University of Southern Queensland

Faculty of Engineering and Surveying

Simulation of GPS Car Navigation Systems in Evaluating the Impact of Poor Quality Road Data

A dissertation submitted by

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Abstract

This dissertation was formulated to research the impacts that road network data errors and their associated navigation errors have on driver safety. Simulation of GPS NMEA data allows navigation testing of roads that were identified to have poor quality road network data. The navigation errors were found by comparing the navigation paths with reality and the severity of these errors were tested by replaying this data to a group of drivers.

The results indicate that poor quality road network data can cause problems with respect to driver safety. These problems are more pronounced on busy major roads, especially freeways and urban highways. All roads tested in this project were chosen due to their various locations and the variety in the overall nature of the roads, ranging from a country road to a busy freeway.

Several problems were identified that may attribute to the cause of navigation errors. They range from software functions in the satellite navigation system to the prolonged period of updating road network data by different levels of government and mapping companies. An innovative set of solutions has been formulated, which include the automatic mapping of erroneous roads and the regular updating of road network data. This can be facilitated through better practices by governments and mapping companies, plus voluntary updating of maps by civilians.

The outcomes of this dissertation will aid in bringing forward safer usage, better overall accuracy and the smooth operation of satellite navigation systems, whilst maintaining their increasing popularity throughout Australia.

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29/10/2008

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Chapter 1

Introduction

1.1 Statement of the Problem

Modern GPS satellite navigation systems can experience navigation problems whilst using the uploaded on-board maps. These problems are mainly associated with missing data from the on-board maps or navigation along roads that are missing in the real-world.

Over the past decade GPS satellite navigation systems have grown in popularity and their ability to reliably navigate drivers to a desired destination. Schekutiev (2006) suggested that an effective satellite navigation system would depend on the user's measuring-navigating equipment being of good quality. Successful navigation also depends on the accuracy of maps that are loaded into the individual systems, which can vary in positional quality. New roads are continually being created so the updating of new road data is critical in successful navigation. Montenbruck & Holt (2002) stated that in an S/A (Selective Availability) free environment, the modelled GPS time typically agrees with true GPS time to within 30 metres. Therefore, accuracy of GPS data from satellites is considered to be quite dependable.

Various companies supply electronic maps for satellite navigation systems. There are a range of methods employed in collecting road network data. When new roads are constructed, the different companies that provide this road network data must keep their maps up-to-date by collecting and then adding the new data to their databases. The lack of data can lead to the suspension of any navigation even if the on-board GPS is still providing position data. This is relevant also to areas where too much data exists. Road data can be stored in their databases but the roads are non-existent or unusable in the real world.

This project seeks to analyse the impact of poor quality road data through simulation. Simulation is an artificial representation of real-world events, usually performed with the aid of computing systems and modern communication methods. The simulation of GPS data has been successful in different ways. Brown, Gerein and Taylor (2000) used a GPS simulator that simulated various factors in the operation of the overall Global Navigation Satellite System (GNSS), including trajectory of the receiver(s), the signal power and environmental effects. Our goal is to get a system that is relatively easy to run and to use modern technologies in the development of a simulator.

1.2 Project Aim

The aim of this project is to develop a GPS simulator and assess the impact of poor quality road network data in car satellite navigation systems.

1.3 Key Research Objectives

The purposes of this project are to complete the following key research objectives; these specifications are agreed and signed in Appendix A:

1) Review GPS car satellite navigation systems, the suppliers of road network data to satellite navigation systems available in Australia and the sources of this data.

2) Investigate the data formats that can be used in simulation of GPS signals (both pre-processed and post-processed) and the use of this data in specific stages of simulation.

3) Assess the quality of different road network data sources and compare the data in different geographic areas.

4) Simulate GPS signals through computer-based simulators to achieve a navigation path to a specific destination.

5) Analyse the impacts on safety by simulating a car navigation system along road networks with erroneous data.

6) If time permits, Investigate advanced simulation to achieve a similar road path to driver's expectation.

1.4 Justification of Research

Most persons who own a Satellite Navigation System (sat-nav) would most likely be able to tell of some problems they have encountered with the operation of the system. Problems encountered with using a satellite navigation system includes incorrect navigation due to excessive data in the maps or the ceasing of navigation due to a lack of map data. The confusion due to the specified route chosen by the system and its justification is also a regular problem but is not a specification in this thesis.

Because satellite navigation systems are available from many different retail stores around the world, continued sales pressures may override the maintenance of good quality data contained in a system. There are concerns about driver safety; therefore these issues need to be resolved whilst maintaining their popularity amongst the general public.

This thesis is will set out to achieve some answers to some specific problems that pertain to Satellite Navigation Systems and their problems associated with location information. Their effects on the safety of road-users will be evaluated and recommendations on further research and development will be given.

1.5 Structure of Dissertation

This dissertation has six chapters, with each chapter written in the order of the research conducted and completed. These chapters will cover different stages from the introduction and the literature review through to the research work, results, recommendations and the conclusion.

Before any formal testing can begin, a literature review has to be completed. It will report on the different background issues that exist through a review of previous research conducted. This section will look at issues ranging from GPS car navigations systems to communications and simulation techniques and risk assessment methods.

The project method will be discussed after the literature review. This chapter will detail the proposed methods of conducting all testing, research, analysis and presentation of results. This section will outline the development of the final GPS simulator and how it will be used in the simulation experiments. A discussion of the intended roads to be used in the experiments will also be presented.

The results chapter will present the errors found in our testing and the driver survey results. These errors will be extracted through the analysis of the differences between the roads in the satellite navigation system (and the navigation) and the roads in the real-world. Results concerning a survey of these errors with drivers and the resultant risk assessments will be presented in this chapter.

A chapter dedicated to a discussion and recommendations for the improvements required to the functioning of car navigation systems will follow the results chapter. Each example used in this project will be discussed and the potential impacts on driver safety will be analysed. Recommendations will be made in response to specific problems incurred in the operation of the satellite navigation system.

This dissertation will conclude in chapter six (6), which will be a response to the issues put forward in chapter one (1). It will outline the achievements made with respect to the project aim and the research objectives.

1.6 Limitations of this project

The limitations of this project would present difficulties in completing all desired outcomes. But testing and experimentation will seek to lessen the effects of these limitations, or perhaps eliminate them altogether.

The development of the simulator is a major aim of this project. But in the early stage of the project it is a visionary concept and if its development is deemed unsuccessful then it would prove to be a major limitation. Although the concepts for the development of this simulator are envisioned, each individual step towards attaining simulation must take place before the development is completed.

The GPS satellite navigation system to be used in this project will have a specific type of on-board maps and navigation program. The characteristics of this program will determine the reactions displayed on the satellite navigation system, in response to low quality road network data. The success of the communications, either through Bluetooth or cable will depend on the initial testing. If Bluetooth is deemed to be unsuccessful during our testing stage, we will need to resort to using a cable connection, such as USB. If this occurs then data transmission and the speed of this transmission will be restricted by the type of cable and how fast the computer can process data using that cable.

The roads which are going to be used for our testing will need to be roads where there is known low quality road network data. To find these roads we need to peruse data providers and find where there is low quality data on roads that are known and its characteristics are known. To do this, Google Earth plus Google Maps and Whereis.com have free access to road network data that has been assembled by private companies.

Chapter 2

Literature Review

2.1 Introduction

This chapter seeks to provide an update of the literature that exists today that pertains to this project, including issues like GPS simulation, collection of road network data, Bluetooth technologies and risk assessments. It will give some perspective in what is known from past research and then use this knowledge to assist with the research proposed in this dissertation. This chapter will explain what is known with respect to GPS simulation, collection of road network data and car navigation systems.

The aim of this chapter is to explain the outcomes of a literature review conducted that will give background information regarding this project.

To achieve the aim for this chapter, research will be conducted using journal databases that are accessible through the University of Southern Queensland. Reviews of the relevant journals will be made and a collection of these journals will combine to form the final literature review.

2.2 Desired Outcomes of Literature Review

This project is seeking to evaluate the overall dependency of available maps that are supplied to GPS satellite navigation systems. Therefore we are not evaluating the accuracy of GPS satellite data, but the data provided in electronic map form. The companies that supply this data can update their databases as often as they see fit. Australia and its population are spread out over a large area and the updating of road navigation data on a national scale can prove difficult.

This review will look at the basics of GPS and the current status of satellite navigation systems, the methods used to obtain road navigation data plus an overview of these data providers. A synopsis of the simulation of GPS and the data and communication means of achieving such will be included in this section. It is critical to understand the types of data that are used in the overall process of the GPS and every aspect that goes into the single unified operation of a satellite navigation receiver. From this, a better understanding of the errors and their potential for navigation problems will be achieved.

2.3 GPS Vehicle Navigation Systems

GPS or the Global Positioning System was developed by the United States Department of Defence. It was the first constellation of satellites put into orbit around the Earth for the purpose of accurately locating a position on the Earth. Gibbings (2005) explains the ease of using GPS- it is accessible 24 hours a day, seven days per week, anywhere on earth and in all weather. Today new GPS handheld receivers have the capability of communicating with more than one navigation system. GLONASS (GLObal NAvigation Satellite System) is the Russian equivalent of the United States-owned Global Positioning System. It contains fewer satellites than its American equivalent but can provide equal standard of positional accuracy. A basic GPS receiver requires communication with a minimum of four (4) satellites to get a single position fix anywhere on Earth. It is possible to derive your position with only three (3) satellites, but a fourth satellite signal will ensure a check of your determined position.

In the past the GPS system was subject to deliberate degradation of the signal, thus had an effect on the accuracy. This was intentional by the United States Department of Defence for security purposes. This degradation was called Selective Availability (S/A) but was shut down on 1st May 2000. Ochieng & Sauer (2002) suggest that GPS satellite navigation could address problems like traffic congestion levels, risk of accidents and time wastage during journeys. Issues concerning safety could suggest one reason why S/A was turned off.

2.3.1 Technical Capabilities

Satellite Navigation systems have functions that drivers can set for their own personal travelling needs. If time is an issue in travelling from point A to point B, functions can be set in order for the system to calculate the shortest distance in the road network between both points. If the driver follows this path but chooses to divert from the chosen path then the system is able to recalculate a new shortest route. Options exist for the avoidance of specific points in the network like tolls booths or busy highways.

As satellite navigation systems advance in capabilities, new possibilities are always realised by the visionaries. Mossberg (2008) suggested that in-car navigation devices could become smarter through direct communication with the Internet and report on the speed of traffic further along a road in real-time. He reports that a new system is available with the capacity to perform such functions. It depends also on the number of similar units that exist along the road at the same time.

Safety issues associated with operating these devices whilst driving are being addressed continuously. Quain (2007) reported that newer devices have voice receiver microphones built into them so that a driver can “bark out” the address of their destination. This can avoid the distraction of typing the address in while driving (thus increasing safety). Other new features like 3-D views of complex intersections are available in specific systems. These views are only available at this stage for major intersections in the United States.

2.3.2 Uses

Any car navigation system available today would have several options for navigation, plus other miscellaneous functions. Most navigation systems have functions that allow you to choose the nature of the road you wish to travel. Options like this include roads with no tollbooths, the calculation of a route away from urban areas plus the ability to add a desired stopping location.

Other miscellaneous options are included in many satellite navigation systems available today. Garmin (2008) offer systems with speak commands and wireless connections to the Internet for information on weather, traffic, fuel prices and news. Navman (2007) offer systems with cameras built-in and TomTom (2008) has speed alert functions.

2.4 Navigation Data

The sole purpose for the existence of roads is to facilitate the transportation of people and objects as quickly as possible from a starting location to a destination. However, there must be information available that informs travellers of the localities along a specific road and distances to and between them. In the past this information would be available through the purchase of paper maps of major towns in the region (depending on the scale of the maps). Today there is a large e-map industry with the availability of electronic maps free over the internet plus options available to purchase electronic maps for use in hand-held computers and satellite navigation systems. These electronic maps are today beginning to take over from their predecessors, the paper maps. There are many other possibilities with using electronic maps- including navigation (with its linkage to GPS), electronic mobility and the ability to update maps without purchasing an entire module (or paper atlas).

2.4.1 Sources of Navigation Data

For effective navigation of a road, location data of roads must exist in a form that can be related and interpretable by those traversing the road. Data related to the location of roads has been collected in several different ways, depending on the purpose of the data and the available technology at the time the road was mapped. As GPS is a fairly new technology, its use in collecting road network data has only been utilized in recent years.

Basically there are five methods of collecting road network data.

- Traditional Surveying Methods
- GPS Data Capture
- Extraction through Remote Sensing
- Extraction from Aerial Photographs
- Video Recordings of Roads

The traditional methods of recording location data of roads were surveying methods where bearings and distances would define the locations of road reserves. These dimensions were presented on survey Plans that would become registered under the relevant state Register. As of today surveyors are continually responsible for these types of duties. Roads are typically surveyed today for the purposes of land access. But survey data of roads are not always reliable in terms of an existent road in the real world. Roads legally exist in Australia whether a satisfactory road surface exists within it or not. But if there is no existing road surface like bitumen or concrete then successful navigation, using this type of data, can prove ineffective.

GPS data capture is the most effective, accurate and fastest method of recording road network data today. It is the easiest method of extracting road data as it can be as simple as fixing a GPS receiver onto a car and driving the routes while regularly recording location data. However, there is metadata to consider, such as width of roads, the names of the roads and the class of road (collector, arterial or local access roads). There are road network data providers in Australia that collect and update their databases using this method.

Extraction from remote sensing is a means of collecting data of the Earth’s surface using satellites and high altitude aircraft. Data can be changed around to be interpreted differently or for a certain purpose. The extraction of road network data would be achieved by the identification of a sample of the road in the image under question and using the sample to identify all the common areas in an image. Lacoste, Descombes & Zerubia (2003) found that this method of generating road network data has some potential, describing it as ‘encouraging’. Nevertheless, there are problems with noise, especially with trees covering roads. This can lead to incomplete data which would require further data detection using other methods. This method of collecting road navigation data is not reliable enough for use on a large scale. Goeman et al. (2005) suggests that remote sensing methods could be a tool for checking the accuracy of existing road network data. However, the technology available is always improving. Improvements in the imagery obtained using technology in the future will give opportunities of utilising remotely sensed data to extract road network data in a large scale.

Extraction of road network data from aerial photographs occurred for purposes other than for GPS satellite navigation. This data would be produced for basic map production, where accuracy was not important. In the past this location data was collected through digitizing of the images. With the advent of GIS these images are being used in electronic formats and data is extracted using algorithms set by the user and this data is produced faster and more accurately than digitizing. Gervin & Ragan (1993) conducted tests on the production of road and house data from aerial photography. The ability to view images in different bands (including infrared) and in false colours can greatly assist in their search for a single ‘customised’ object search in a single image.

Recording videos of roads is an option that is open for those needing to extract road data on a small scale. Normally this type of information is recorded as such for more than only mapping purposes. Harris et al. (1992) used the video data of roads recorded in Doncaster Metropolitan Borough Council for mapping their road network and for asset information collection for road furniture, like bus stops and road signs. This method of data capture is achieved by driving all the routes in a road network whilst recording the video of the road. Other methods of this type of data collection, such as aerial video data capture used by Pless & Jurgens (2004), use ‘geo-referenced’ video data that capture the distribution of relative movements between frames (spatio-temporal). Each pixel in each image is given a score based on a given function. The score determines the likelihood that this pixel represents an image of a road.

2.4.2 Quality Issues

Successful navigation of a driver along a given road requires some knowledge of the positions of their starting and finishing points, plus the road/s between these two points. Quality issues are defined as data that is included or missing from maps which can obstruct the process of satellite navigation. Two basic possibilities can occur here.

- Lack of road network data in the maps used for navigation.
- Included content of surveyed roads that are not used by everyday traffic.

The difference between what a map shows as a representation of the real world compared to reality can be quite different. In Australia it is not uncommon to be travelling along a road where suddenly, a satellite navigation system ceases to operate due to the absence of data on the travelled section of road. This is evident in new roads, whether it’s a new freeway or a new access road in a recently completed subdivision.

