are many other users, who can still be

benefited, with a new GPS VRS network. Therefore, Identification of these potential users and their usage is another open issue.

4.8 Conclusions: Chapter 4

This chapter focused on the actual results obtained from the research methods. Three main research methods were followed as explained in the chapter, and the results and the findings were included. Results showed that multiple solutions should be adopted, when establishing the GPS infrastructure in Queensland depending upon each circumstance. Areas, where dense construction projects located, are suitable, for future VRS expansion while, the areas with scattered construction projects would rather still be benefited of using stand alone GPS systems, for the construction projects. However, there are other districts, where implementation of series of nodes or a clustered net work is suitable.

Chapter five will focus and discuss the results, alternative solutions and implications. Also, further research and recommendations based on the findings in this research will be discussed in the next chapter.

CHAPTER 5

DISCUSSION AND IMPLICATIONS

5.1 Introduction

Chapter Four provided the observations about the density patterns of the QDMR projects in Queensland, the results of cost/benefit analysis and the out come of the business case. This chapter will analyze the reasons for these results and further discuss the implications and conclusions.

The aim of this chapter is to discuss the achievements of the research study, applications and its usefulness. Further, this chapter will discuss the results, alternative solutions and implications. In addition to all above, explanation of discrepancies, contradictions and inconsistencies will also be considered in the chapter.

The results obtained in chapter four will be linked with the original aim of the research project, to justify the achievements. Up to what extent the results relate to the main research topic? Is VRS method is suitable for Queensland? Is it beneficial to expand VRS coverage to allow QDMR to use machine guidance and control on construction projects? Should VRS Network be used or use stand alone bases? Who should be responsible for expansion of the network? Answers to these questions will provide a comprehensive understanding of the research study.

5.2 Discussion

This research study confirmed that, VRS expansion from its present coverage in to other areas in south east Queensland is valuable and justifiable. The aim of this research was to investigate, GPS usage on machine guidance and control for, construction projects associated with the QDMR, in order to make recommendations

on future infrastructure needs with respect to a possible VRS expansion. Results also, attested that, it is beneficial to expand VRS coverage to allow, QDMR to use machine guidance and control on construction projects. This is a very important achievement from this research study.

This research study not only confirmed the possible VRS expansion in south east Queensland, but also, revealed that, VRS expansion is not suitable for the areas with a large area extent and scattered QDMR projects. VRS expansion beyond the areas discussed under section 4.3 is not economically viable at present, due to several reasons. These reasons can be identified as, low density, short term QDMR projects, unidentified users, establishment and maintenance costs, security issues and etc. Also, considering the districts and the areas in the north, central and western Queensland, with long term QDMR projects and considerable amount of budget allocations, a series of nodes (independent net work) approach may be applicable. A clustered network system, which is similar to the one discussed under chapter 2.4 in Minnesota in United States, is preferred in these situations. This approach is also suitable for districts such as Cloncurry with a huge budget of A\$50 million worth of long term construction projects and, Roma district with A\$54.8 million worth of projects.

GPS usage for machine guidance and control in the construction projects associated with QDMR is currently, at a very low profile, as reviewed in chapter two. Unavailability of affordable GPS infrastructure is a major issue that needs to be addressed, immediately to solve the above problem. Attributes in sections 4.7 and 4.7.1 demonstrated, cost savings can be achieved, by using the GPS machine guidance in a VRS environment. Therefore, QDMR, may consider the results, and incorporate these, to develop strategies, in order to improve and enforce GPS machine guidance usage in their construction projects. Although, an expected outcome within two years time, were considered in the example to calculate the cost savings, it will be much higher, if a longer period is selected. Therefore, it is important to use, GPS machine guidance instruments in the construction projects associated with QDMR, in a VRS environment.

Attributes of results discussed under section 4.5, 4.6 and 4.7 are further highlighted in sections 5.2.1 and 5.2.2. as interpretations and alternative solutions.

5.2.1 Results/Interpretation

The past researches have confirmed, the productivity gains, and cost savings, can be achieved, from the usage of GPS machine guidance instruments, in the construction industry, as extensively discussed in the chapter two. Geographical locations of the QDMR projects pointed out, the requirement of new GPS infrastructure in Queensland. Further study about the spread and the density of the QDMR construction projects in Queensland, suggested that, there should be multiple solutions or approaches to address the problem of establishing the future GPS infrastructure. Districts with large area extents and sporadic projects, rather still be benefited of using stand alone systems, because the investment of establishing the GPS infrastructure cannot be justified, whatsoever. However, it was observed that some areas may have the potential of establishing series of nodes, due to the amount of funds allocated, and the project duration concerns.

One of the most important findings in this research study was the possibility of VRS expansion in the south east region in Queensland. Results from example 1 and 2 highlighted that, at least A\$124,300 approximately, can be saved per station, annually, if the existing VRS network is expanded in to the other areas in south east Queensland, considering the QDMR situation only. The subsidy allocations, under RIP in QDMR for the next five years, in combination with the above business case designated that, extension of VRS network in the eastern coastal area from Nerang up to Mackay is a best option at the outset. Extension of the network beyond Mackey has to be implemented, in stages according to the demands in the future.

Primarily, small townships between, these major towns, can be selected as the other locations for the network stations. As shown in red circles in Figure 4.1, the following local government areas can be selected as the other locations to establish the VRS stations. The local government areas such as, Dalby, Mundubbera, Mariam Vale, Duringa and St Lawrence can be identified as the other areas, due to its geographical location between the major districts. There are other benefits of selecting these small towns, as the VRS network locations. Local community participation and contribution

in the technology, low maintenance costs of the structures, mining and farming sector involvement, fast and efficient delivery of services to the local areas are some of the advantageous of selecting these small townships, as the locations of the new GPS infrastructure. Basically, five of these local government locations (as shown in red), along with the six or seven other stations should be implemented at beginning of the VRS CORS expansion. However, selecting the exact locations, within these areas will be a task, which has to be carried out by all the parties. Involvement of many organizations, in this process may enable to justify the needs, rather giving only an administrative approach to the process.

Considering the QDMR situation, a possible VRS expansion can be implemented in the south east Queensland. Districts such as Nerang, Brisbane, Gympie, Bunderberg, Rockhampton, Mackey, Emerald, Toowoomba and Warwick can be included, in the list. Roma, Cloncurry and Cairns districts would be benefited, with a clustered GPS network or series of nodes. Also, some areas in these districts still need to use stand alone systems. Example: Weipa in Cairns, Normanton in Cloncurry and Quilpie in Roma District.

All the above suggestions have been made, based on the present and future QDMR projects, listed under RIP program. However, QDMR situation can be extrapolate in to other sectors to find out whether there are alternative solutions. Section 5.2.2 will discuss these in detail.

5.2.2 Alternative Solutions

Section 5.2.1, revealed, GPS infrastructure developments in Queensland can be implemented by multiple methods. Among these proposals, the major development was the novelty of the VRS expansion in the south east Queensland. However, VRS expansion in the south east corner again, could be split in to 2 stages. Careful consideration into the figure 4.1 showed that, a triangle joining the districts of Mackey, Rockhampton and Emerald can run as another independent network, while all the

other districts in the south east region, still connected in the VRS expansion. This may allow implementing the VRS expansion in stages, so that, all these areas can be joined at a later stage.

Although, QDMR situation is considered in this research, to find a persuasive answer to the possible VRS expansion, it is noteworthy to consider the other users as well. Who are the other users of GPS infrastructure? Government organizations such as Queensland Railway, Queensland Health, Local Government organizations within the region, mining companies, farmers and general public can be identified as the other main users. All these potential users and their expected usage may have a huge impact, on the VRS expansion. Specifically, mining industries in the region already have, their own stand alone GPS systems established, as highlighted in the literature review. Integration of these systems into the proposed network, while gaining their support will be an alternative solution for future VRS expansion.

Existing Australian Fiducial Network (AFN) station at Townsville and the proposed Australian National Network (ANN) stations at south east corner of Queensland will have an immense impact on the future VRS expansion in south east Queensland. It was recently revealed, that AUSPOS will establish these station in the Queensland, as part of the national network. With comparison the figure 4.1 to figure 5.1, it can be noticed, the proposed stations under ANN are mostly, close to the selected stations under this research project for future VRS expansion, by considering the QDMR perspective.

Therefore, proposed ANN stations will undoubtedly, strengthen the future VRS expansion. This means QDMR only need to establish few more stations to fill the gaps between the ANN stations.

VRS expansion incorporating the ANN and AFN stations should be originated by QDMR in consultation with DNRW, as the responsible authority for geodetic infrastructure developments in Queensland. QDMR should initiate the task of future VRS expansion, with the help of all the parties, including the other government organizations, private sector companies, universities and the potential GPS users, under direction of DNRW.

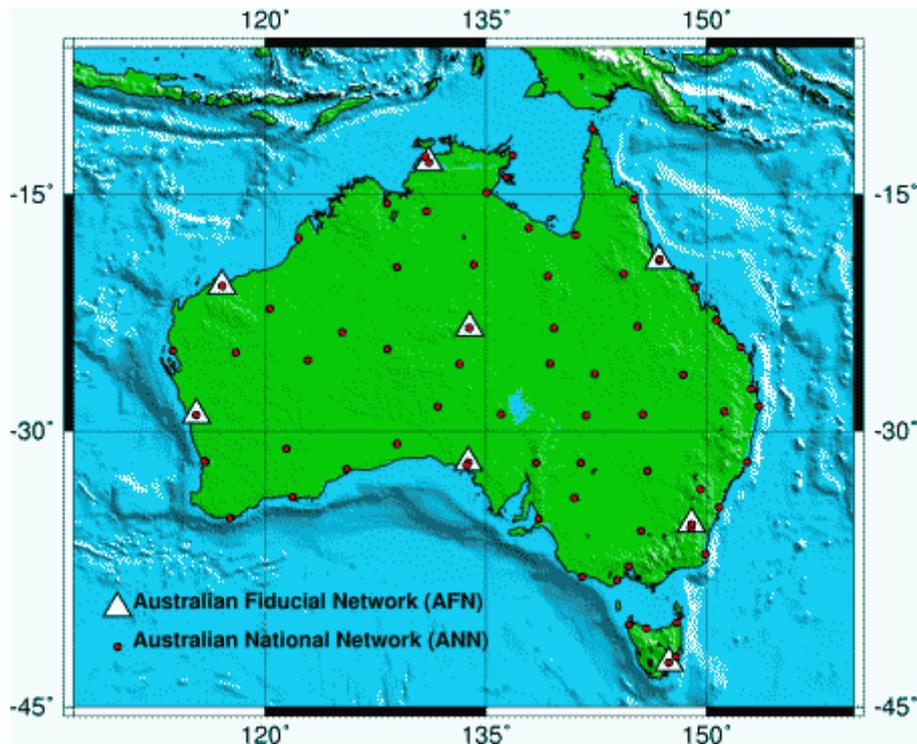


Figure 5.1

Proposed Australian National Network (ANN)
(Geoscience Australia 2007)

What are the implications of this research study, on future GPS infrastructure needs in Queensland? Appropriateness of this research study, to the research profile will be compared in section 5.3.

5.3 Implications

The interpretation of results in section 5.2.1, explained, the relationship between the multiple approaches of GPS infrastructure developments in Queensland, in QDMR perspective. QDMR situation was extrapolated and applied, to other prospective users, in the section. Alternative solutions to the VRS expansion in south east Queensland, were highlighted in section 5.2.2. The implications of the results/findings to the research profile are further explained in this section.

GPS net work systems, and the VRS CORS systems in the world, and Australian contexts were discussed, in sections 2.4 and 2.5. The results from this research project, revealed that, there is a potential of VRS expansion in south east Queensland. Specifically, this can be displayed as an extension to the existing Sunpoz network, in Queensland. Details elucidated in 2.5.4, directly link with the new results for VRS expansion.

The triangle of proposed VRS network connecting, Mackay, Rockhampton and Emerald, explained in section 5.2.2 can be compared with the system similar to the Perth Network. As stated in section 2.5.3, this system has been set up by a private company. There are many mining and farming communities in the above region, as per the details from the Australian Bureau of Statistics. Most of these companies, may have already established, GPS infrastructure to support their projects. Integration of these networks, to the proposed future infrastructure, would be an enhancement to the program. Also, Independent GPS networks should be implemented in the Districts such as Cairns, Roma and Cloncurry, with the involvement of private sector, similar to the networks elucidated in section 2.4.

Importance of using GPS machine guidance instruments in the construction projects associated with QDMR was highlighted in section 4.7; to the details elucidated in section 2.7.5.

5.3.1 Categories of GPS Network Developments in Queensland

This research study confirmed that, there are multiple solutions to the research problem. VRS expansion is not suitable for each and every part of Queensland. Therefore, results from this research study can be summarized in to three main categories of GPS infrastructure developments in Queensland.

- 1) VRS expansion preferred, or establishment of a new GPS net work is suitable.
- 2) Series of nodes or clustered GPS net work system preferred.
- 3) Only stand alone GPS systems are suitable.

5.4 Further research and recommendations

The revelation of a possible VRS expansion in south east Queensland was the successful outcome from this research project. Also, the results, suggested that multiple approach of GPS infrastructure developments should be carried out in Queensland. It is beneficial, for QDMR to use GPS machine guidance instruments in their construction projects under VRS environment. Who else will be benefited by using this infrastructure? Whether mining, agriculture and other companies will be benefited from such a system? Basically, further research should be carried out to assess the other users and their potential usage of proposed GPS infrastructure.

Design of a GPS network in Queensland, will be another major task that follows. Although, this research project considered, the QDMR situation to assess a possible VRS expansion in Queensland, other users and their potential contribution should also be assessed, before designing a net work. However, recommendations based on this research will be useful, for assisting the decision making, on establishing GPS infrastructure needs at government level. Some of the recommendations from the research are listed as follows;

- 1) Currently, VRS expansion is only suitable for a limited area, as per the project, where the investment can be justified. Main road districts, where VRS expansion is suitable is listed in Table 5.1
- 2) VRS expansion in south east region can be implemented in stages. Areas connecting, Nerang, Brisbane, Gympie, Bundaberg, Toowoomba and Warwick as stage 1, while Rockhampton, Mackay and Emerald districts as stage 2.
- 3) Districts with significant investments, and long term construction projects, need to be provided with independent networks, with 3 minimum stations each or more. These districts are listed in the Table 5.1
- 4) Stand alone systems are the only other option for the rest of the areas, unless private sector involvement or/and additional funds are available from the government to establish new net works.