Quality issues link with the problems of the containment of excessive data, that is, road data which occurs in maps that represent surveyed roads, but which are not open to traffic. Many of these roads are fenced areas in a rural paddock that connect to an open road. Instances are common where a guidance system instructs the driver to turn off a road and find that there is no road to follow. These types of instances can raise questions about the safety of drivers using these navigation systems, especially when you consider the ‘worst-case’ possibilities. Instances like driving roads at night where a driver has no prior knowledge of the road could lead to problems with safety, especially if there is traffic following the driver. Navigation systems would operate best when data of the status of roads is included with their metadata.

2.4.3 Map and Data Providers in Australia

The providers of commercially available road map data in Australia have a prime responsibility of maintaining the currency of their datasets. Australia is a large country with a small population, which makes this task more difficult than on other continents like Europe and North America.

Today there are two main providers of road network data for use in satellite navigation systems

- Navteq
- Sensis

Navteq is based in the United States and they are the major suppliers of road network data for satellite navigation systems in North America and Europe. In 2007 Navteq entered the Australian GPS satellite navigation map provider market, adding some competition to the previous sole provider of this data, Sensis. Navteq provides data to large Internet companies like Google and Yahoo. Their maps were produced by driving all roads around Australia and capturing this data using GPS plus added data from PSMA (Public Sector Mapping Agencies).

Sensis is the owner of Whereis, which is the main supplier of road network data in satellite navigation systems in Australia and New

Zealand. Their road maps are used in the majority of satellite navigation systems used in Australia, including Garmin, Navman and TomTom. Whereis source their data from UBD, which are the major paper-based street directory supplier in Australia. UBD source this original data similar to Navteq- through data collection using GPS. Furthermore, UBD receives their data from local councils and state government road authorities.

Both of these suppliers provide basic options in their navigation, for example, different methods of route calculations (eg: avoiding tolls or highways), Poi's (points of interest) and safety alert points like speed cameras.

2.5 GPS Simulation

The concise Macquarie dictionary of the English language 2001 defines 'simulation' as "pretending; feigning". It also defines it as "the representation of physical systems, phenomena by computers". Some types of simulation can involve replicating natural phenomenon in the real world by their simulation using computers. GPS simulation involves the replication of GPS signals or data using computer programs to reflect real world positioning. GPS can be simulated for several different purposes. Brown, Gerein & Taylor (2000) developed a MATLAB product that allows software simulation of complex GPS environments. This includes the effects of interfering source signals and antenna and receiver characteristics on the received GPS signals. Their simulator brought about these advantages:

- The ability to simulate specific conditions as often as necessary; and
- The ability to save exact RF (radio-frequency) conditions for historical and legal purposes.

Dong (2003) developed an IF (intermediate frequency) GPS signal simulator that considers various sources of error like satellite clock error, atmospheric errors (ionosphere and troposphere) and user-defined errors. It is used to simulate surveying-grade GPS receivers along with typical code-phase GPS receivers, like those found in satellite navigation systems. Hannah (2001) simulated the effects of multipath on GPS receivers. Development of a simulator took place and it required testing in the real-world to evaluate the accuracy of the simulator.

2.5.1 Raw GPS Data

Raw signals from GPS satellites provide receivers with much information. They contain modulated codes that give us an ability to calculate pseudo-ranges between satellites and receivers. This is achieved by calculating the amount of time from the transmission of the signal to its receiving. All GPS receivers know what the codes are at any given time from any satellite. When they receive the signals, the receivers calculate the difference in time between the transmission of this code from the satellite and when it is received. The pseudo-range can be known from all satellites visible to the receiver. Measurements using these codes are accurate to about 10-15 metres at any given time.

Included with these modulated codes are Ephemerides and Almanac data. Almanac data is given to GPS receivers to aid in satellite searches in the future. It uploads data of the positions of the satellites for a specific amount of time in the future. Broadcast ephemerides are data that corresponds with factors that affect all satellites. This includes data on eccentricity, satellite health, clock bias information and other orbital information like mean motion and right ascension (and its rate).

The quality of the raw satellite signals are continually improving. Today there are two codes accessible to civilians- C/A code, which is transmitted on the L1 signal plus the newer L2C code, transmitted on the L2 signal. Signals will continue to improve when the new L5 signal is implemented with all new satellites.

2.5.2 NMEA Data

NMEA, which stands for National Marine Electronics Association is a type of data used to communicate between electronic equipment, including GPS. In the context of GPS, this is the output data of the position fixes calculated by the GPS receiver. They are expressed as sentences, which contains information completely for intended purpose of the electronic equipment. For example the following is a NMEA sentence transmitted from a GPS receiver:

$PMGNTRK,2852.109,S,15333.636,E,00011,M,024255.18,A,,100408*6C

$PMGNTRK represents Magellan GPS receiver track log.
2852.109, S, is the latitude of the measured point.
15333.636, E, is the longitude of the measured point.
00011,M, is the elevation and the unit of measure (metres in this case).
024255.18 is universal time (in 24 hour time).
A signifies Active, where V could mean Void.
100408 is the date of string creation.
*6C is the checksum, which is used by programs to ensure no errors are present in the data caused by transmission (Baddeley, 2001).

In GPS there is a minimum amount of data required in the NMEA sentences for a GPS receiver to effectively read incoming data. This data includes coordinates, plus other statistics and almanac data. Four types of sentences are sufficient for all GPS receivers. They are called:

- GGA
- RMC
- GSA
- GSV

GGA (Global Positioning System Fix Data) is a sentence that contains data of essential fix data which provides data on 3D positions and accuracy. Typical data in this sentence includes Latitude, Longitude and Elevation data, plus a number score (from 0-8) which determines the quality of the position (eg: GPS fix = 1 while RTK Fix = 4).

RMC stands for Recommended Minimum Sentence (C) and contains very basic coordinate data. They contain data on GPS PVT (Position, Velocity and Time) like Velocity of user in knots, plus the track angle compared to true north.

GSA (GPS DOP and active satellites) provides data on the nature of the position fix. This sentence contains data about the satellites used to initiate a position fix, the values of different DOP's (dilution of precision) plus data on the nature of the position fix (eg: 2D, 3D or no fix).

GSV (GPS satellites in view) is a sentence specially designated to communicate data about the satellites used in the position fix. As each of these sentences can only provide data for only four satellites at a time, more than one sentence may need to be sent to communicate all available data. Data included in this sentence includes the sentence number, number of satellites in view, satellite number, elevation and azimuth, plus the SNR (signal-to-noise ratio) which is an indicator of the strength of the signal.

NMEA strings are either stored as a file or transmitted to a form of visual display, like a map. In satellite navigation systems, NMEA strings are sent to the programs where the data is analysed and instantaneous positions are compared against on-board maps. Strings are sent frequently, which provides a flow of movement along the monitor, which displays the position of the driver.

The NMEA sentence shown above is only one example of many different types of NMEA sentences, which can contain numerous types of different data. Types of data that can be included in a NMEA sentence includes any such data related to GPS, whether it is Latitude and Longitude data, DOP (dilution of precision) of satellites and the satellites in view, bearings and distances and height data. Even additional information like weather (temperatures, wind speed and direction) and estimated positional error can be included in NMEA sentences.

2.5.3 Communications

There is some different ways of achieving a simulation of GPS data. But it would be difficult and impractical to simulate anything inside the single unit (eg: computer). We seek to simulate GPS data using a GPS receiver but bypassing the actual GPS signal position fixes obtainable in receivers. Instead we would seek to stream the NMEA data into the GPS receiver so that travelling around in the real world during this project is kept to a minimum. Basically, communication is necessary between a computer that is streaming NMEA data and a GPS receiver that can receive this data and use it to drive a path. Two options are available- using cables or wireless communications.

Cables will simply plug into both devices and attach each other for direct communication. The main problem is the speed of transfer of data would be limited to one speed (the speed the cable is designed and built for). Other limitations include specific plugs in both devices and the lengths of cables. Although good cable technology is available (e.g. USB), wireless technology is available for communication between such peripherals.

Bluetooth is a wireless technology that enables portable electronic devices to connect and communicate wirelessly through short-range, *ad hoc* networks (Haartsen, 1998). Depending on the device used, Bluetooth devices vary in its range of communication. Some devices can communicate at a distance of 100 metres while mobile phones with in-built Bluetooth capabilities have a range of only several metres. The capabilities of Bluetooth are of direct communication with eight (8) different devices like computers, home and mobile phones, hands-free devices and GPS receivers. It is an inexpensive and is an automatic alternative to cables. Bluetooth is the ‘stand-out’ communication means because of its ease of use and the fact that it is the latest technology in the wireless arena.

2.6 Risk Assessments

The purpose of a risk assessment is to calculate the likelihood of an event occurring during a process, mainly considering any event that may hinder the smooth performance of a process. In terms of software development costs, Kansala (1997) says that the inclusion of a risk assessment (with traditional cost estimation) will yield truly realistic estimates. In this project, risk assessments will be used to determine the overall risk of a car accident occurring due to a navigation error.

There are six (6) different steps in risk assessment, as given by Aagedal et al. (2002) and the University of Queensland Occupational Health and Safety Risk Assessment Management Guideline (2000). These steps are:

1. Establish the context
2. Identify hazards
3. Analyse risks that may result because of the hazard
4. Evaluate the risks
5. Treat the risks
6. Review and Monitor the risks

The scope of this project will look at steps one (1) to five (5), with particular emphasis on steps three (3) to five (5).

The analysis stage is where two different functions are analysed and presented- the likelihood and consequence of a risk. These combined gives an estimate level of risk, as given by Aagedal et al. (2002). The estimated level of risk is normally calculated using a pre-developed chart.

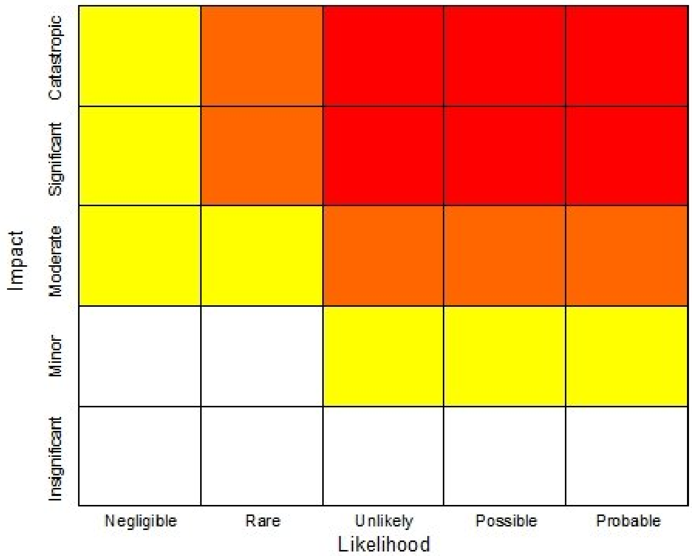

Figure 2.1- Risk Assessment Combining Likelihood and Impact

The chart above is one example of a simple risk analysis. The combination of likelihood and impact are merged by crossing each other, thus giving a score, based upon the square intersected. For example, if the likelihood was unlikely and the impact was moderate then we would obtain an orange score, which is considered a high risk score.

2.7 Conclusion

This chapter has presented the outcomes of the literature review that was conducted. Journals and theses were found in the search that related to all the issues addressed. Background information to this project was found that will assist in understanding how to complete the remaining sections of this dissertation.

Major findings in this chapter included a critical analysis of modern car navigation systems, the sources and collection of road network data, a review of GPS simulation and GPS NMEA data plus methods of communications including Bluetooth. A brief overview of Risk Assessments completed this chapter.

Chapter 3

Project Method

3.1 Introduction

This chapter will outline the methods on how this project will be conducted and completed. This is necessary because a record of how this project is to be completed is required by means of informing the reader of the account of the main occurrences that led to the successful completion of this project. The main problem that will be addressed in this chapter is resolving a solution to the method of completing this project.

The aim of this chapter is to explain how all the methods needed to complete this project will occur, from the testing to the analysis and recommendations stage.

To achieve the aim for this chapter, an assessment of the literature review will assist in deciding the final procedures for this project. The composition of the GPS simulator will dictate the form of the final revision of this chapter. Deciding on the best method of data collection will not be difficult and will be completed very soon into the progress of the testing stage. The analysis stage will outline how the analysis will be conducted and which risk assessment will be used in this project.

3.2 Overview of Project Method

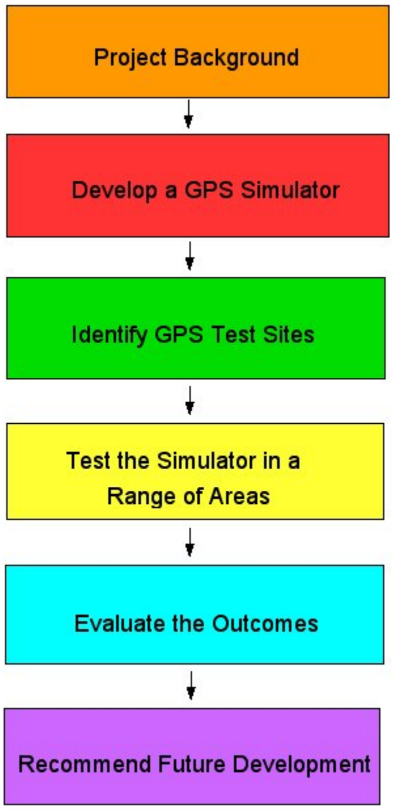

Figure 3.1- Project Method

3.2.1 Project Background

Background knowledge of the different aspects of the project has been covered, ranging from the GPS satellite navigation systems to simulation concepts. This stage of the project is covered in the second chapter of this dissertation.

3.2.2 Develop a GPS Simulator

The aim for this project included the ambition to develop a GPS Simulator. A simulator will be developed using a computer program that can generate and output NMEA sentences to a COM port on a computer that will then send these sentences via Bluetooth wireless signal to a Bluetooth-enabled GPS receiver. Some work will be needed to ensure this occurs successfully. However if any stage of this plan put forward here is unsuccessful, assistance may be required to facilitate the function of this proposed simulator.

There is a range of different NMEA generator/streaming software packages available, depending on the specific purpose of the simulation. Putting it all together into one single system will require some amount of time in testing the different stages separately and then bringing it all together to form one complete simulator. Testing will also give us an evaluation of its overall suitability for this project. The purchasing of needed equipment like base maps and a GPS satellite navigation system will be required during this stage.

3.2.3 Identify GPS Test Sites

This stage involves identifying some specific roads that may have erroneous data for the purpose of testing the GPS receiver. As discussed in the Literature review, there are two different types of errors we are seeking to test- missing data pertaining to existing roads and surveyed roads that are not operational as a road (excess data). We will focus on finding data related to roads that are familiar and if necessary, resort to roads that are unfamiliar. For this purpose, most of these roads will exist in the South-east Queensland and Northern New South Wales regions. Once these sites are chosen, coordinate data for these roads will be found using Google Earth or by capturing NMEA data whilst driving these roads. Different roads will be chosen depending on the type of errors that are present and the type of road (urban streets or rural highways). If we simulate a road using coordinates obtained from Google Earth, field inspections may be required. The capture of NMEA data by driving routes can be achieved using a computer program that reads the NMEA sentences outputted by a GPS receiver that either connects to the computer using a USB cable or via Bluetooth.

3.2.4 Test the Simulator in a Range of Areas

These sites will be tested by our simulator through the transmission of NMEA sentences from the computer to the GPS receiver. The sites will contain erroneous data and will either encounter navigation problems (due to missing data) or smooth navigation along non-existent roads. The reaction of the navigation system will be noted for further analysis. Preparation of data for simulation will be the collection of NMEA text files with captured data or the coordinates of roads obtained using Google Earth. Successful simulation of a road that does not exist will be tested and situations that would occur in the real world (like the choice of driving a different road) will be evaluated. When the chosen roads are tested using the simulator, their suitability will be assessed. If for some reason a road is unsuitable then a new road will be chosen and the steps to be taken (like data capture) will be completed.