Main Road Districts	VRS expansion suitable	Independent Network preferred	Standalone Network desirable	Proposed ANN stations	Existing AGRN stations	Existing Sunpoz stations
Cairns		√	√	√		
Townsville		√	√	√	√	
Cloncurry		√	√	√		
Mackay	√	√		√		
Rockhampton	√	√		√		
Emerald	√	√				
Barcaldine		√	√	√		
Bundaberg	√			√		
Roma		√	√	√		
Toowoomba	√					
Warwick	√					
Gympie	√			√		
Brisbane	√					√
Nerang	√			√		

**Table 5.1
Recommendations on future GPS Infrastructure Developments in Queensland**

- 5) When designing the networks, the existing stations such as ANN, Sunpoz, ARGN stations should be incorporated in to the design.
- 6) Small townships between the major districts should be selected as new locations, to provide the full area coverage, distance and other technical requirements of a GPS network.
- 7) DNRW as the responsible authority should provide controls for Queensland, in consultation with QDMR, QR, mining, Agriculture and other users.

- 8) Appointing a committee or a commissioner to regulate the activities, may be useful.

Table 5.1 is a summary of GPS infrastructure requirements, and present and proposed developments in Queensland. This information state that, most of the infrastructure developments are planned in the main road districts. This will enable more funds to be invested on locations between the major towns. Establishing more VRS stations in the townships, between these major districts will provide the full area coverage for GPS machine guidance usage in the construction projects.

5.5 Conclusions: Chapter 5

This chapter described the achievements of the research study, applications and its usefulness. Critical reviews of evidences were given to show that, the outcome was directly related to the aim. Sections 5.2.1, 5.2.2 and 5.3 explained the interpretation of results, alternative solutions and implications in the research study.

Further research openings from the current project, and the related research options were discussed in the chapter. Future recommendations based on the project were listed, along with the findings as a table of information.

CHAPTER 6

CONCLUSIONS

6.1 Introduction

Chapter five discussed, the results obtained in the test regime. This chapter provides a summary of outcomes in the research project. This research was undertaken to investigate the GPS usage and machine guidance in the construction projects associated with QDMR, to give recommendations for future infrastructure needs. It investigated the QDMR projects, and the GPS usage on machine guidance in QDMR projects. Further, this project investigated the locations, budgets and durations of the projects to prepare recommendations on future infrastructure needs.

6.2 Conclusions

The aim of this research was to investigate GPS usage on machine guidance and control for construction projects associated with the QDMR in order to make recommendations on future infrastructure needs, with respect to a possible VRS expansion. Literature review in chapter two stated the past and current knowledge of the similar research carried out in Australia and around the world. An appropriate research method was developed to achieve, a successful outcome to the project, and the method was adequately explained in chapter three.

Three main research approaches were designed in the project, and the results were included in chapter four. Collected information about the QDMR projects were approximately plotted on a map, and further data analysis were carried out. Data patterns with respect to geographical locations, spread and density, budget allocations and the durations of the projects were analyzed, to find out a clear suite of evidence to prove the research. A case study was carried out as the second research method. This

was a simple task of data investigation about a typical construction project, to obtain the costs associated with general construction projects. However, this information was valuable in the third research method, because, it provided the percentage values for further calculations. If, these values were obtained by comparing the actual figures from several projects, it could have been a more realistic value. However, access to this information was not quite possible from the available data resources. Cost/benefit analysis and the associated Business Case demonstrated that, it is beneficial to expand VRS coverage to allow QDMR to use machine guidance and control on construction projects. Results not only demonstrated that, the VRS expansion is possible in the south east region, but also, suggested that multiple options should be adopted when establishing GPS infrastructure in Queensland. VRS expansion is suitable for the main road districts with high density of construction projects, while other areas may provide with either, independent GPS networks or use stand alone systems.

6.3 Possible Further Research

Chapter 5.4 demonstrated the recommendations of this project, and the possibilities of further research work. Further, research work relate to this project is mentioned in this section. Although, QDMR situation has been considered in this research project to give the recommendation about the future GPS infrastructure need in Queensland, it is important to consider the other potential GPS users, as well. Investigations and the research work in this area will help for decision makers to develop the strategies for future infrastructure developments in Queensland.

Designing a GPS VRS network is another major task, which has to be based on the recommendations of several research works of all the potential users. Therefore, design of this network can be highlight as another area of further work.

6.4 Summary

This research work revealed that, it is beneficial for QDMR, to use GPS machine guidance and control in their construction projects. The important finding in this research was that, there is a potential for VRS expansion in south east Queensland. Also, the research work revealed that multiple solutions should be adopted depending on the individual circumstances, when establishing the future GPS infrastructure in Queensland.

BIBLIOGRAPHY

Apsystems 2003, *Benefits of GPS Machine Guidance on Dozers, Automated Positioning Systems*, March 2003, viewed on 11 May 2007.
<http://www.apsystems.com.au/Downloads/Technical%20Papers/MachineControlDoz.pdf>

Baker, H. *Machine Guidance, A2002 update*, viewed on 20 August 2007,
<http://www.positioning.com.au/MM/content/2002/MM19/feature/MM19_feature.html>

Brownjohn, K. (2006): '*Electronic Surveying at Paradise*', RoadTek, Main Roads News letter, pp 2-4.

Cislowski, G. & Higgins, M. (2007): '*Sunpoz enabling centimeter accuracy GNSS applications in Queensland*', Spatial Sciences Queensland, May, pp 30-34.

Clucas, J. (2006): '*Perth Network Established*', POSITION, No 25, October-November, pp 65-66.

Fairall, J. (2003): '*Navigation by Satellite*', POSITION, No 5, June, p 59.

Finner, L. (2003): '*The challenging face of location information*', POSITION, Vol: No 4, April-May, pp 43.

Gordini, Cristian, K. Allison N. Grgich, P. Martin J. (2006): '*A performance analysis of sparse GNSS CORS network for real time centimetric level positioning*', *A case study in Victoria, Australia*.

GPS infrastructure and GIS, Technology & More, Issue (2006):- February, p 13.

Jonsson, S. (2000): *'The impact of advanced machine guidance on productivity in earthwork'*. University of Washington in Seattle, WA.

Jonsson, S. Dunston, P. Ahmed, K. and Hamilton, J, *Factors in Productivity and Unit Cost for Advanced Machine Guidance*, viewed on 27 August 2007.
<http://www.dot.state.mn.us/tecsup/files/pdf/mc_unit_costs.pdf>.

Kinlyside, D.A. & Tan, T.A. (2005): *'SydNET- 'First Results'*. Association of Public Authority Surveyors Conference, March 2005.

Leica 2007, *'GPS Machine Guidance, Productivity in Land Reclamation at Surface Mine*, viewed on 15 September 2007. <<http://www.leica-geosystems.com>>.

Main Roads, 2007, *Projects, Maps and Publications*, viewed on March-October 2007,
<http://www.mainroads.qld.gov.au/web/global.nsf/SITEMAP?OpenForm>
<<http://www.mainroads.qld.gov.au/MRWEB/Prod/Content.nsf/DOCINDEX/Proj>>

McGowan, S. Ohio, *DOT's VRS Network, Building the Nation's First statewide RTK GPS Infrastructure*, viewed on 27 August 2007
<<http://www.profsurv.com/archive.pup?issue+95&article+1341>>.

Millner, J. Asmussen, H. (2007): *'Network Corrections'*, POSITION, No 28, April-May, pp 58-60.

Paul, G. (2007): *'Organizing GNSS'*, POSITION, No 27, March, p 43.

Rizos, C. Yan, T. Omar, S. Musa, T. Kinlyside, D. *Implementing Network – RTK, the SydNET CORS Infrastructure*. Paper presented at the 6 th International Symposium on Satellite Navigation Technology Including Mobile Positioning and Location services, viewed on 13 August 2007,
<http://www.gmat.unsw.edu.au/snap/publications/rizos_etal2003a.pdf>

Seymour, C. (2003): *Automated Positioning Systems, GPS Machine Guidance in the Mining Industry*, Paper submitted for 12 th International Symposium on Mine Planning and Equipment Selection (MPES) 2003, held on Kalgoorlie, 23-25 April viewed on 15 June 2007. <[http://www.apssystems.com.au/Downloads/Technical %20Papers/MachineGuidanceMiningIndustry.pdf](http://www.apssystems.com.au/Downloads/Technical%20Papers/MachineGuidanceMiningIndustry.pdf)>.

Sherman, L. Chen, A. Enge, P. Gao, G. Akos, D. (2006): '*Images and spectral signatures of the New GNSS signals*', Inside GNSS, GPS/Galileo/Glonass, May June, p 46-55.

Technology, (2007): Spatial Sciences Queensland, January, pp 39.

Thomas, L. (2003): '*Geonet watches sharks*' POSITION, No2, Dec-Jan, pp 23.

Trimble 2007, '*Enabling productivity through innovations*', viewed on 15 September, <www.trimble.com/index.aspx>.

Trimble 2007, *Trimble Terramodel*, viewed on 15 September 2007, < <http://www.geocomp.com.au>>.

Trimble 2007, *Trimble VRS, What's the Bottom Line?* viewed on 18 th may 2007. <[http:// trimble.com/docushare/dsweb/Get/Document-287606/T&m_0305_VRSBottomLine.pdf](http://trimble.com/docushare/dsweb/Get/Document-287606/T&m_0305_VRSBottomLine.pdf)>

Appendix A.

Project Specification

University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

ENG4111/4112 Research Project
PROJECT SPECIFICATION

FOR: *Nawanandana Chandrasiri Liyanawaduge*

TOPIC: GPS usage and infrastructure needs for machine guidance and control in the construction projects associated with the Department of Main Roads, Queensland.

SUPERVISOR: Mr. Peter Gibbings

SPONSORSHIP: Faculty of Engineering and Surveying, USQ.

PROJECT AIM: This project seeks to investigate, GPS usages on machine guidance and control for construction projects associated with the Dept of Main Roads in Queensland in order to make recommendations on future infrastructure needs.

PROGRAMME: (Issue B, 14th April 2007) – Amendments

- 1 Research the background information on different types of GPS systems. What they are being used for, and where they are being used, including GPS machine guidance instruments for construction projects associated with the Dept of Main Roads.
- 2 Identify the current issues with regard to the GPS usages on machine guidance. Issues such as data availability from the existing base stations, different type of GPS usages, cost of data, accuracy and the reliability of data.
- 3 Past, present and project future GPS usage on machine guidance and control in the construction projects associated with the Main Roads, Queensland.
- 4 Assess the importance of installing infrastructure for future construction projects in the Main Roads, Queensland. Extrapolate the Main Road situation to make assumptions on the general construction industry.
- 5 Prepare recommendations which will be useful for assisting the decision making for installing infrastructure needs at government level.
- 6 Prepare a dissertation to suitable standard.

AGREED N.C. Liyanawaduge

Date: 14 / 04 / 2007

Date: / / 2007

Co-examiner: _____

QDMR Road Projects

APPENDIX B1

Location or District	Project Name	Description
Northern District (Townsville)	Bruce Highway upgrade	Bruce Highway Upgrade
	North of Townsville	North of Townsville
	Bruce Highway upgrade south of Tully	Bruce Highway Upgrade
	Gregory Developmental Road	Gregory Developmental Road
	Hervey Range Road	Hervey Range Road
	North Ward Road	North Ward Road
	Ring Road	Ring Road
	Ring Road Section 1 (Douglas Section)	Ring Road Section 1 (Douglas Section)
	Townsville Port Access project	Linking the Flinders and Bruce Highway to the Port of Townsville
North Western District (Cloncurry)	Burke Developmental Road Upgrade	Burke Developmental Road Upgrade
	Flinders Highway (west of Charters Towers to Cloncurry)	Flinders Highway
	Gilbert River Bridge (Burke Developmental Road)	Gilbert River Bridge
Peninsula District (Cairns)	Endeavour River Bridge	Construction of new higher level bridge over the Endeavour River at Marton on the Endeavour Valley Road.
	Kennedy Highway upgrade	Mt Garnet to Three ways (Forty mile Scrub) road widening and sealing.

Location or District	Project Name	Description
	Kuranda Range Road proposed upgrade (Kennedy Highway, Smithfield-Kuranda)	Upgrade of 12.7km section to four lanes, with a straighter alignment
	Mulgrave Road Upgrade - Cairns	Upgrading the road between Ray Jones Drive and Sheridan Street
	Peninsula Developmental Road	Lakeland to Comalco lease boundary 26km east of Weipa upgrade
Central District (Rockhampton)	Accelerated Road Rehabilitation Project	Accelerated Road Rehabilitation Project
Mackay District (Mackay)	Forgan Bridge duplication	Forgan Bridge duplication
	Hospital Bridge replacement	Hospital Bridge replacement
	Joint levee Road	Involves the construction of a combined levee bank and two-lane road from Sams Road through to Kooyong Intersection, Mackay
	Mackay Buccasia Road	Completion of the four-lane of the Mackay-Buccasia Road which links Mackay's Northern Beaches to the City centre
Central Highlands District (Emerald)	Walker street intersection upgrades	Walker street intersection upgrades
	Capricorn Highway	Capricorn Highway
	Clermont to Alpha Road	Clermont to Alpha Road
	Gregory Highway	Gregory Highway
	Peak Downs Highway	Peak Downs Highway

APPENDIX B3

Location or District	Project Name	Description
South Western District (Roma)	Carnarvon Highway	Widening of the bitumen seal between Roma and Injune.
	Cooper Developmental Road	Sealing of the Cooper developmental Road between Quilpie and Bundeena
	Diamantina Developmental Road Roma-Taroom Road	Between Quilpie and Windorah Upgrade of the Roma-Taroom Road
	Warrego Highway	Widening of the Warrego Highway
Southern District (Toowoomba)	New England Highway, Highfields	Between Cawdor Road and Reis Road at Highfields
	Southern Queensland Accelerated Road Rehabilitation Program (SQARRP) bridge replacement project	From Stanthorpe to north of Bundaberg
Wide Bay District (Bundaberg)	Toowoomba Bypass	Toowoomba Bypass
	Bundaberg Ring Road	The new 14km Bundaberg Ring Road
	Ferry Street and Alice Street intersection upgrade	Ferry Street and Alice Street intersection upgrade
	Maryborough-Hervey Bay Road	Improving the Maryborough-Hervey Bay Road within Hervey bay
Border District (Warwick)	Walker street intersection upgrades	Walker street intersection upgrades
	Cunningham Highway – Fisher Park west	West of Cunningham's Gap, Fisher Park to Maryvale.
	Cunningham Highway – Warwick to Inglewood	Between Warwick and Inglewood