3.2.5 Evaluate the Outcomes

The results will be analysed and an assessment of the quality of road network data used in satellite navigation will begin. Results will be kept separate, depending on the type of quality issues being analysed. The results will be reported based on the erroneous navigation achieved during simulation and an assessment of these effects on the safety of drivers through driver surveys and the accompanied risk assessments. The simulator will be assessed at this stage to determine its overall effectiveness in giving us reliable information.

3.2.6 Recommend Future Development

The results from this project will only be the first step in the process of evaluating and improving road network data for GPS applications. Future development will be required to achieve any improvements in the data. These recommendations will be made based upon the results of all analysis and risk assessments conducted during this project. Recommendations will be made based upon the overall quality of the road network data plus other recommendations for further research in the future.

3.3 Initial Satellite Navigation System Testing

Even though the overall accuracy of the GPS receiver is not part of any critical analysis in this project, the point-positioning accuracy has to be reviewed because of the snapping function in the CoPilot 7 software. The snapping function onboard satellite navigation software needs to be investigated by finding out the accuracy of the on-board GPS receiver and finding the approximate offset distance (perpendicular distance between a driver and a road) required for snapping to cease functioning. This situation can occur where a driver travels along a road that is not stored in the on-board maps in the satellite navigation system and this road exists parallel to a known road (say a neighbouring street that is parallel to an arterial road). Snapping involves the automatic movement of the navigation onto that neighbouring road. The CoPilot 7 software will 'snap' a driver onto a road that exists in the on-board maps, thus would affect the accuracy of a navigated path presented by the satellite navigation system.

To test the accuracy of the on-board GPS receiver, testing the position over known marks with coordinates will need to be made. Data related to some Permanent Marks or State Survey Marks will need to be found and the coordinates of these marks will be used to test the GPS by recording its position whilst sitting over these marks.

To test the offset distance snapping function we will find a straight section of road (a highway away from any urban areas) and record the coordinates of both ends of the road at different offset intervals. The coordinates will be found using Google Earth and the offset distance from the road (and their specific coordinates) will be found using the ruler function in Google Earth. Testing will be conducted to find out the different effects these offset distances make as the distances get larger and how far away the offset value needs to be before snapping will cease to function. Once this information is collected and analysed, a determination of the effects of snapping can be determined and how snapping affects the navigation along an unknown road and its safety on drivers.

Figure 3.2 – Ruler Function in Google Earth
(Source: Google Earth, 2008)

3.4 Development of GPS Simulator

The concept of developing this simulator was aimed at using some of the latest technology available today. Utilising wireless technology in the development stage was our initial aim and the vision of being able to use Bluetooth technology to transmit GPS data to a satellite navigation system was optimistic.

Several achievements were attained during the development stage that can be classed as important events in the final development of the simulator. The first event was a successful transmission of NMEA GPS data from a basic NMEA generation program to a GPS module on a mobile phone, using Bluetooth. Four basic NMEA sentences were transmitted in this initial stage: GGA, RMC, GSA and GSV. These sentences were able to display information like Latitude, Longitude, Accuracy, Altitude and Speed (all of which can be set in the NMEA generator program). Trip distances and navigation were two other available options that were utilised using this module. The use of this basic NMEA generator program (called NMEA Generator) had restrictions that would make it difficult for us to continue this

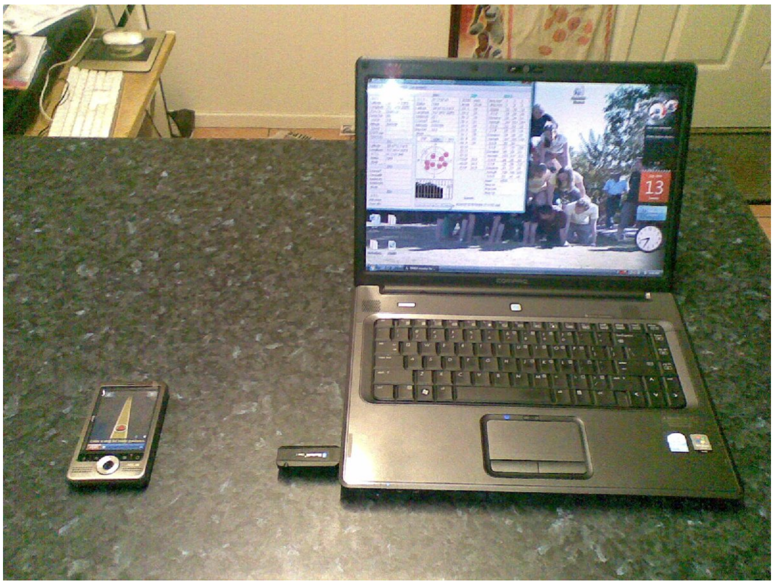

Figure 3.3 – GPS Simulator

project effectively. A different program was found that could record NMEA data from a GPS receiver and replay this data through a designated COM port. Both of these events were important achievements in the development of the simulator. This new program is called GPS-NMEA Monitor and it recorded NMEA data into a text file. This replay of NMEA data was similar to the NMEA generator, such that the data was transmitted through a Bluetooth COM port.

The final steps involved finding a GPS satellite navigation system that would receive NMEA GPS data through a Bluetooth connection. Options here proved to be more difficult due to the inability for conventional GPS receivers (eg: Navman, Garmin or TomTom) to accept Bluetooth signals from other external GPS receivers, even though there were other Bluetooth functions in-built into the units. The best solution to this was to use a PDA (personal digital assistant) with the option to connect to an external GPS receiver using a Bluetooth connection. After some research into the different brands of PDA computers that are capable of receiving NMEA Bluetooth signals it was decided that the best option was to purchase an Asus A696 (with CoPilot 7 navigation software and Navteq maps). After some initial testing this simulator became a very substantial development for this project.

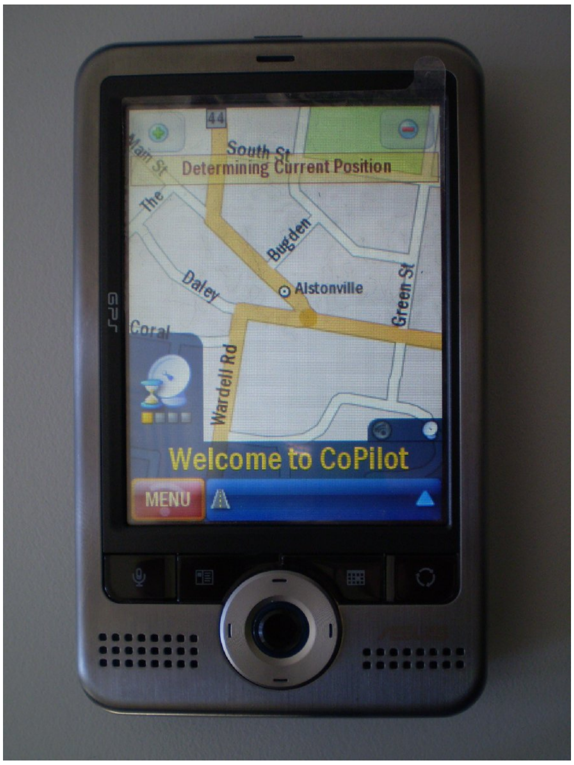

Figure 3.4 – ASUS A696 PDA Satellite Navigation System

3.5 Collection of NMEA Data

The GPS simulator was specifically developed to test roads with low quality road network data. This was to be achieved so that the analysis of the satellite navigation system's reaction to low quality road network data could be repeated without the need to drive the roads repetitively. Although these roads need to be driven to collect NMEA data, this would only need to be completed once. The coordinates of some other roads will need to be collected using Google Earth.

The collection of NMEA data is a critical component of the project, as this data will be used in the simulation of the navigated roads. The actual collection of this data is to be conducted using two different methods. Each individual section of road that will be tested will determine the method of data collection. The two methods are:

- Direct collection of NMEA data using a GPS receiver
- Indirect collection of coordinate data using Google Earth

If the roads to be tested are only a small section of road then collection of data using Google Earth will be the best option. This coordinate data will be used by inserting these coordinates in the NMEA generator software. This method of data collection will also be used with roads with excessive data. To collect this data in Google Earth, the cursor would need to be held over the node on a road so that the latitude and longitude of that point would be displayed and thus written down and stored. Doing the same for all the points along the road would give us the positions of nodes along the road at the points where the direction of travel would change. If this coordinate data is entered into a text file in the correct format, this data can then be copied and pasted into the configurations settings file and the data will be ready to be used when the NMEA generator program is opened. The collected coordinate data is included in Appendix B.

***Figure 3.5 – Cursor on Road in Google Earth with Coordinates Displayed at Bottom of Screen**.*

(Source: Google Earth, 2008)

The other option for recording NMEA data involves driving the roads to be tested and collect this data using a GPS receiver. This receiver is connected to a laptop and communicates with the NMEA data collection software program through a USB COM port. The GPS receiver used for this option of data collection is the Magellan Explorist XL. This GPS receiver connects to the laptop using a USB cable and all NMEA data is streamed into the program and recorded in a text file (saved as .nmea).

Once the NMEA text files are saved, they can be used to replay the journey using the recorded NMEA data. The COM ports are assigned to the satellite navigation system and the data is streamed to the device. Once the GPS settings in the PDA are set to Bluetooth (and to the transmission from the computer) the PDA will receive this data and begin its navigation to the predetermined destination.

3.6 Simulator Setup for NMEA Data Transfer

The replay of the NMEA data will use the same program utilised to collect this data, that is, GPS-NMEA monitor. Before this program is used for NMEA data replay, the Bluetooth USB adaptor needs to be setup. This involves setting up the Bluetooth adaptor to talk to a specific Bluetooth-enabled device using a COM port. To set a COM port for a specific device, the software provided with the device gives the option to add a device as a COM port to another Bluetooth-enabled device. Once the device is scanned, the software assigns a COM port number for exclusive communication between the computer and the assigned Bluetooth device.

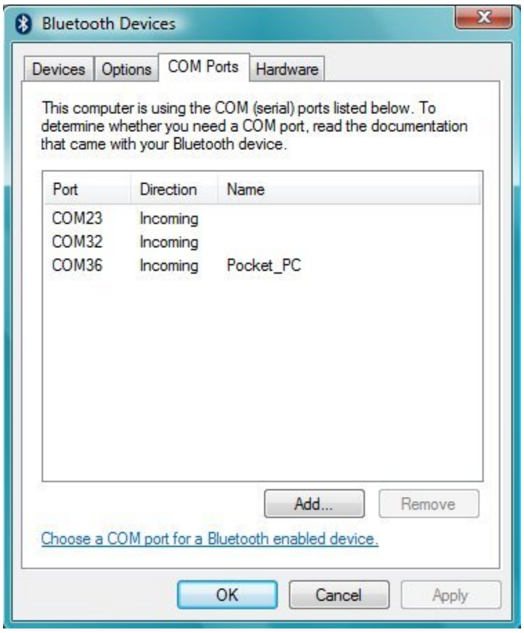

Figure 3.6 – Bluetooth COM Ports

When a COM port is assigned to the satellite navigation system, COM ports need to be assigned on the PDA. This will ensure direct communication between the PDA and the computer. Finally the last settings to be made are in the CoPilot 7 software. There are options that allow either the use of the in-built GPS receiver or a Bluetooth-enabled GPS receiver. Once the Bluetooth option is set and the computer is chosen as the GPS receiver then simulation is ready to commence.

Once the simulator is ready, a .nmea file is to be assigned in the GPS-NMEA monitor program. The COM port settings that were set in the computer for NMEA data transfer to the PDA also need to be made in the options menu. Once the NMEA file is opened, transfer of the data is ready to begin. On the bottom of the screen is the play button; a simple press of this button will begin NMEA data transmission.

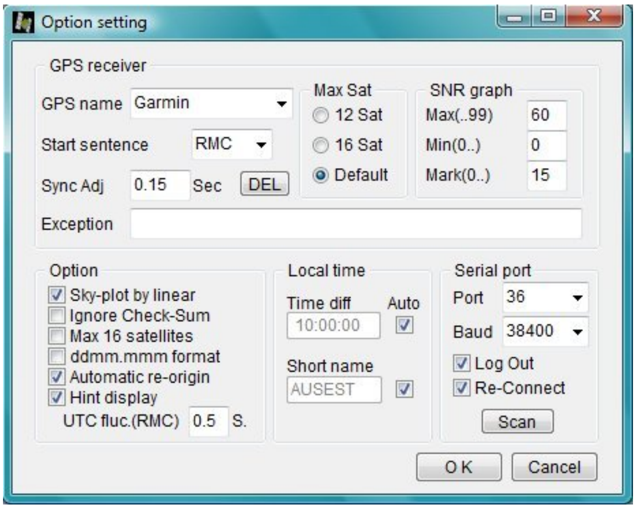

Figure 3.7 – COM Port Options in GPS-NMEA Monitor

To ensure successful transmission of data the satellite-navigation system would be displaying the dynamic effects of this data through the movement of the vehicle down a recorded path. To ensure navigation, a destination must be set. The destination must be set so that snapping onto roads does occur and that a reasonable assessment of the driver's safety can be examined and determined. If the simulation does not occur the most likely problem is an error in the settings, either in the computer program, the COM port assignments or the CoPilot 7 settings. All of these settings must be correct for simulation to occur.

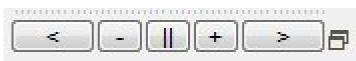

Figure 3.8 – Play/Pause Buttons in GPS-NMEA Monitor

3.7 Monitor Satellite Navigation System for Navigation Errors on Missing Roads

This stage of the method entails identifying errors present in the navigation made by the car navigation system. The nature of these roads is known- therefore the identification of any navigation as incorrect will be made easier due to known information about the roads. These errors will be identified and used in the next stage of this project, the survey of drivers.

3.7.1 Missing Roads- Pacific Highway, Brunswick Heads, NSW

This first example of testing a road with missing data is the new deviation of the Pacific Highway, extending from Yelgun to Brunswick Heads, approximately 45 kilometres north of Ballina, NSW. This new section of the Pacific Highway was constructed to improve traffic flows through this area, by means of bypassing towns like Billinudgel and Ocean Shores. This new road is approximately 8.6 kilometres in length.

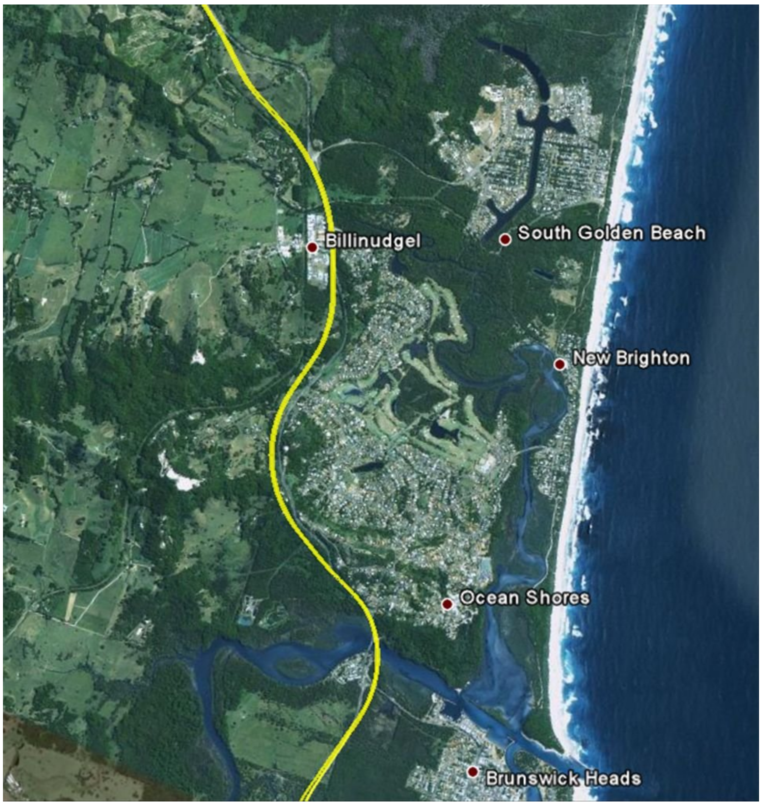

Figure 3.9 – Pacific Highway, Brunswick Heads
(Source: Google Earth, 2008)

Although this new section of the highway is a new road, it follows a similar route to the old highway and we would expect the snapping function to be active during the testing of this road. But the new road does deviate in specific sections which would allow the snapping function to be tested and evaluated. The old road also had a roundabout on the highway at the Brunswick Heads turnoff which remains in the maps that are loaded into the satellite navigation system.

Analysis of this road would give us a suitable perception of the effects of low quality road network data on a major highway. This highway has improved driver safety but the effects of low quality road network data can be a confusing and potentially dangerous situation for drivers who do not travel this road regularly.

3.7.2 Missing Roads- Elevation & Aspects on Lennox, Lennox Head, NSW

The second example of roads with missing data are two new subdivisions that exist approximately half a kilometre apart on North Creek Road, south of Lennox Head, NSW. These subdivisions finished construction in 2007/2008 and are only a few minutes drive to local beaches and neighbouring towns like Lennox Head and Ballina.

These new roads will be tested to give us an assessment of the effects of low quality road network data in urban areas, where pedestrian activity would be high. The expected reaction of the satellite navigation system to these roads is expected to either snap onto neighbouring streets or navigate into an area with no data.

3.7.3 Missing Roads- Hogbin Drive, Coffs Harbour, NSW

The third example of testing roads with missing data is the new extension of Hogbin Drive, in Coffs Harbour, NSW. This new road links between the existing Hogbin Drive roads, the focus being the section between Orlando and Howard streets. This new road gives residents of areas south of Coffs Harbour like Sawtell and Toormina better access to areas north of the city centre. It reduces travel times through bypassing the congested section of the Pacific Highway which goes through the centre of the town.

Construction of this new road was finished in February 2008 and sections of the road have been constructed in bushland away from existing roads. This new road will give an opportunity to analyse a major urban road and how safe it would be to travel this type of road without appropriate navigation. The expectations of the navigation of this road are for some snapping to occur onto roads that exist parallel on both sides plus some movement in areas with no road network data.

3.8 Monitor Satellite Navigation System for Navigation Errors on Excessive Data Roads

The method used to monitor navigation errors in these test sites will be no different to the method used in the test sites used in missing road data monitoring. These test sites however are based on roads that either non-existent or where access along these roads are restricted due to physical monuments in the real world.

3.8.1 Excessive Data Roads- Acacia Street, Killarney, QLD

The first example to test with respect to the problem of excessive data is Acacia Street, Killarney, QLD. This road exists as a dirt track along the southern section along the road from Willow Street, heading North-west. The northern section above the Condamine River does not exist and nor there is a bridge over the river.

Figure 3.10 – Acacia Street, Killarney
(Source: Google Earth, 2008)

When a driver is approaching Acacia Street whilst on Ivy Street, there is no road where the satellite navigation system would tell the driver to turn right. A driver approaching either end of Acacia Street would encounter different problems with respect to the nature of the road.

Figure 3.11 – North-west Entrance to Acacia Street, Killarney

3.8.2 Excessive Data Roads- First Avenue, Lismore, NSW

The second example is a road that has been closed from access due to the installation of a concrete drain even though the on-board maps in the satellite navigation system suggest that the road remains accessible. First Avenue in Lismore, NSW was originally surveyed and connected to the main arterial road that exists through Lismore, the Bruxner Highway. But this thoroughfare is closed to through traffic and is today only an access road for the houses on the north side of the drain. Traffic lights were installed in 2005 to connect Diadem Street with the Highway.

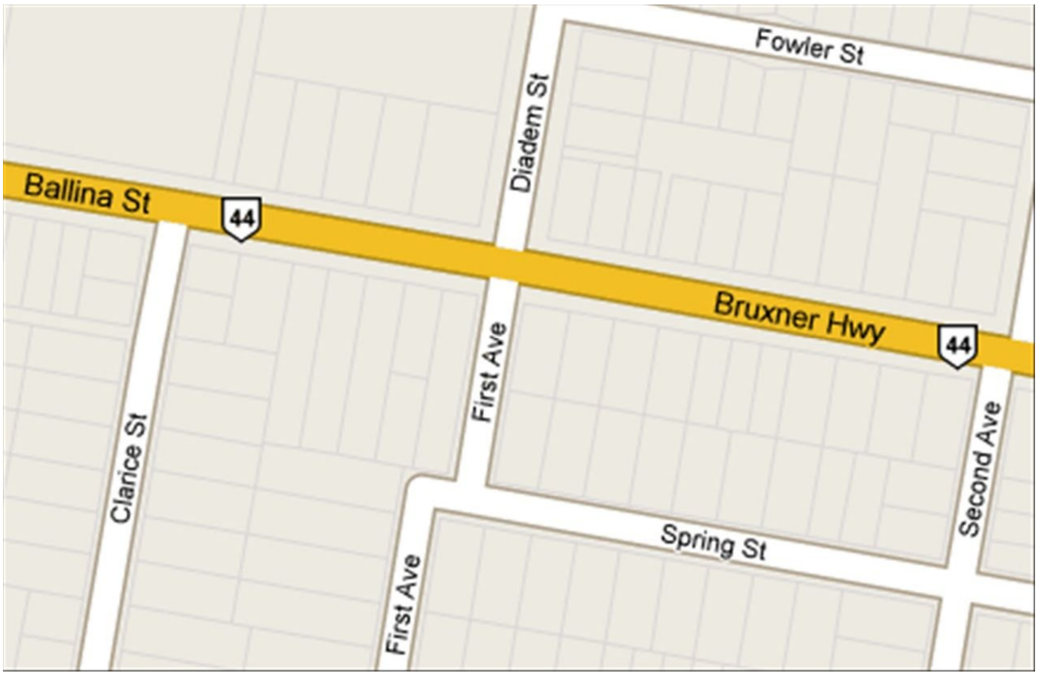

Figure 3.12 – First Avenue, Lismore

(Source: Google Maps <http://maps.google.com.au>, 2008)

Testing of these roads would be conducted to test the satellite navigation system by approaching First Avenue from the east along Ballina Road. This may pose some safety issues as this section of the highway from Dibbs Street to Second Avenue is a steep descent, which may cause drivers to gain speed approaching the First Avenue intersection. Some testing would also be conducted to test the safety of drivers who approach First Avenue from the west along Ballina Road.

Figure 3.13- Entrance to First Avenue, Lismore

3.8.3 Excessive Data Roads- Loveday Road, Cooby Dam, QLD

The final example is the testing of a road that was originally surveyed in an area where one of the major water-supply dams for Toowoomba, QLD now exists. Loveday Road is approximately nineteen (19) kilometres north of Toowoomba and exists along the southern edge of Cooby Dam with approximately half a kilometre of the road passing through the dam (if the dam was at full capacity).

Testing of this road will be conducted to see if the satellite navigation system would navigate us through the dam plus some testing of the possible reactions of drivers who would use this road. Some roads, yet to be mapped, exist around the dam and may be used in our testing.

Figure 3.14 – Loveday Road through Cooby Dam

(Source: Google Maps <http://maps.google.com.au>, 2008)

Figure 3.15- Loveday Road through Boat Ramp Sign

3.9 Survey of Drivers

When all the navigation errors have been identified in all six of the above test sites, a method of replaying these roads with errors will be finalised so that a suitable survey of drivers will eventuate. This survey will consist of the replay of the subject roads to a sample of everyday drivers, using the simulator. A series of questions will be presented to the drivers as they observe the actions of the satellite navigation system. With some given knowledge of the roads, they will answer the questions as a first reaction answer.

Certain situations in the driver's environment will be told to them during the simulation replay. This will influence the decisions they make, based on their own driving experience and level of driving they regularly perform. The questions developed and used for this survey is contained in Appendix C.

3.10 Risk Assessment

When a sufficient number of persons have participated in the driver survey, all the results will be combined to form a risk assessment for each of the sample roads. When a driver participates in the driver survey, they will be asked to rate the road with respect to the potential dangers the navigations pose to drivers. Each surveyed driver will rate the road in terms of:

- Probability of a Car Accident
- Potential Consequence of a Car Accident

An average outcome will be adopted for each site and a possible exposure score (rated from rare to continuous) will be determined, based upon the volume of traffic using the roads. The final risk score given to each road will range from Low to Very High. This final risk score will give an indication if the individual roads could have an impact on road safety if these satellite navigation systems are used.

3.11 Formulation of Further Recommendations

Improvements and recommendations for changes in the management and modification of road network data will be completed when the testing and the analysis stages have been completed. The full report of all recommendations is completed in Chapter five of this dissertation. The recommendations will address issues concerning the manipulation of road network data and procedures to change this data when roads are closed or simply do not exist in an area.

3.12 Conclusion

This chapter has outlined the methods that will be employed in the successful completion of this project. A simulator will be developed to aid in testing roads with low quality road network data, six (6) different roads will be tested using the developed simulator and their impact on road users will be evaluated using survey driver testing and risk assessments.

The literature review has assisted in developing a suitable project method. However, some stages like the development of the simulator and the driver surveys will be further developed as this project continues.

Chapter 4

Results

4.1 Introduction

This chapter will present the results related to all the testing which occurred during this project. This testing included the identification of navigation errors from the satellite navigation system and the driver reaction testing. These results will be presented to demonstrate the potential errors that can arise in satellite navigation and how drivers would react in certain situations. This chapter will further assist the direction of the discussions and recommendations chapter. Problems that will be addressed in this chapter are the nature of the navigation errors and the most likely driver reactions to the examples used in this project.

The aim of this chapter is to present the navigation errors that occurred during the simulation stage and the driver reaction test results that will indicate how a driver would react in these situations.

The simulator will operate and drive along the navigation paths and along the routes. Any variations between the navigation paths and the physical real-world roads will be identified. A driver reaction survey will be developed and the simulator will replay these navigations to a selection of drivers and their reactions to certain navigations will be noted as part of the risk assessments.

4.2 Satellite Navigation System Testing

The initial testing of the ASUS A696 satellite navigation system was to gain a better understanding of the capabilities of the system. The testing of certain functions would show how the functions would affect the results of this research. Testing of this data has brought some more background information and has provided some solutions to the capabilities and accuracies of the satellite navigation system.

The accuracy of a typical point-positioning quality GPS receiver is 10-15 metres with selective availability turned off. To achieve a result within this range would give a satisfactory result, namely that the quality of the GPS receiver in the satellite navigation system is acceptable. Measurements were taken using control marks (State Survey Marks) around Ballina, NSW. The control marks data were obtained from Deposited Plans and SCIMS (Survey Control Information Management System) data.

The control data for these marks are based on the GDA94 datum, which is slightly different to the measurements made by the GPS receiver, which will have data based on the WGS84 datum. The difference between these two data in 2008 would represent an ellipsoidal distance of about one metre. This difference exists because WGS84 datum is a dynamic datum; whilst GDA94 is a static datum (it represents the value of ITRF datum in 1994). The main reason why there are static and dynamic data is due to plate tectonics, and the relative movements of different plates around the world.

The results can be seen as comparable to each other, as this distance is minimal compared to the accuracy of the GPS receivers. The results for these tests were taken using two separate GPS receivers – the ASUS A696 and the Magellan Explorist XL.

Table 4.1 – Results of Point Accuracy

SSM78477	ASUS:	28˚51’38.29” S; 153˚32’11.91” E
	Magellan:	28˚51’38.34” S; 153˚32’11.94” E
SSM69195	ASUS:	28˚51’41.49” S; 153˚35’39.24” E
	Magellan:	28˚51’41.47” S; 153˚35’39.23” E
SSM64149	ASUS:	28˚51’56.56” S; 153˚33’31.50” E
	Magellan:	28˚51’56.56” S; 153˚33’31.50” E

Figure 4.1 – Location of State Survey Marks Used for Testing
(Source: Google Earth, 2008)

These results show good consistency between the receivers and the control mark data. Distances between any coordinates were less than 1.8 metres between the receivers and less than 2.8 metres between the receivers (on WGS84) and the GDA94 control data. The GPS receiver is therefore dependable for the accuracy needed for the experiments conducted. The position given by the GPS receiver would be sufficiently accurate, even if the situation arises where the maps do not contain roads when the GPS receiver is indicating a path through its position fix.

Experiments were conducted to test the effects of the snapping function in CoPilot 7. These experiments were conducted using the simulator (and the NMEA generator program). Offset distances were inserted into the program, in steps of fifty (50) metres from a straight section of road.

The section of road that was used to conduct these experiments were a straight section of the New England Highway at Missen Flat, approximately 42 kilometres south of Toowoomba. Tests were run on along the western side of the highway. In term of the results, there were no problems with snapping onto the road within 200 metres offset. When any distance above 200 metres were tested (first interval was 225 metres) there were some problems with snapping. Some experiments snapped onto the roads but some repeated experiments failed to achieve any snapping. A distance of 250 metres was tested and there were no snapping at this offset when several experiments were conducted. With this data gathered, we would suggest that snapping would definitely cease functioning somewhere between 230 – 250 metres offset from any road.

4.3 Suitability of GPS Simulator

After the testing has been completed it would be proper to assess the suitability of the simulator. In terms of its overall suitability it proved to be quite vigorous in the testing stage and the overall operation was excellent.

The section of the testing that tested the roads with missing data was very effective, as it simply replayed real-world NMEA data of these roads. To achieve this using a simple program and then transmit it through a Bluetooth COM port now opens up opportunities for similar testing using this technology in other applications. The GPS-NMEA monitor software allowed recording of NMEA data plus the replay of this same data through a designated COM port. Problems do exist with the simulation if there is too much distance between the computer and the satellite navigation system due to the limitations of Bluetooth.

With respect to testing the roads with excessive data, the GPS simulator overall performed very well. There was a dependence on data that was not collected in the field but when it operated it was very effective. The only problem experienced was a problem with the Baud rate of the NMEA generator. It reported that it was too slow, even when the port was set to transmit at the fastest rate. This would occur for around five to ten seconds before the simulation would resume. But sometimes as the simulator began, it would stop generating any NMEA data and the generator would need to be stopped and started again. If this problem were to be solved then the smooth operation of the simulator would be assured.

The GPS simulator has been capable of producing the type of simulation that was originally envisaged at the commencement of this project. Errors in the road network data were tested sufficiently so that the risk analysis of these results can be formally completed.

4.4 Navigation Error Results

The results presented in this section are summaries of the navigation errors that were identified. The definition of a navigation error is any difference between the instructed driving path and the possible 'real-world' driving path.

4.4.1 Navigation Error Results- Pacific Highway, Brunswick Heads, NSW

This example had data that was collected on both directions of the new freeway and both were used in the testing of this road. On the day the NMEA data was collected, the traffic volume on this road was moderate- high and the weather was wet and rainy. The satellite navigation system did provide incorrect navigation due to the low quality road network data and this data could possibly affect the safety of drivers using this satellite navigation system.

The two different directions that were tested on this road produced similar results, as the minimum distance between the dual carriageways would only be around five to ten metres. We found three main errors in the road network data that may have some effect on driver safety.

- Snapping back and forth along the Old Pacific Highway.

- Snapping onto Old Pacific Highway instead of accepting movement over an area with no data.
- Navigation at a roundabout that no longer exists.

There is a section of the highway that does not exist parallel to the old highway and thus some problems were experienced with snapping on this road and the location where this snapping occurred. The navigation software decided to stick to the old highway instead of snapping onto other local roads that do run parallel to this new highway because the old road was part of the intended navigation route.

Snapping that occurred onto the old highway was intentional by the navigation software but it should not happen if the road the driver is travelling along does exist as a separate road. Because the snapping offset distance is less than 200 metres, the snapping occurred with ease.

On the Old Pacific Highway deviation, there was a roundabout located at the turnoff to Brunswick Heads. With the freeway now at this location, the roundabout exists on the western side of the dual carriageways. As the simulation approached this section of the road, it told the driver to continue on through the roundabout by taking the second exit. With the roundabout now absent from the highway, the snapping function snapped onto the old highway and alerted the driver of the roundabout ahead.