Location or District	Project Name	Description
	Fatigue-related safety measures	Fatigue – related safety measures
	Leichhardt Highway, Gnowindindi - Taroom	To widen and seal a series of sections of the Leichardt Highway
	Warwick Traffic Management Study	Warwick Traffic Management Study
North Coast Hinterland	Beerburum Road Upgrade	From Pumice stone to Haskins Street
Sunshine Coast	Bribie Island Road upgrade project	From Aerodrome Road to Saint Road
	Bruce Highway (Cooray to Curra) Strategic Planning Study	85km section of Bruce Highway between Cooray and Curra, north of Gympie
	Bruce Highway Upgrade – Boundary Road to Caboolture	Bruce Highway upgrade – Boundary road to Caboolture
	Bruce Highway Upgrade – Gympie	Main Roads is upgrading 3.4km section of the Bruce Highway through Gympie
	Caboolture Bypass – Stage 2	The Caboolture Bypass will connect the D'Aguliar Highway to the Bruce Highway, Beerburum Road
	Caboolture – Bribie Island Road Transport Corridor Review	A study into the social, environmental and financial cost of a potential Mingi Bypass
	Caloundra- Mooloolaba Road	Caloundra Road to Creek side Boulevard
	D'Aguliar Highway upgrade- Kilcoy By pass	Bypass will leave the D'Aguliar Highway, west of Saleyard Road
	Deception Bay Road upgrade (Bruce Highway to Luscombe Road)	Proposed upgrade between the Bruce Highway and Luscombe Road
	Eumundi-Kenilworth Road	Eumundi-Kenilworth Road

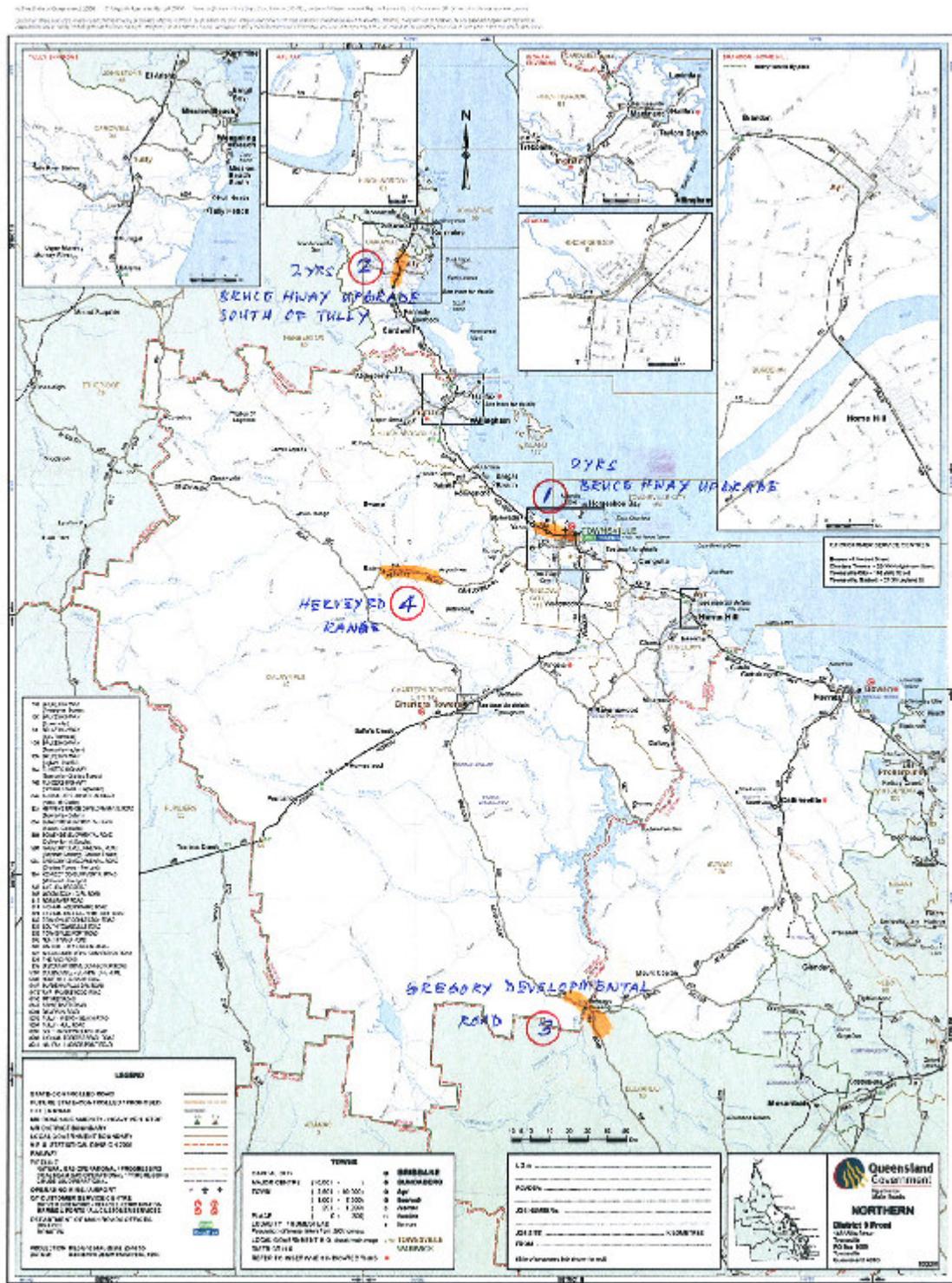
Location or District	Project Name	Description
	Maroochydore Road upgrade	Between the Bruce Highway and Marlines Creek (east of Kunda Park)
	Menzies Drive - Mudjimba Beach Road intersection upgrade	Upgrade the Menzies Drive - Mudjimba Beach Road intersection on the David Low Way
	Mornyfield Road upgrade project	The upgrade is for the section of road from Uhlmann Road roundabout to east of Garfield Street
	Multi-modal transport corridor	A future transport corridor from Caloundra Road to the Sunshine Motorway, Sunshine Coast
	Mambour Connection Road Safety Improvements	Between Kiel Mountain Road and McKenzie road, Mambour
	Steve Irwin Way upgrade – southern section	Steve Irwin Way upgrade planning study – Bruce Highway Interchange to Caloundra Street, Landsborough
	Steve Irwin Way upgrade – northern section	Landsborough to Caloundra Road Interchange, Bruce Highway
	Sunshine Motorway – Maroochy Boulevard Interchange	Construction of a new interchange on the Sunshine Motorway
	Sunshine Motorway – Maroochydore Road to David Low Way, including Maroochy River Bridge.	Constructing a new bridge across the Maroochy River, east of the existing bridge.
	Sunshine Motorway Upgrade – Pacific Paradise Interchange and Bypass	Pacific Paradise Interchange and Bypass
	Sunshine Motorway Upgrade – Sippy Downs Drive to Kawana Way	Upgrade to four lanes and developing a new interchange at Dixon Road – Claymore Road.
	Sunshine Motorway – 5M2032 Planning Study.	Plan to identify the best solutions for the corridor over the next 30 years.