4.4.2 Navigation Error Results- Elevation & Aspects on Lennox, NSW

This simulation began by driving along Skennars Head Road that continued onto North Creek Road. Navigation towards Lennox Head (located about four kilometres north) was set so the effects of snapping would be an option if the satellite navigation system seemed it should be the best solution. The traffic on these roads were light when the data was collected and the weather was clear and fine.

Figure 4.2 – Elevation and Aspects on Lennox (Roads Driven in Yellow)

(Source: Google Earth, 2008)

Two separate turns off North Creek Road occur- at Elevation and then at Aspects on Lennox. In Figure 4.2, Elevation is the southern subdivision mapped and Aspects is the other site further north. The first site driven was Elevation (approached from the south) and the satellite navigation system drove into areas where no data exists and the navigation stopped. CoPilot displayed the roads that were nearby during the drive through the subdivision, which included roads like Skennars Head Road, North Creek Road and Tara Downs (all of which lie east of the subdivision). When the driver turns and drives towards North Creek Road it can be seen in the distance but no snapping occurs, even when the direction of travel was parallel to that road.

Leaving Elevation, CoPilot snaps back onto North Creek Road and continues this until we turn into Aspects on Lennox. When the driver enters Aspects, the screen displays the car on North Creek Road moving back and forth until it begins to drive into areas where no data exists. This occurs until the driver reaches a section near North Creek

Road where CoPilot snaps back onto that road and suggests possible roads the driver could be on, including roads north of Aspects like Montwood Drive and Rainforest Way. Once the driver reaches North Creek Road once again, navigation towards Lennox Head resumes to normality.

4.4.3 Navigation Error Results- Hogbin Drive, Coffs Harbour, NSW

This example was an informative example of how low quality road network data can affect navigation through an urban area. Several situations occurred that were incorrect when compared to the reality of what exists in the real world.

Figure 4.3 – Hogbin Drive, Coffs Harbour (Roads Driven in Yellow)

(Source: Google Earth, 2008)

This road was navigating towards the Coffs Harbour Airport, which is situated south of the city. Our navigation commenced on Orlando Street, Coffs Harbour, heading South-east towards Coffs Harbour Jetty. Traffic was moderate on the day this route was driven and there were no problems in terms of the weather. The first noticeable error in the data is the absence of the new roundabout at Hogbin Drive. Once the driver passed the roundabout, turning right into the new section of road, navigation continued as CoPilot snapped onto Watsonia Avenue, one of two neighbouring streets. As the distance from Watsonia Avenue increased, movements back and forth along the street continued. When the driver passed the end of Watsonia Avenue, navigation ceased and CoPilot showed the driver driving in an area with no data. No snapping onto Brodie Drive occurred, even though it was nearby, as were Glenreagh and Barrie Streets.

The location of the new bridge over Coffs Creek was not contained in the maps either, so as a consequence, the driver continued over the mapped location of Coffs Creek as if there was no creek there. The driving also continued through where Coffs Street was located (just past Coffs Creek) but this street does not exist as an intersection. The southern end of the new Hogbin Drive extension exists parallel to the older deviation of Hogbin Drive and turns onto the old Hogbin Drive at the Howard Street roundabout.

Overall there were problems that exist with snapping onto neighbouring roads and driving in areas with no data and through objects that are considered ‘barriers’ in driving. Other problems included missing objects like roundabouts.

4.4.4 Navigation Error Results- Acacia Street, Killarney, QLD

Because this example was testing a road with excessive data, an amount of information was obtained with regards to the possible routes a driver would take in response to low quality road network data. Testing was conducted to see if CoPilot would operate if navigated along a road that does not exist in the real world plus on specific roads that would be used in reaction to missing roads.

The first testing to be conducted on this road was to investigate whether CoPilot would actually navigate a driver along this missing road. These tests were conducted approaching Acacia Street from the east and from the west. Both tests resulted in successful simulation of the navigation of this street in both directions. The problems lie, however with the absence of a bridge on the Condamine River (which the road crosses) and the absence of any road along the North-western section of this road.

One reality route was tested from the western approach to Acacia Street plus another possible route from the eastern approach. The western approach involved the driver realising the absence of the road and continuing along Ivy Street into Killarney. The reaction to this decision resulted in CoPilot navigating the driver to turn around at Banksia Street intersection (another 250 metres further up the road). When this was ignored it recalculated another route but told the driver to turn right at Cypress Street. This seemed strange as the turn to Cypress Street takes the driver back in the direction to Acacia Street.

When the testing was conducted for the possible reaction from the eastern approach, the navigation along Acacia Street was encouraged by CoPilot. This reaction involves ignoring Acacia Street and continuing along Willow Street by veering right. When the driver continued onto Willow Street and headed towards the central business district, CoPilot instructed the driver to turn around once. After this instruction was ignored, CoPilot recalculated the new route through the central business district and to turn left into Ailanthus Street.

4.4.5 Navigation Error Results- First Avenue, Lismore, NSW

Like Acacia Street, Killarney, the example used at First Avenue, Lismore was tested by approaching the error road from both directions-east and west. Tests were carried out to determine whether the navigation would occur if it was possible. Tests were also conducted based on the most likely reaction made by a driver who discovers the error in this road.

According to the satellite navigation system, navigation along this route would have occurred if it was possible. The first route tested that would represent the likely reaction of a driver was the approach from the east along the Bruxner Highway. When the driver approached First Avenue, CoPilot instructed to turn left and continue. A driver would see the barrier across the road and most likely continue along Bruxner Highway. When this occurred, CoPilot told the driver to make a u-turn at the roundabout at the intersection with Wyrallah Road and Conway Street. This would be, presumably, to navigate back to a turn right at First Avenue.

The second test would prove this possibility. When the driver approached First Avenue from the west, CoPilot told the driver to turn right into the street. The most likely reaction made by a driver to this navigation would be to continue straight ahead, because there is no right-turn lane at this intersection. When the driver continued through this intersection, CoPilot recalculated a new route, which tells the driver to turn right at Second Avenue, at the base of the hill.

4.4.6 Navigation Error Results- Loveday Road, Cooby Dam, QLD

The road that exists through Cooby Dam was tested once to see if navigation along this road would occur. As well, two different possible reactions were tested.

The navigation through the mapped road proceeded normally without any issues. Even though there were no issues, the dam was drawn on the map and when the driver continued along this road, the driver went over the water without any alerts or problems. The first possible reaction route approached this section of the road from the North-east. The most likely reaction was that the driver would continue driving along an unmapped, dirt road that continues to the left of the navigated road. The new direction the driver travelled along caused the satellite navigation system to snap onto a section of road previously driven (further north-east) approximately 400 metres away from the driver. As the driver continued along this road, CoPilot showed the driver moving back and forth along this specific section of the road. This seemed unusual because our testing on snapping showed that snapping would cease operation at an offset distance of 230-250 metres.

The second situation was of a driver approaching the dam from the southern side. The reaction tested here is where the driver realises the road does not continue, but follows a dirt road that veers to the left. Once the driver veered left and proceeded along the dirt road, CoPilot stopped all navigation and continued through an unmapped area.

4.5 Driver Reaction Results

The driver reaction testing had some varied results, with different drivers disagreeing in various situations. Some of the drivers have used a satellite navigation system previously, whilst some drivers have never used one. The results also varied between different types of drivers, ranging from a learner driver to a truck driver. All drivers were told of the individual conditions of the road, which include the nature of road, typical traffic volumes and terrain. A total of seven (7) drivers were surveyed. The drivers presented their views of the potential human injuries in terms of the specifications listed in the University of Queensland Occupational Health & Safety Risk Assessment and Management Guideline.

Table 4.2- Human Injuries Consequences

(Source: University of Queensland Occupational Health & Safety Risk Assessment and Management Guideline.)

Catastrophe	Numerous Fatalities
Disaster	Multiple Fatalities
Very Serious	Fatality
Serious	Serious Injury (Permanent Disability, Amputation)
Substantial	Disabling Injury, Requires Medical Treatment
Minor	First Aid Treatment

4.5.1 Driver Reaction Results- Pacific Highway, Brunswick Heads, NSW

Two different navigation errors were replayed using the simulator to the drivers. They were the jumping and snapping along the different sections of the old highway near Billinudgel and the approach to the roundabout at the intersection of the road to Brunswick Heads.

The first question posed to the drivers was based upon the jumping back and forth along the old highway. If the drivers saw this happening, five (5) said they would keep going and two (2) drivers said they would pull over and check the navigation system.

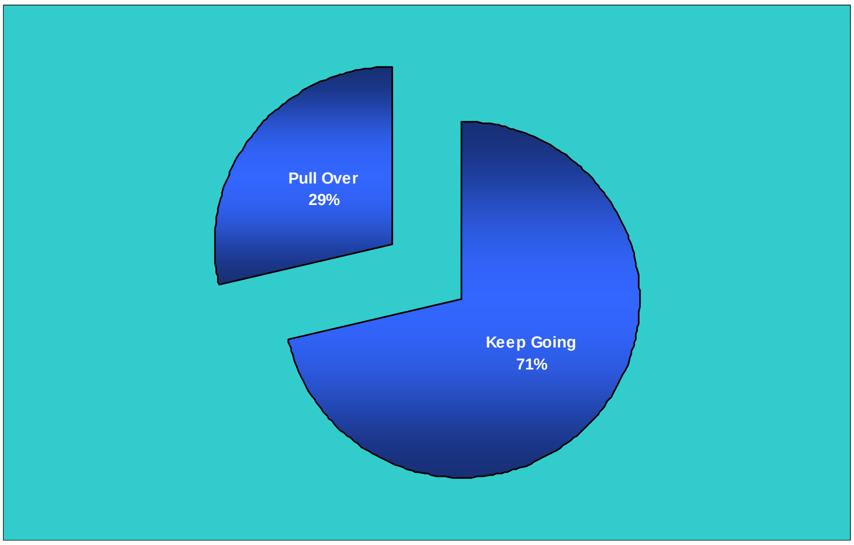

Figure 4.4- Jumping/Snapping Results

The second set of questions focused on the roundabout. They were focused on the driver's reaction to the approaching roundabout and their reaction to the missing roundabout. All drivers said they would slow down if they approached the roundabout. Six (6) of these drivers said they would accelerate and continue when they realise there is no roundabout to negotiate. The other driver said they would look around for it, and then continue.

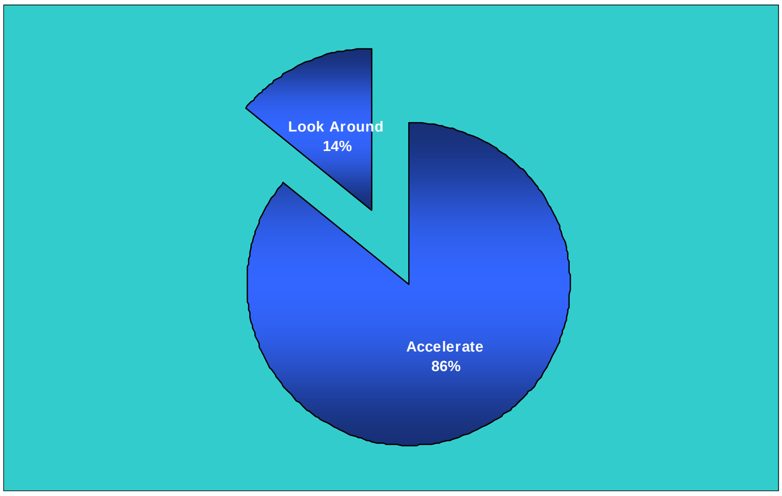

Figure 4.5- Reaction when Driver Realises Roundabout Does Not Exist

The drivers evaluated this road in terms of the potential for an accident and the consequence of an accident. The potential for an accident to occur ranged from conceivable to quite possible and the consequence ranged from minor to catastrophic.

Table 4.3- Driver Evaluation for Pacific Highway, Brunswick Heads, NSW

Probability		**Consequence**	
Almost Certain	0	Catastrophic	1
Quite Possible	2	Disaster	1
Unusual but Possible	3	Very Serious	4
Remotely Possible	1	Serious	0
Conceivable	1	Substantial	0
Practically Impossible	0	Minor	1

4.5.2 Driver Reaction Results- Elevation & Aspects on Lennox, NSW

In this example, two repeated questions were made when the drivers entered the two neighbouring subdivisions. The drivers were asked what their reactions would be when navigation stopped as they entered a subdivision. Four (4) drivers said they would ignore the navigation and keep going and the others either checked maps or turned around and continued along North Creek Road.

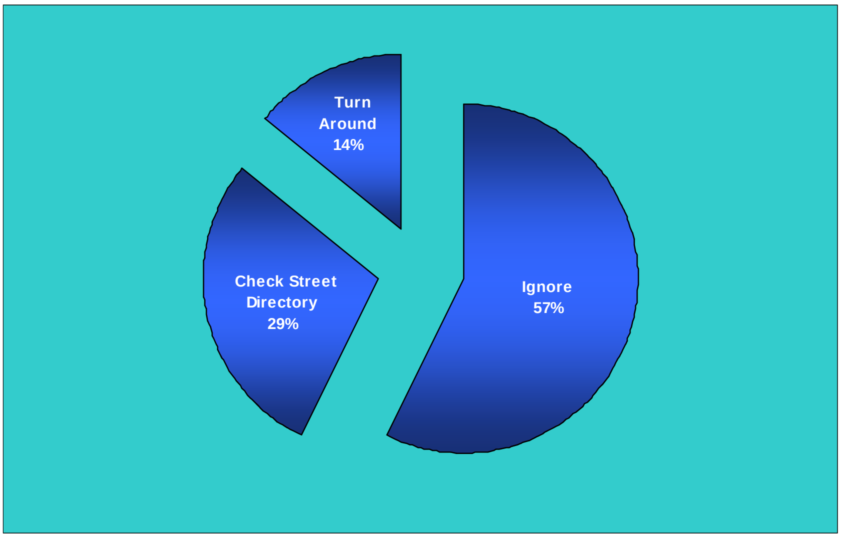

Figure 4.6- Reaction when Driver Enters Area with No Navigation

The question was repeated when the driver entered Aspects. Five (5) drivers said they would keep driving and the remaining two (2) drivers would ignore the navigation system and look for directions from the road signs.

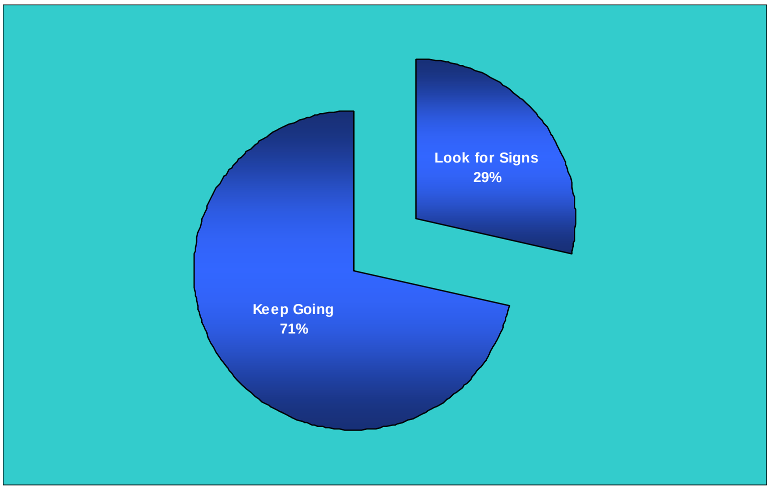

Figure 4.7- Reaction to Second Loss of Navigation

The drivers evaluated this road; the range given for the potential of a car accident was from practically impossible to unusual but possible and the consequence of an accident ranged from minor to substantial.

Table 4.4- Driver Evaluation for Elevation & Aspects on Lennox, NSW

Probability		**Consequence**	
Almost Certain	0	Catastrophic	0
Quite Possible	0	Disaster	0
Unusual but Possible	1	Very Serious	0
Remotely Possible	1	Serious	0
Conceivable	2	Substantial	4
Practically Impossible	3	Minor	3

4.5.3 Driver Reaction Results- Hogbin Drive, Coffs Harbour, NSW

Three different navigation errors were replayed to the drivers in this example. The first involved the navigation system snapping onto Watsonia Avenue, which is parallel to Hogbin Drive. The navigation told the driver to continue and turn right at Rosella Street, so the driver would turn back and head towards Orlando Street.

Figure 4.8- Northern Section of Hogbin Drive (in Yellow)

(Source: Google Earth, 2008)

The drivers were asked what they would do when they were told to turn right. All drivers responded that they would slow down and prepare to turn right. The next question was based upon their reaction when they realise there is no right turn at that point in the road. All drivers replied they would continue ahead, either ignoring the GPS or just proceed with some confusion.

The second question is similar to the questions posed in the Elevation & Aspects on Lennox example. The navigation system stopped navigation along a section of the road. The drivers were asked how they would react- six (6) drivers would keep driving and the other driver (the learner driver) said it would be up to the instructions given by the supervising driver.

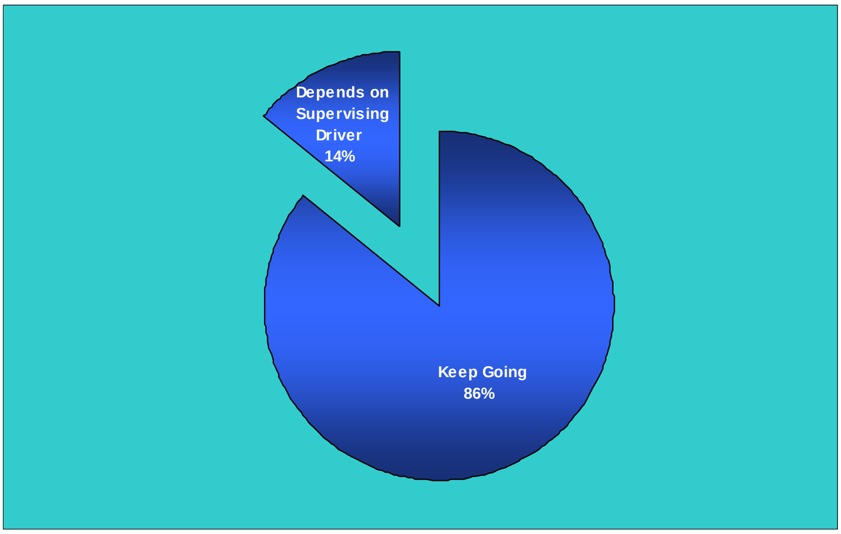

Figure 4.9- Driver Reaction to No Navigation (Hogbin Drive)

The final question involved what the driver would do when they saw a creek approaching on the navigation system. Theoretically, the driver should not be concerned about it because any driver would see a bridge approaching along the road. But one driver indicated they would slow down when approaching the bridge. The remaining six (6) drivers responded by continuing along the bridge.

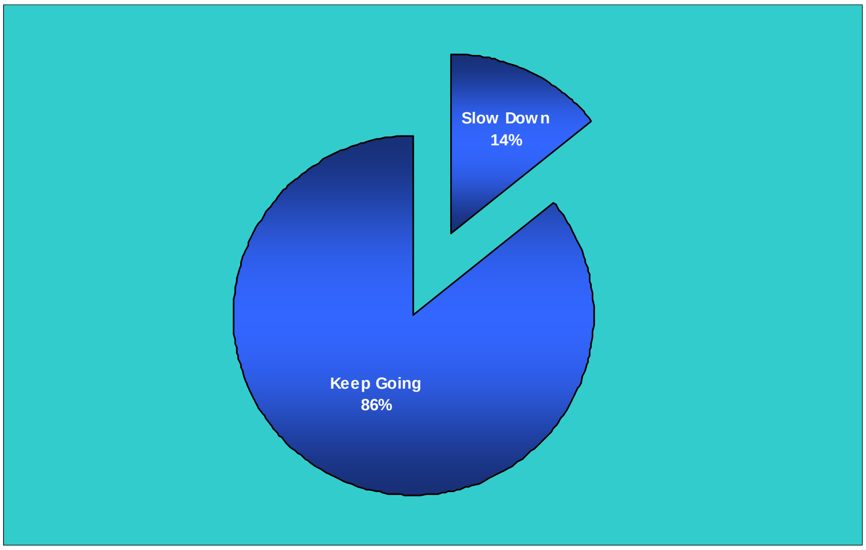

Figure 4.10- Driver Reaction to Approaching Creek (Hogbin Drive)

The final question involved their reaction when they realised a bridge would traverse the creek. All drivers would continue across the bridge and continue along the road, waiting for resumption in the navigation.

The drivers' evaluated the overall safety of the road and the navigation system ranged significantly. The probability of an accident on this road ranged from conceivable to quite possible and the consequence of an accident ranged from minor to very serious.

Table 4.5- Driver Evaluation for Hogbin Drive, Coffs Harbour, NSW

Probability		**Consequence**	
Almost Certain	0	Catastrophic	0
Quite Possible	1	Disaster	0
Unusual but Possible	0	Very Serious	1
Remotely Possible	1	Serious	0
Conceivable	5	Substantial	3
Practically Impossible	0	Minor	3

4.5.4 Driver Reaction Results- Acacia Street, Killarney, QLD

The replay of the navigation approaching this road was only performed on the western approach because it is the section of road that does not exist. Two groups of questions were asked to our drivers- the first involved the approach to the road and the reaction when they realised there was no road to turn right. All drivers said they would slow down approaching this turn (this is further encouraged because the driver is slowing from a 100km/h zone to a 60km/h zone).

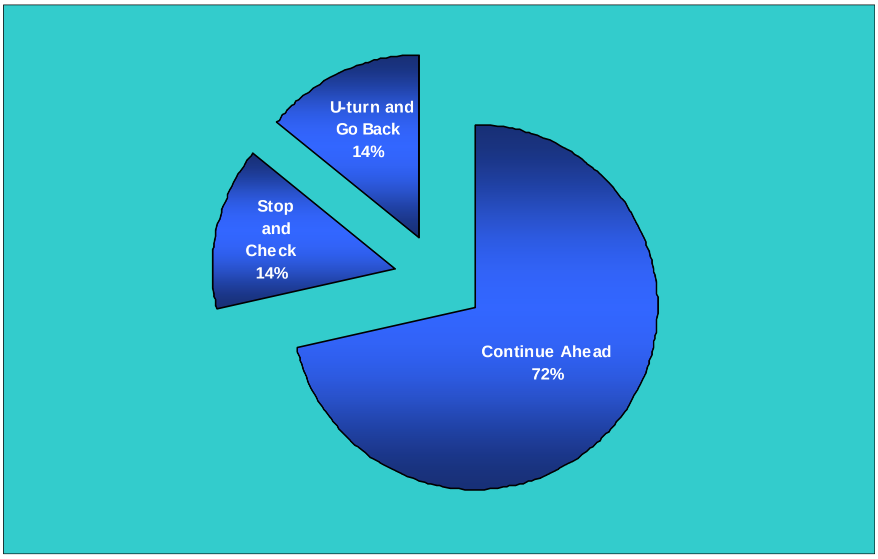

Figure 4.11- Driver Response to No Right-turn Road (Acacia Street)

Five (5) drivers said they would continue ahead when they realised there was no road when they were told to turn right. One driver would stop and check the navigation system and the other driver would turn around and look for other roads that existed before the instructed right-turn.

The second question was asking the drivers reactions to the navigation that was instructing the drivers to make a u-turn. These reactions were the same as the previous question. Five (5) drivers would continue, one driver would turn around and the other driver would stop and check their navigation system.

The drivers decided what the potential risk of an accident would be- their responses ranged from practically impossible to unusual but possible. The responses to the possible consequence of an accident ranged from minor to very serious.

Table 4.6- Driver Evaluation for Acacia Street, Killarney, QLD

Probability		**Consequence**	
Almost Certain	0	Catastrophic	0
Quite Possible	0	Disaster	0
Unusual but Possible	2	Very Serious	1
Remotely Possible	0	Serious	1
Conceivable	4	Substantial	2
Practically Impossible	1	Minor	3

4.5.5 Driver Reaction Results- First Avenue, Lismore, NSW

This road was only replayed with the driver approaching First Avenue from the west, heading east along the Bruxner Highway. This would involve the driver possibly attempting a right-hand turn across the busy intersection. Their decision would be the focus of the testing on this road. The first question was what the driver would do when told to turn right ahead. All drivers responded that they would slow down and prepare to turn right by entering the right lane. Their next question poses the question 'would you turn right?' Six (6) drivers said they would not turn right mainly because there is no existing right hand turning lane. Most of these drivers said they would continue and turn right further along the road. The other driver would turn right, but indicated they would turn around when they reached the drain that crossed the road.

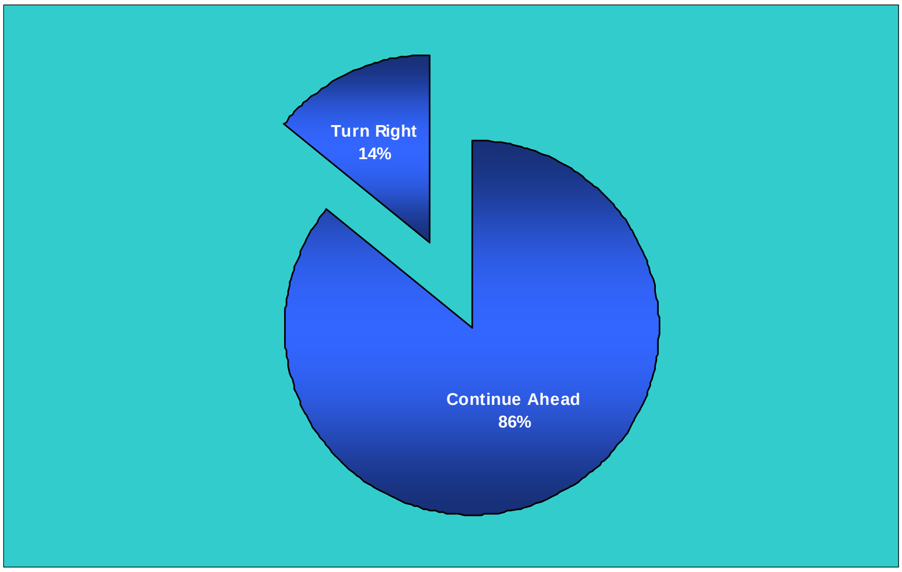

Figure 4.12- Driver Response to Restricted Right-hand Turn (First Avenue)

Overall the evaluation of the potential and consequences of a car accident caused by this navigation were higher than most previous examples. The drivers rated the potential for a car accident in a range from practically impossible to quite possible and the consequences to range from minor to disastrous.

Table 4.7- Driver Evaluation for First Avenue, Lismore, NSW

Probability		**Consequence**	
Almost Certain	0	Catastrophic	0
Quite Possible	1	Disaster	1
Unusual but Possible	1	Very Serious	0
Remotely Possible	1	Serious	1
Conceivable	2	Substantial	3
Practically Impossible	1	Minor	2

4.5.6 Driver Reaction Results- Loveday Road, Cooby Dam, QLD

Although this road was originally chosen because of the physical inability to drive it, the replayed simulation and driver reaction indicated very little in terms of adverse safety concerns caused by the navigation. There was only one basic question posed in this example, which was the reaction a driver would make when they realised the road goes through the dam.

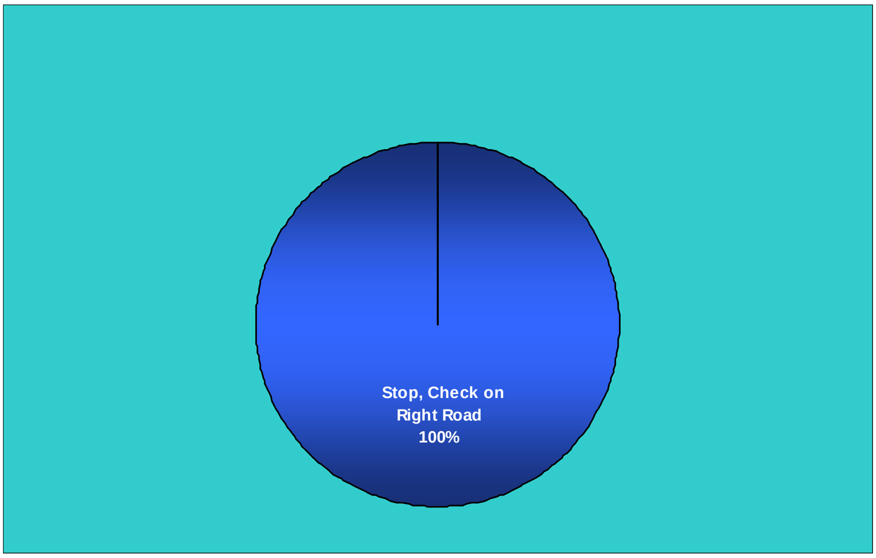

Figure 4.13- Driver Response to Dam on Road (Loveday Road)

All drivers said they would stop and check that they were on the correct road and then plan a different route if needed.

The evaluations made by the drivers' raised insignificant safety concerns. The probability of an accident ranged from practically impossible to remotely possible and the consequences ranged from minor to very serious.

Table 4.8- Driver Evaluations for Loveday Road, Cooby Dam, QLD

Probability		**Consequence**	
Almost Certain	0	Catastrophic	0
Quite Possible	0	Disaster	0
Unusual but Possible	0	Very Serious	1
Remotely Possible	1	Serious	0
Conceivable	3	Substantial	1
Practically Impossible	3	Minor	5

4.6 Conclusion

This chapter has presented all the results related to all testing and simulation that occurred in this project. These results include several navigation errors, for example, suspension of navigation, incorrect snapping and navigation along non-existent roads. Driver survey results show some of the road examples used have a high likelihood of an accident and potential negative consequences, including injury or death.

Navigation errors were identified and these findings were reported in this chapter. Driver reaction testing and safety evaluations were conducted and these results were presented in this chapter. The nature of the navigation errors were identified and varied between the different examples. All driver reactions were presented and these reactions will be used in the final risk assessments for each example.

The aim of this chapter has been completed- to present the navigation errors that occurred during the simulation stage and the driver reaction test results that will indicate how a driver would react in these situations.

Chapter 5

Discussion & Recommendations

5.1 Introduction

This chapter will report on the analysis of the results presented in the previous chapter. A series of recommendations will be presented in the second-half of this chapter, based upon the navigation errors that did occur and their causes. The problems this chapter is seeking to solve are:

- The analysis of the results into some formal findings with respect to the impact of driver safety from the use of satellite navigation systems and
- The formal recommendations stage.

The aim of this chapter is to report on the final analysis of the results with respect to the driver survey results and to report on the recommendations based on the navigation errors identified in this project.

The final risk assessments will be presented and they will be the main focus in the final evaluation of the impact on driver safety in each example, due to incorrect navigation. They will be compared against each other to determine the most dangerous examples and identify situations where errors would not have any effect in diminishing driver safety.

5.2 Risk Assessments

The risk assessment used in this project is a simple Risk-Score Calculator. The calculator adopted for this project was taken from the Occupational Health and Safety Risk Assessment and Management Guideline from the University of Queensland, Brisbane. It considers three different factors to decide the risk score for each situation- The potential occurrence of an accident, the exposure (or frequency) of a risk and the consequences of a risk if an accident occurs. The combination of the three will give a risk score. The exposure calculation will be based upon the likely frequency of a satellite navigation system providing these navigation errors. The remaining two factors are the average responses given by the drivers in the reaction and evaluation tests. The probability and exposure will combine to form a line that extends to a tie line. A second line will pass from the intersection point on the tie line through the consequence and intersect with the corresponding risk score.