Location or District	Project Name	Description
South Coast Hinterland District (Merang – Gold Coast)	Gold Coast Highway bus lanes	A major upgrade of 4 km of Gold Coast Highway between Broadbeach and Miami
	Gold Coast Highway, Government Road to North Street	Government Road to North Street (Frank Street)
	Hope Island Road duplication	Upgrade duplication of Hope Island Road
	Mudgeeraba Interchange upgrade	An early stage of the Pacific Motorway upgrade
	Nerang – Broadbeach Road	Between Allambi Gardens and Nielsen's Road, Carrara
	Oxenford Deviation	Tamborine – Oxenford Road to bypass the Oxenford town centre.
	Pacific Motorway noise treatment project	Pacific Motorway Noise Treatment
	Pacific Motorway Nerang South interchange	Pacific Motorway Nerang South Interchange
	Pacific Motor way Upgrade Planning Project (Merang to Tugun)	Pacific Motorway Upgrade Planning Project (Merang to Tugun)
	Smith Street major upgrade and 24 – hour Transit lanes	Smith street major upgrade
	Southport – Merang Road upgrade	Southport – Merang Road (Queen Street to Hinde Street) upgrade
	Tamborine Village roundabout	Tamborine Village roundabout
	Tugun Bypass project	Tugun Bypass project
	Waterford- Tamborine Road upgrade	Main Roads is planning to upgrade the Waterford -Tamborine Road between Plunkett Road and Tamborine Village

Location or District	Project Name	Description
Metropolitan District Projects (Brisbane)		
	Acacia Ridge rail crossing overpass	Acacia Ridge rail crossing overpass
	Airport Drive interchange – new signals	New signals at the interchange of Airport Drive and the Gateway Motorway, Hendra.
	Boundary Road, Thornlands	Upgrading Boundary Road from Panorama Drive to Cleveland – Redland Bay Road at Thornlands.
	Brisbane Urban Corridor	Several roads on Brisbane's Southside from the 11km Brisbane Urban Corridor
	Centenary Highway extension	Centenary Highway extension
	Darra to Springfield Transport Corridor – road and rail project	Darra to Springfield Transport corridor
	Gateway Motorway South Planning Study	Gateway Motorway: North Planning Study
	Gateway Upgrade project	Duplicating the Gateway Bridge and upgrading 20 kilometres of the Gateway Motorway
	Goodna Bypass	Bypass to connect directly to the Warrego and Cunningham Highways, and the Logan and Ipswich Motorways
	Granard Road intersection at Balham Road and Beatty Road	Granard Road intersections at Balham Road Beatty Road
	Gympie Road upgrade	This upgrade affects Gympie Road through Petrie, Strathpine, Brendale, Aspley, Chermanside and Kedron.

Location or District	Project Name	Description
	Houghton Highway Duplication Project	Duplication of the Houghton Highway by building a new bridge between the Deagon Deviation at Bridgton and Elizabeth Avenue on the Redcliffe Peninsula.
	Ipswich Motorway	Updating a vital traffic connection between Ipswich and Brisbane
	Ipswich Motorway upgrade: Ipswich – Logan interchange	Ipswich Motorway Upgrade: Ipswich/Logan Interchange
	Ipswich Motorway upgrade: Wacol to Darra upgrade	Upgrade of the Ipswich Motorway between Wacol and Darra
	Main Road and Kessels Road intersection upgrade planning study	An investigation into providing grade separation
	Moggill Road Upgrade	Upgrading Moggill Road between Kilkivan Avenue (south) and Pullenvale Road
	Mt Lindsey Highway upgrade	Mt Lindsey Highway upgrade, between Green Road and Granger Road
	Pacific Motorway transit project	Improvements to 16km of the Pacific Motorway through Rochedale South, Springwood, Daisy Hill, Shailer Park and Loganholme.
	Pacific Motorway VI Bikeway	Construction of a continuous cycle route parallel to the Pacific Motorway, between the Logan River and Nathan.
	Port of Brisbane Motorway Upgrade Planning Study	Future motorway link between the gateway Motorway and the Port of Brisbane
	Redland bay Road upgrade (Vienna Road to boundary Road)	Upgrade of Redland Bay Road from two to four lanes between Vienna Road at Copalaba and boundary road at Alexandra Hills
	Redland Corridor Project- Concept planning phase	Main Road is studying options to upgrade three road sections in the Redland area.

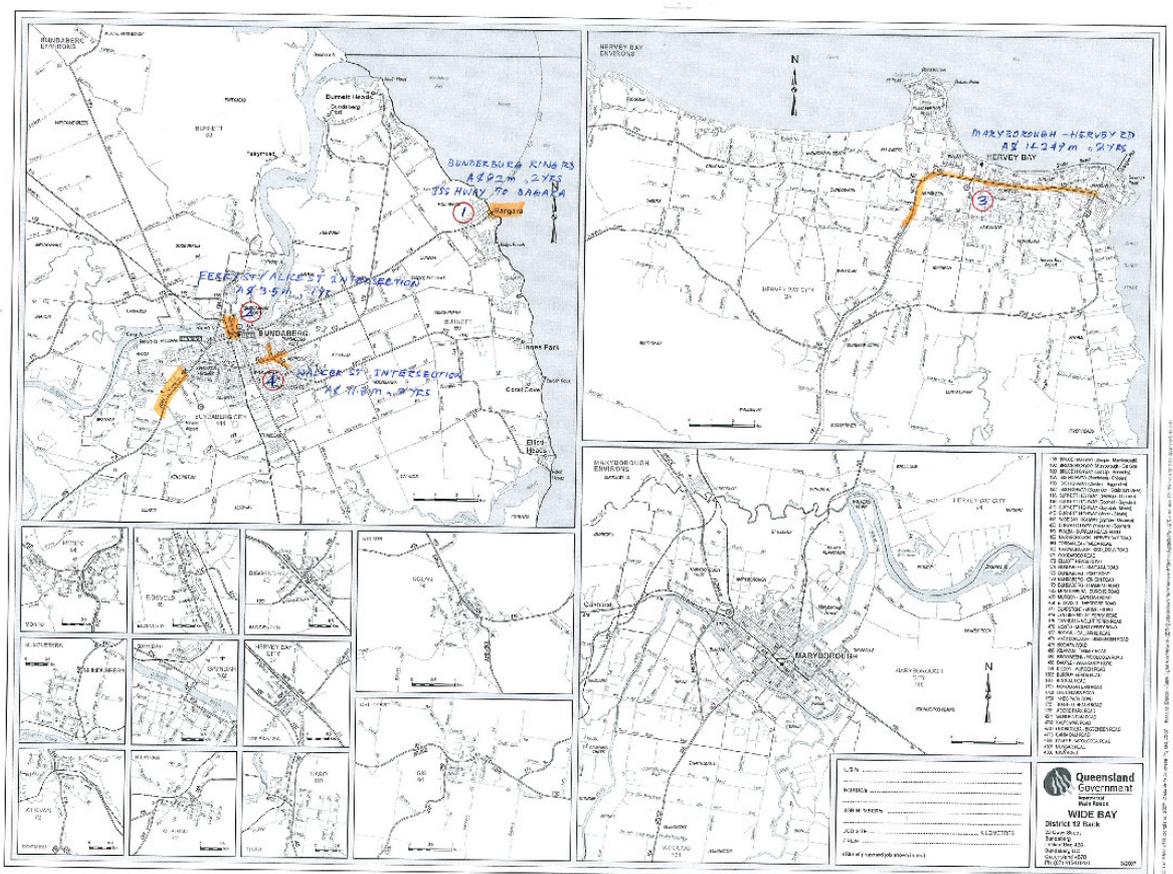
Location or District	Project Name	Description
	Riverside Expressway and ramp maintenance works	Riverside Expressway report on maintenance and repairs
	Toowoong Roundabout cyclist and pedestrian crossing	A safe north-south crossing for cyclists and pedestrians at eth Toowoong-end of the Western Freeway
	Wacol Interim Traffic Improvement Project	Intersection of Lakeside Street, Wacol Station Road and Progress Road, Wacol.
	Warrago Highway and Brisbane Valley Highway Intersection upgrade, planning study	Three options to upgrade the Warrago Highway and Brisbane Valley Highway Intersection at Black soil.
	Wembley Road Planning Study	Investigating options for upgrading Wembley Road Between Bardon Road and the Logan Motorway
	Western Brisbane Transport Network Investigation	The Western Brisbane transport Network Investigation is a benchmark study for south east east Queensland.



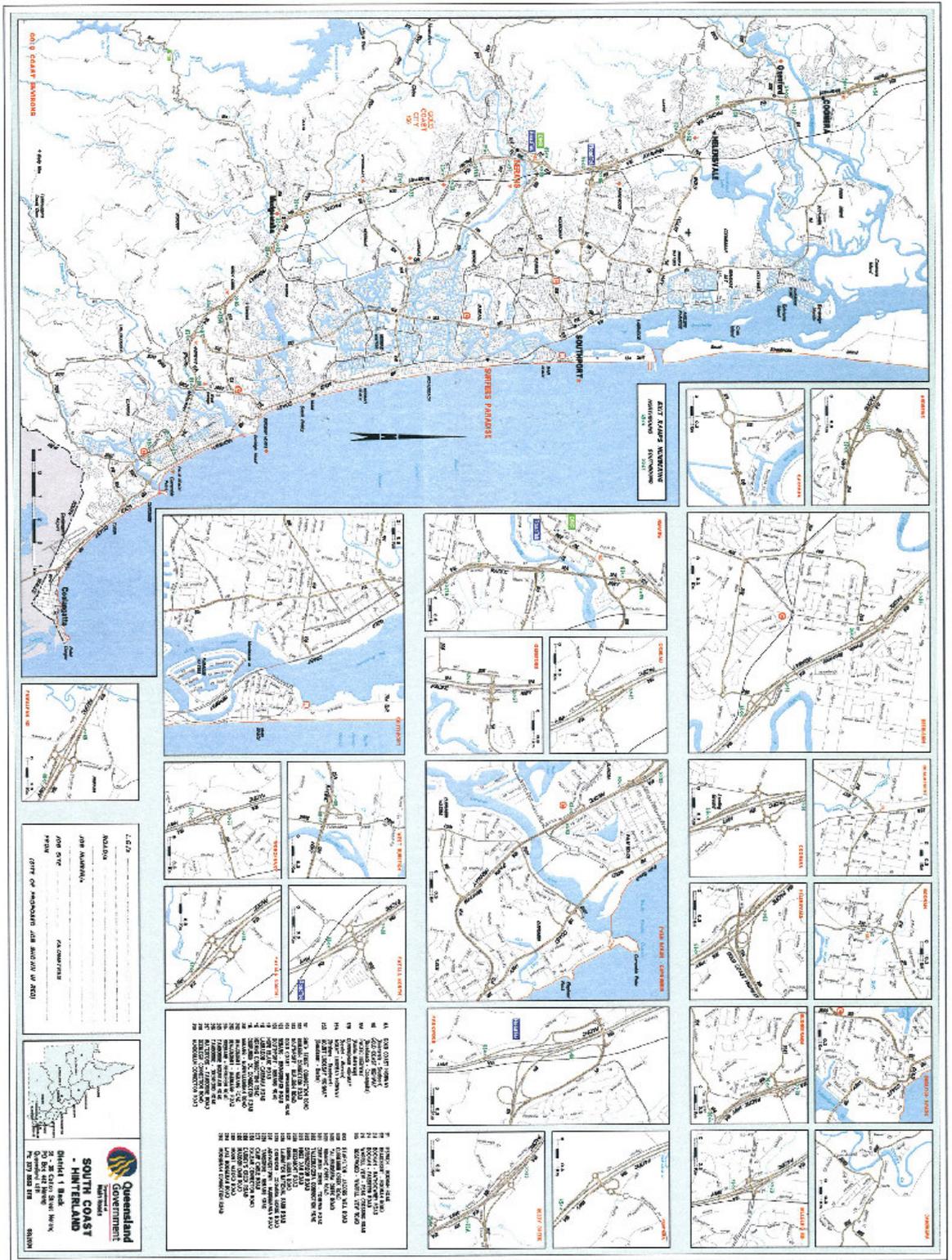
Appendix B10 – Northern District (Townsville)

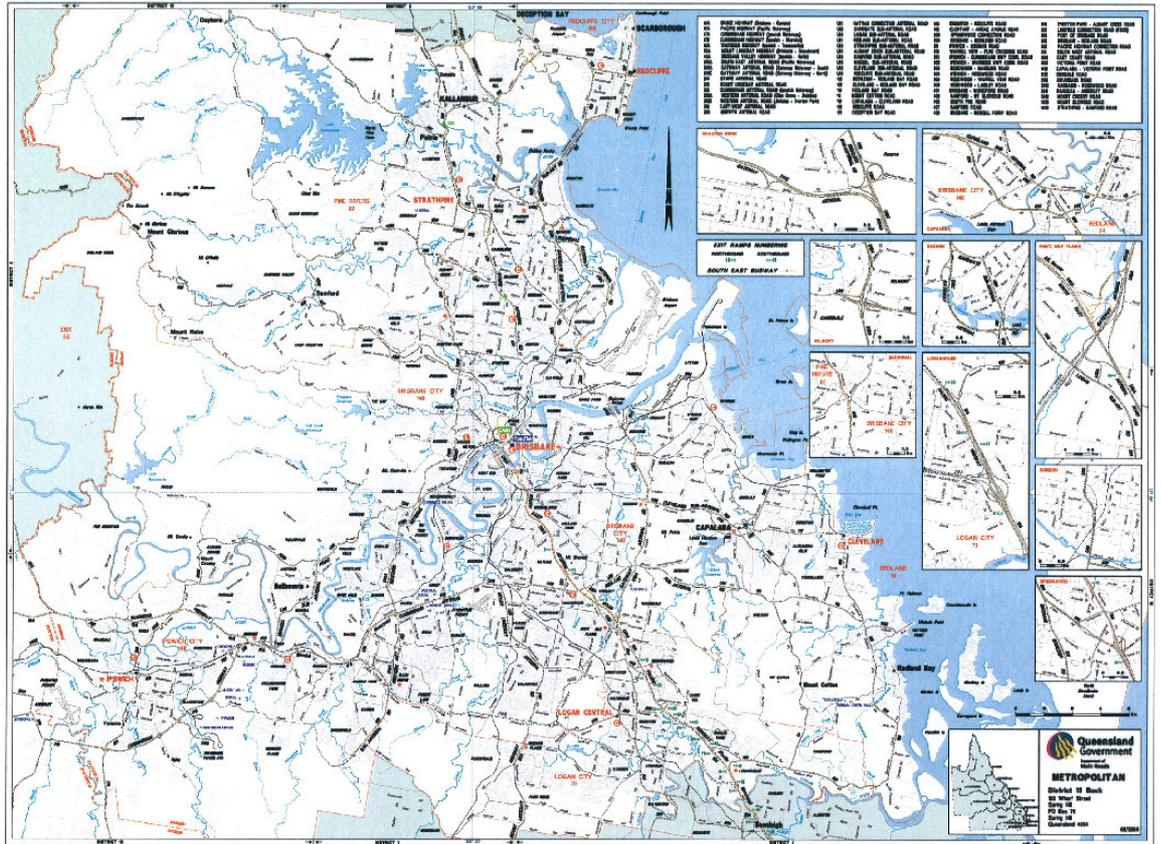


Appendix B14 – Peninsula District (Cairns)