5.2.1 Risk Assessment for Pacific Highway, Brunswick Heads, NSW

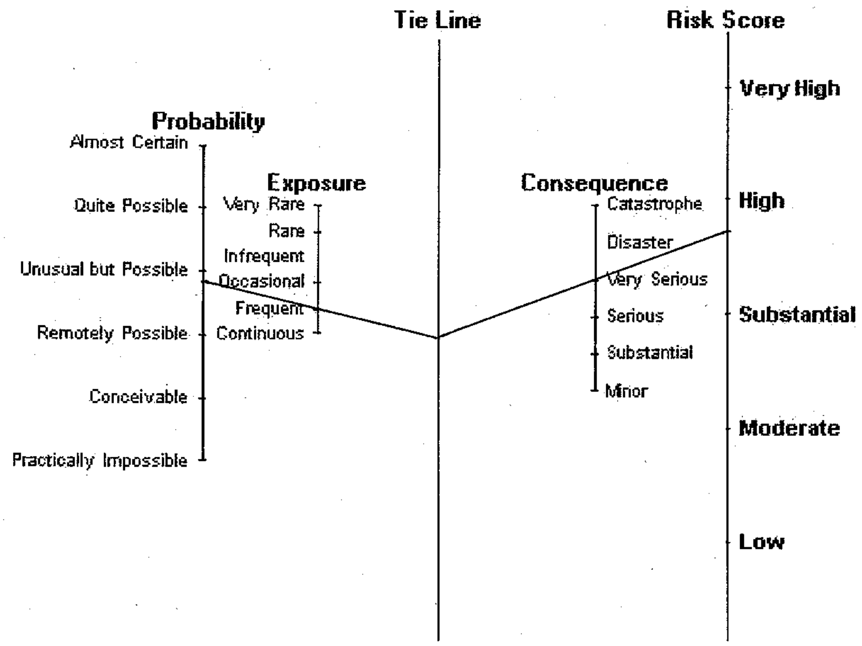

Figure 5.1- Risk Assessment Calculation for Pacific Highway, Brunswick Heads, NSW

The risk calculation for this example gives the highest risk score for all our roads tested. Frequent exposure was considered here because of the high number of persons that use the road, whether for holidays, business or transport. A substantial to high score means the overall risk of an accident occurring as a result of incorrect navigation is large, and something needs to be done to reduce this risk immediately (advice from Occupational Health and Safety Risk Assessment and Management Guideline from the University of Queensland).

Recommendations that will reduce this risk will be presented later in this chapter.

The drivers that were surveyed thought the most dangerous situation would be where a driver would slow down when approaching the roundabout that was indicated by the satellite navigation system. As a response to slowing down suddenly, a driver following (a truck in the worst case situation) our drivers may not be able to slow down quickly in response, thus an accident could occur. This example was the worst situation, as the other example where snapping jumped along different sections of the highway was considered ineffective in diminishing driver safety.

5.2.2 Risk Assessment for Elevation & Aspects on Lennox, NSW

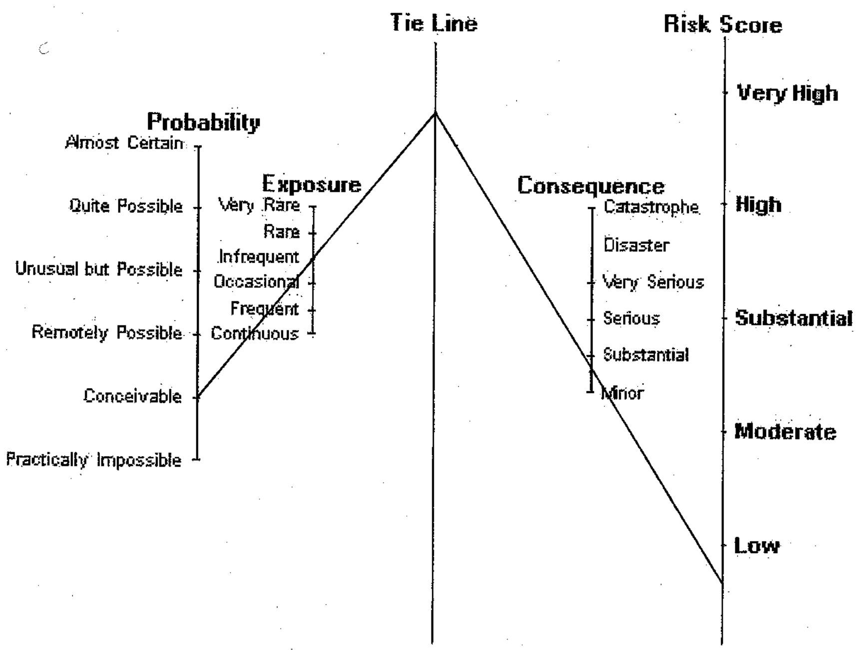

Figure 5.2- Risk Assessment Calculation for Elevation & Aspects on Lennox, NSW

This example tested the safety of using a satellite navigation system in a new urban subdivision. The risk score however showed that the risk of an accident on this road was very low. This can be contributed to the nature of the navigation error that can be considered insignificant and also the low traffic volumes along these roads.

Most drivers indicated they would ignore the navigation if the road was not there and drive around the subdivision, relying on road signs to get to their destination. Their reactions were similar as they entered both subdivisions and they thought their actions and that of other road users would not affect their overall safety.

5.2.3 Risk Assessment for Hogbin Drive, Coffs Harbour, NSW

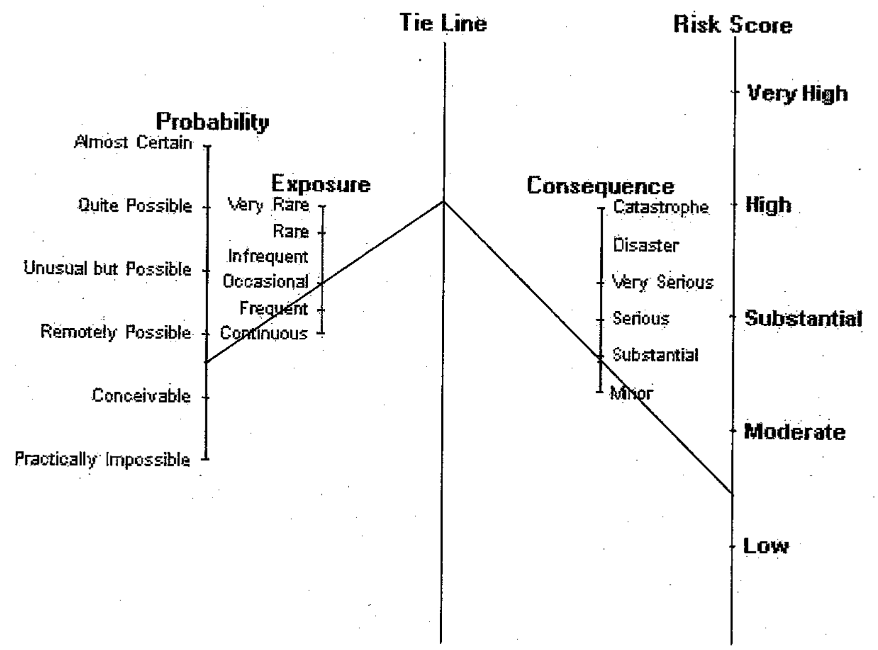

Figure 5.3- Risk Assessment Calculation for Hogbin Drive, Coffs Harbour, NSW

This example ranked third (3rd) in the overall risk score- it was scored between a low and moderate risk. The biggest problems that the drivers thought would affect their safety were the snapping onto the neighbouring streets and the approach to the creek. The consequence of them slowing down to turn right along Watsonia Avenue may cause an accident involving traffic moving in either direction. Some of the drivers were worried about the creek that appeared on the navigation screen, but they decided to keep going when they were told a bridge crosses the creek.

5.2.4 Risk Assessment for Acacia Street, Killarney, QLD

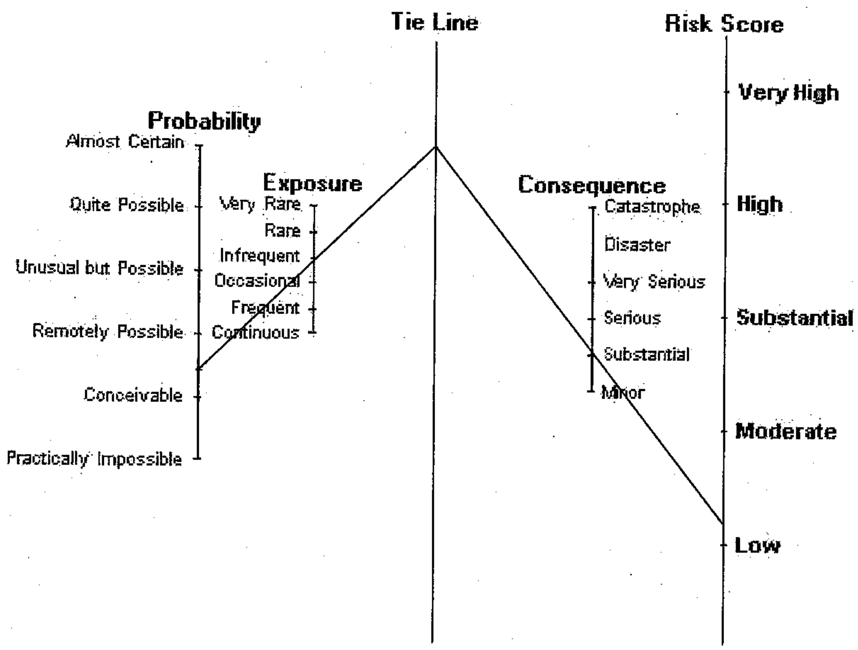

Figure 5.4- Risk Assessment Calculation for Acacia Street, Killarney, QLD

The final risk score for this road was just above low, which applies a very small chance of an accident occurring along this road due to the direct influence of a satellite navigation system on a driver seeking navigation. The fact that any driver needs to slow down because of a lower speed limit in the vicinity indicates that an accident due to a sudden reduction in speed is very unlikely. If this navigation occurred along a road where the speed limit remained at 100km/h, then a higher risk score may be calculated.

The actions decided by our drivers in response to navigation to turn around also had little impact on the risk score. But because the risk score lies in between low and moderate indicates that an accident could occur, though it would only be a small accident with some moderate consequences.

5.2.5 Risk Assessment for First Avenue, Lismore, NSW

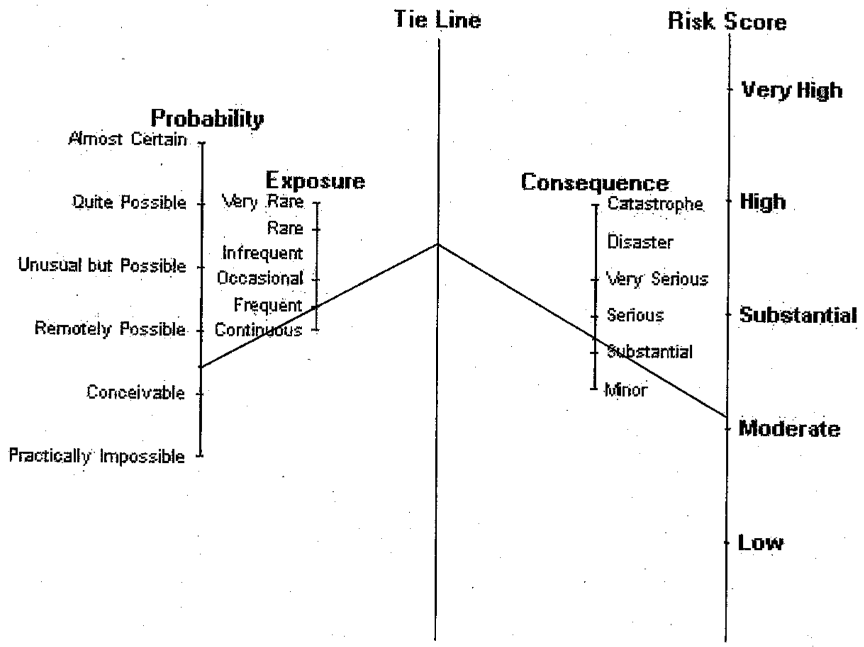

Figure 5.5- Risk Assessment Calculation for First Avenue, Lismore, NSW

This example ranked the second (2nd) highest risk score, behind Pacific Highway, Brunswick Heads. It gained a score of just above moderate risk, mainly due to the difficulty to access First Avenue from the highway and the implications of being caught in the opposing traffic flow.

Most drivers chose to continue along Bruxner Highway when the navigation told them to turn right. Even though they decided to do this, it still managed to gain a moderate risk score. The drain that crosses the road further in was not rigorously tested but posed no concern to the driver who did decide to turn into the street. Some drivers chose not to turn right simply because there was no designated right-hand turn lane.

5.2.6 Risk Assessment for Loveday Road, Cooby Dam, QLD

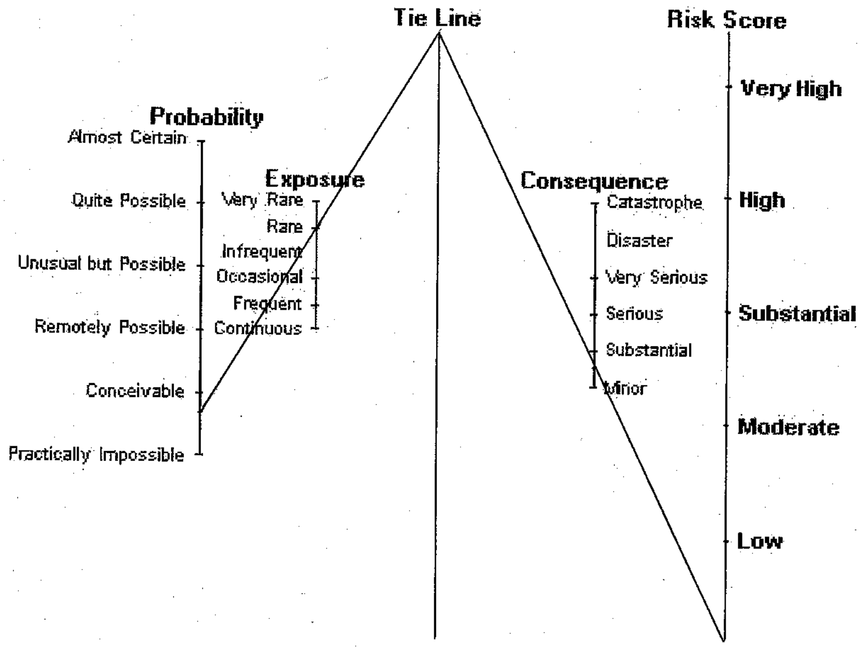

Figure 5.6- Risk Assessment Calculation for Loveday Road, Cooby Dam, QLD

As expected, this road had the lowest risk score of all the examples tested in this project. From the figure above, this road scored a very low risk score. The reasons for this are mainly due to the low traffic volumes and the slow vehicle speeds along the dirt track leading toward the dam. If a driver did follow this navigation, they would become very confused because the road simply disappears into the dam. But low scores given by the drivers, combined with a rare exposure gave this road the lowest score.

5.3 Discussion & Comparisons

The main feature to come from these risk assessments is the relationship between the risk score and the combination of both traffic volume and the type of road being travelled. The two highest risk score roads have high traffic volumes and are located on highways. The third highest score was Hogbin Drive, Coffs Harbour, of which has a high traffic volume but is not located on a highway. The next two highest scoring roads have only a moderate traffic volume and were tested on collector roads. The lowest-scoring road had very little traffic volume and was located on a country road. Therefore, roads that are either located on major highways or have high traffic volumes should be the main focus in data updating when these roads are modified in any way (including the connecting road networks).

The combination of a different number of factors gave the Pacific Highway, Brunswick Heads a greater risk score than all the other examples. This road has the highest speed of all roads tested (110km/h) and had a high composition of heavy vehicles. These factors, mixed with high traffic volumes and highway classification clearly make these roads the most dangerous with respect to incorrect navigation.