Appendix B20 – Widebay District (Bundaberg)



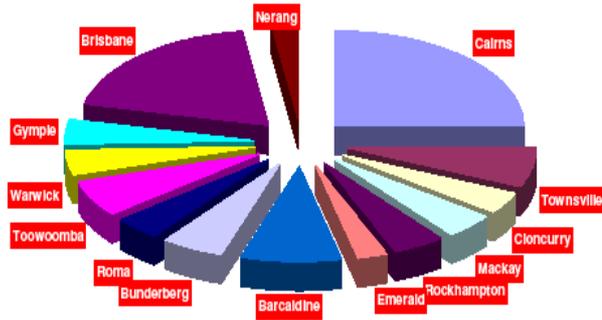


Appendix B26 – Metropolitan District (Brisbane)

Appendix C

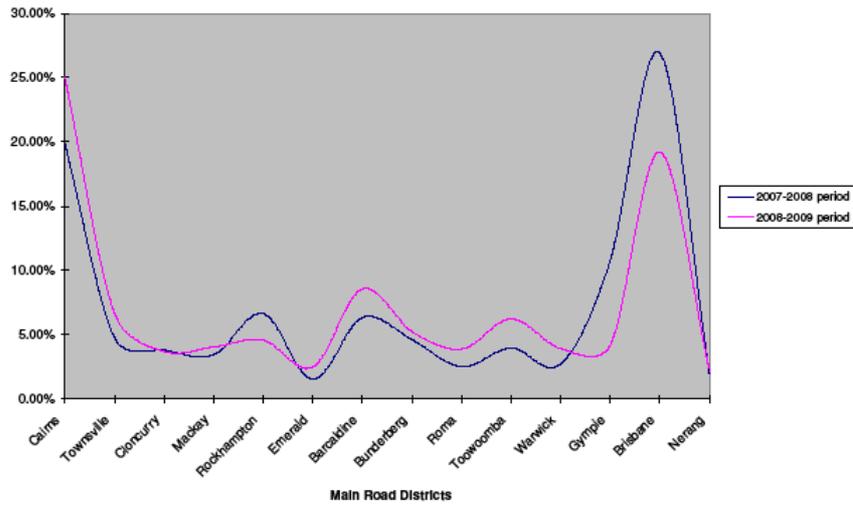
Graphical Results

Main Roads Projects - Subsidy Allocations, 2008-2009

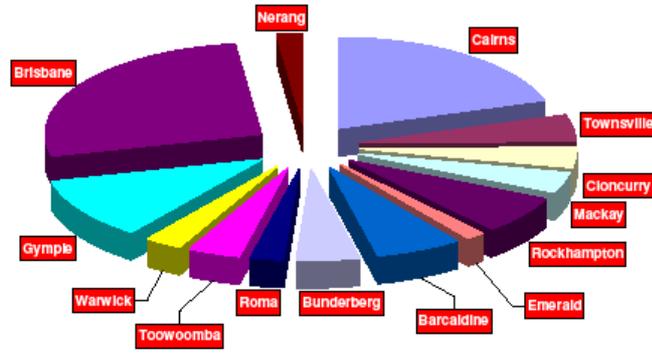


Comparison of subsidies

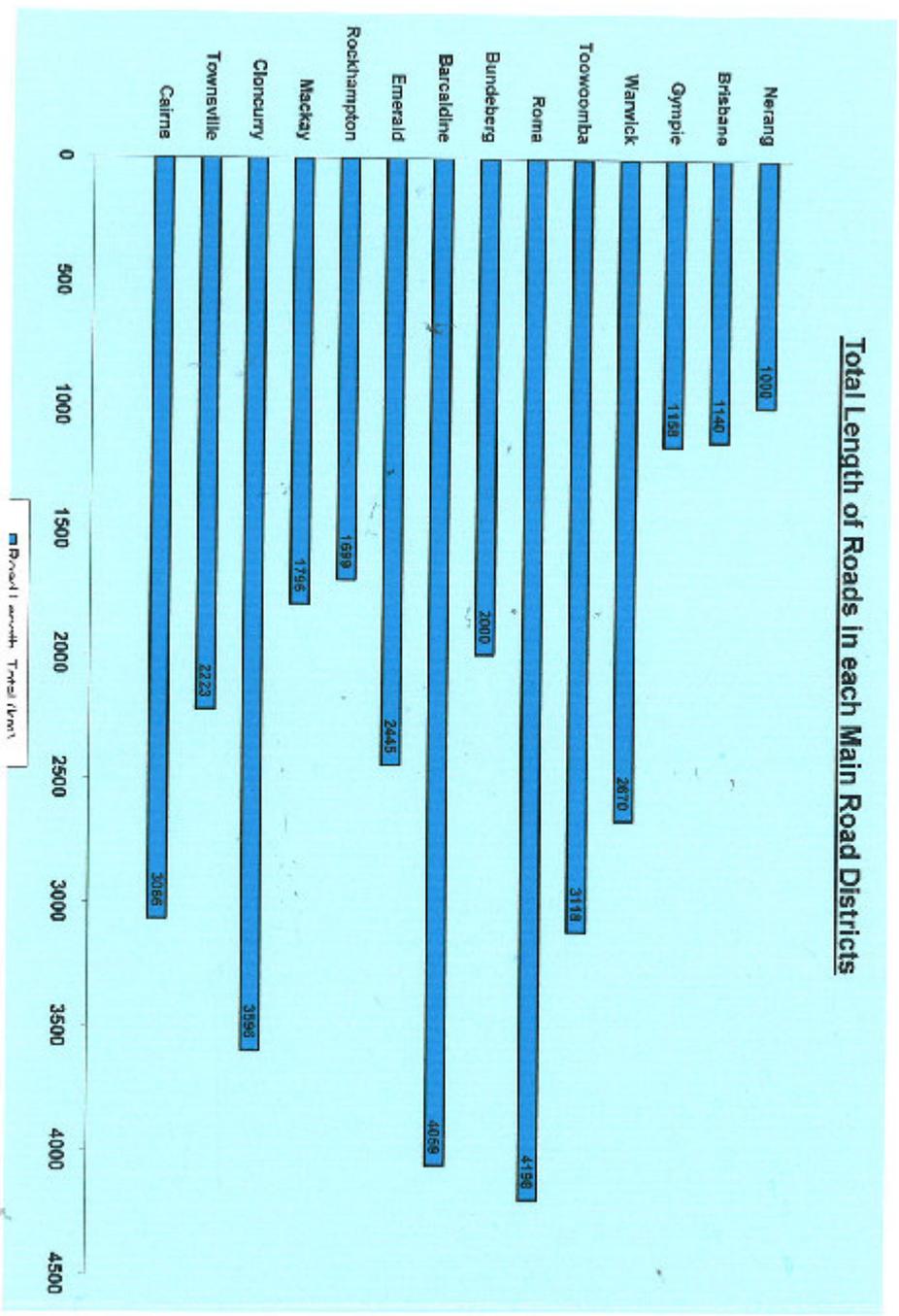
Subsidy Allocations for Road Projects in Queensland



Main Roads Projects - Subsidy Allocations, 2007-2008



Total Length of Roads In each Main Road Districts



12