Clearly the type of navigation error, combined with the characteristics of the road differs on each road, and as a result, the risk score. The examples of First Avenue, Lismore and Hogbin Drive, Coffs Harbour have similarities, in that both roads have high traffic volumes and are located in a busy urban area. But the characteristics of the road (restricted access at First Avenue) and the type of navigation error (snapping at Hogbin Drive compared to restricted access at First Avenue) change the risk scores in comparison between the two examples.

Elevation & Aspects on Lennox example scored a similar risk score to Acacia Street, Killarney, but clearly both examples are very different to each other. Therefore all roads need to be weighed up in terms of their individual characteristics like traffic volume, traffic composition, speeds, location and the type of navigation errors.

Figure 5.7- Relative Geographic Location of All Examples

(Source: Google Earth, 2008)

The examples used in this project were concentrated in the North-east New South Wales and South-east Queensland areas. Although this may be the case, the six (6) examples used in this project varied in terms of location and the type of errors used in the testing. Their comparison in terms of the varied geographic location showed that different types of road network errors are spread across the entire area studied, and potentially, across all of Australia. It seems, however, that in areas where development of roads is constantly taking place that road network errors concerned with missing data is common. Lesser populated regions, like country areas, are affected more with the excessive roads problems (although as well common in larger towns).

Table 5.1- Rank of Highest to Lowest Risk Score

Road	Rank
Pacific Highway, Brunswick Heads	1
First Avenue, Lismore	2
Hogbin Drive, Coffs Harbour	3
Acacia Street, Killarney	4
Elevation & Aspects on Lennox	5
Loveday Road, Cooby Dam	6

5.4 Recommendations & Solutions

The recommendations and solutions presented here are derived from the navigation problems and errors encountered in these six (6) examples only. Other examples may generate their own unique problems and other solutions could be extracted through analysis of these roads.

5.4.1 Less Snapping Offset Distance

One of the main problems faced during the testing of roads with missing data was the issue of snapping and how it affects incorrect navigation. Incorrect snapping can lead to the commencement of navigation along a road that exists parallel to the road the driver is travelling along. This road may have no direct connections to the road that the driver is travelling along and could tell the driver to turn at an incorrect intersection. A conclusion to be drawn from our testing is that it may be better to exclude snapping if it regularly snaps onto an incorrect road. There is no purpose of using a satellite navigation system if it snaps onto an incorrect road, whether the driver is on a known road or not.

Our testing showed an approximate snapping offset distance of 230-250 metres using CoPilot. This figure needs to be dramatically reduced. A typical point-positioning quality GPS receiver can calculate a position solution within 10-15 metres. Unless the GPS receiver is experiencing a position fix problem due to minimal satellites in view, a position within these parameters should be reasonable. A snapping offset distance of about 50 metres only is recommended. This figure should be reduced even further when CoPilot is operational in a city, as many different roads exist parallel to one another and within close proximity.

5.4.2 Public Mapping Databases

Opportunities exist today for normal civilians to participate in online mapping, and to input their own neighbourhood road network data into online websites. These websites can be accessed freely over the Internet using a basic webpage browser. One example of these mapping websites is OpenStreetMap.org. This website is owned by Wikipedia and provides free roadmap input into their online maps.

A civilian who has the capabilities can record a road through the use of a point-positioning quality GPS receiver. The coordinates of the roads can be recorded and uploaded into OpenStreetMap, or can be manually inputted using the online paintbrush. A GPS NMEA data file can be uploaded and used to input a new road. Different types of roads can be specified (eg: highway or local access) and road input is unrestricted and anybody who desires may contribute to the construction of these road networks.

This solution may contribute to assisting companies like Navteq or Whereis to update their databases more regularly. Civilians can provide this form of assistance to these companies thus reducing the time difference between modifications in the road network and updating of information into their databases. However, there are risks involved in allowing the public to become involved in the updating of roads. The collection of road network data is traditionally compiled by spatial scientists, who have been trained in the fields of surveying, GPS and GIS. A typical civilian may not understand the necessary steps in accurately obtaining geographic information and their lack of knowledge can lead to errors in updating road network data. The facilities would also be vulnerable to deliberate incorrect additions of data. For these reasons, the development and implementation of such systems would need to be completed with the possibilities of these risks occurring to remain low and for the accuracy of these systems to continue to increase.

5.4.3 Additional Changes to Snapping Function

Other modifications can be made to the snapping function to improve performance and safety. In the example of the Pacific Highway, Brunswick Heads, CoPilot snapped onto the older deviation of the highway for much of the journey along the new highway. But if CoPilot ceased all snapping functions after about 50 metres, then a higher percentage of the road would not experience any snapping, thus no navigation. Even when this occurs, the satellite navigation system would still be recording freeway speeds (110 km/h). If this situation is measured by the satellite navigation system there should be on-board functions that automatically recognise that the driver is travelling along a road that, in fact does exist in the real world. Mapping of these roads as error reports will be discussed later.

The road network data that governments and companies collect is a network that connects with every other road in the network. In this sense, all roads are connected to each other and there is always a possible route from one address to another (which is attached to the road network). The road structure ranges from arterial roads like freeways and highways to local access roads like cul-de-sacs and loop roads. However, the road structure is a concept that is not included in the snapping functions and its inclusion would help prevent incorrect snapping. An example is shown below.

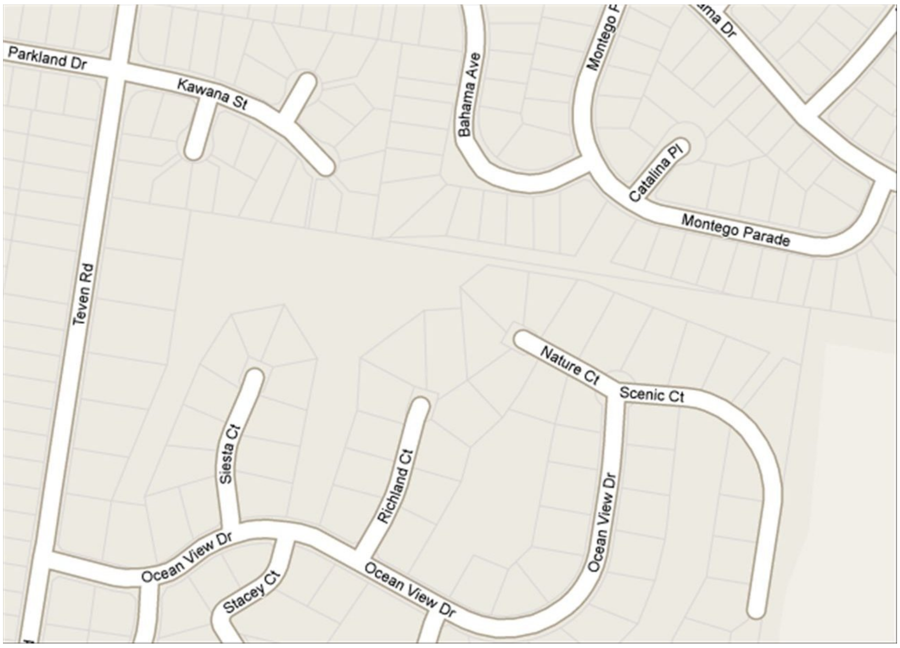

Figure 5.8 – Road Network of Linked Roads

(Source: Google Maps, http://maps.google.com.au, 2008)

In the figure, there are two separate subdivision areas that are only connected to each other by Teven Road. If Kawana Street is extended further east so that it passes in between the two subdivisions but remains unmapped, the CoPilot program would snap onto one of the neighbouring streets, like Montego Parade, Bahama Avenue, Nature Court or Scenic Court. But if a car does travel along the mapped section of Kawana Street then it would be logical for the journey to consist of the turn-around and subsequent travelling along Teven Road and then left or right into an appropriate subdivision. If the CoPilot software wants to snap the driver onto Scenic Court (on the south-side of Kawana Street) then the logical journey would involve travelling south along Teven Road, turning left into Ocean View Drive and then right into Scenic Court. This path must be travelled before snapping onto Scenic Court occurs. If this path is not travelled in this specific order then snapping should not occur onto that road. For these functions to operate some advanced programming would need to be added into CoPilot so that snapping would only occur onto a road that is next in a networked order.

In the example of Hogbin Drive, Coffs Harbour, it was identified that the new unmapped road existed between two parallel roads that exist on the eastern and western sides of the road. Snapping occurred on both sides of the road at different stages along Hogbin Drive. An improvement to be made here could be the temporary suspension of all navigation whilst the driver is moving through an unmapped area with parallel roads on both sides of the road. This uncertainty is unlikely to be related to problems with a position fix in the GPS, but it could be caused by an unmapped road. Linked to this recommendation is the verbal notification by the satellite navigation system to continue driving and that navigation will resume when a known road is reached. This may contradict the discussion above about travelling along a set network. However, error reporting (as discussed later) would ensure this type of low quality road network data is identified and reported.

Figure 5.9 – Watsonia Avenue & Brodie Drive both parallel to Hogbin Drive (Yellow Line)

(Source: Google Earth, 2008)

5.4.4 Use of Online Facilities for Error Reporting

The companies that retail road network data maps in Australia have made provisions on their websites to report errors in their maps. Whereis and Navteq have special websites for defining an error in their maps and what actions need to be taken to rectify errors.

The facilities that Whereis and Navteq have provided are comprehensive in their content and the amount of information somebody can provide to them is sufficient to identify the problem and its location. Both Whereis and Navteq have options where somebody can report an error concerning the location of a POI (point of interest), whether it is missing or should be removed. Both of the companies' websites have facilities to report errors in the roads they have stored in their maps, whether it's a missing road or a mapped road that does not exist. Whereis allows drivers to report errors by entering the 'to and from' navigation points that a driver uses to receive navigation. The details of the journey taken by the driver are to be filled in and a description of the specific errors encountered is to be completed to assist in error resolution. Navteq provides direct selection of the type of road errors encountered, including the nature of the erroneous road, the incorrect positioning of addresses and the type of restrictions placed on roads.

Both companies provide facilities to attach photographs of the roads in question as an attachment to the submissions. Other erroneous objects can be submitted on both websites, like bridges, tunnels and cartographic objects like lakes, rivers and parks.

5.4.5 Alternative Route Calculation

In some of the examples used to test the navigation of a vehicle using low quality road network data, the need to calculate a local alternative route was necessary to successfully continue a journey. This was particularly the case with Acacia Street, Killarney, where CoPilot constantly instructed the driver to turn-around and drive towards the

area of road that is non-existent. This problem was identified as a local area problem where one problematic road was encountered, but the continuing road is considered accurate.
The evidence for this recommendation is strong but its overall practicality and the effect this function would have on safety would need to be tested and proven that safety would not be unfavourably affected. This function would have to be activated by the driver if a similar problem is encountered, so that immediate calculation could occur. Such a function may require an explanation of its purpose and effectiveness to the driver who would operate the system. The effect this function may have on driver safety would be raised when the driver executes this function, and especially whether the function operates by a touch-screen button. The issues involve the overall essentiality of a specific touch-screen button in CoPilot (or any navigation software) to accompany the screen space used to display any GPS navigation and whether this function can be executed safely.

5.4.6 Communication between Governments and Mapping Companies

This problem is the main reason why errors in road network data do exist. Although governments have supplied mapping companies with data of some roads they have responsibilities over, the data they have supplied for some roads is considered low quality. New roads intensify this problem, where the period of time between the opening of a road and the road network updates are too excessive.

These companies exercise their own data capture of the road network in Australia and would maintain their maps independent of all levels of government. However, this project has found these methods to be poor practice, especially when driver safety is found to be at risk. The roles that both private mapping companies and governments have on driver safety improvement need to be recognised. Thus, communication of the status of new roads between governments and mapping companies need to increase. Private mapping companies need to ensure better accuracy of road network data because of potential liability claims that can occur due to injury or losses, partly caused by poor quality road network data.

This process can be setup and executed using two different methods- either voluntarily or set as a requirement through legislation. The enforcement of new road notifications through law would be difficult and vague to setup, as notifications would need to be sent to specific companies (which include Whereis and Navteq). If a third company emerges in the future, laws may need to be rewritten and the definition of a private mapping company may, or may not apply to them. Voluntary notifications would be a better option for state and local governmental authorities to adopt, but obviously, it would remain optional only. In New South Wales, survey plans need to be approved by local councils before registration of plans can occur. If copies of these plans that are given to councils for approval are forwarded to companies like Whereis and Navteq they would be formally notified of an approved plan for registration and notified of potential future road resumptions.

5.4.7 Automated Mapping

This idea for an ongoing solution to low quality road network data would also require extra software to be in-built into the navigation programs. The aim of such a program is to automatically record waypoints and paths that are identified as potentially low quality road network data. The theory behind this solution involves the recording of such data and the upload of this data to the map-provider at such a time when on-board maps are downloaded as an update.

Roads with low quality road network data can be identified in a number of different occurrences. The movement along an unmapped road that causes a loss of snapping can be recorded by storing a series of waypoints which are stored in an error file, of which these files would be uploaded to the mapping company when map updates occur. Even where recorded vehicle speeds are only travelled on specific roads (like freeways)- automated mapping can record such events. The existence of low quality road network data would become clearer through the uploading of this data, especially if such error data is supported by a different driver who drives the same road and records the same errors in these maps. Frequency of errors recorded in the same area would provide some evidence for a need to update road data in that specific area.

The automatic mapping of erroneous roads can be related back to our discussion on the road network structure. If a road is used by the snapping function before a predetermined route/s is travelled, then these waypoints should be recorded into the error folder. This example of the identification of road network data in error is mainly related to errors due to missing data.

In the testing and research stage of this project, Navteq maps were used in our navigations. These maps also contained other geographical information like waterways, parks and railways. In our example at Hogbin Drive, Coffs Harbour, the driver passed over an unmapped bridge and it appeared on the map that the driver was driving over a creek with no bridge. Irregularities like this can be included in automated mapping and error reporting. Even if drivers appear to drive through an area of parklands or cross a railway line at an undesignated crossing, it could be stored and reported in the error reports.

5.4.8 Confirmation of Accuracy of Data from Governments

Although data from different levels of government are being supplied to commercial mapping companies, some of this data is problematic in that it contains data of roads that do not exist in the real-world. For companies like Whereis and Navteq to prevent this problem from growing, confirmation and checks of data received from governments need to be completed before roads are inserted into their maps. With the facilities available today, this investigation can be completed in two different ways:

- Field Inspections
- Analysis of Aerial Photography

Field inspections involve the actual visitation of the road and to examine its condition and ability to access. The difficulty with this option is the limitations on people from mapping companies to visit all the roads provided to them for inspection, due to the size of Australia. This solution would be suitable to a mapping company that maps a small country or area, but in Australia, it may prove too difficult and uneconomic unless a large inspection or several nearby inspections are required.

The second option, inspection using aerial photography is a better option in Australia's case. The majority of urban areas in Australia are concentrated around the east, south and west coasts. Therefore the effectiveness of aerial photography to capture all urban areas regularly is superior to individual field inspections. Google Earth has become an excellent source of free aerial imagery across the world and continues to be an excellent resource for this purpose. In the case of Australia, inspections using aerial imagery are recommended as the first option. If aerial imagery proves inconclusive, field inspections may be required.

5.5 Conclusion

This chapter has reported on the analysis of the results presented in the results chapter. Some roads have a moderate to high risk score, which suggests that driver safety in these cases cannot be guaranteed. Recommendations have been presented that were based upon the navigation errors that occurred and their causes. Some of these recommendations included improvements to the snapping function in satellite navigation systems, automated mapping and greater responsibilities for mapping companies and governments. This chapter solved the problems that were required to be resolved. These were the analysis of results into some formal findings with respect to the impact of driver safety from the use of satellite navigation systems and to report on some formal recommendations.

Risk assessments were completed to report on the final analysis of the results and recommendations were presented, as to fulfil the requirements of the aim of this chapter.

Chapter 6

Conclusion

6.1 Introduction

This chapter will conclude this thesis with an outline of all achievements and explain the final outcomes drawn out from the research performed. The problems this chapter will solve are related to answering the problem stated in the project aim in chapter one (1), plus an overview of the future use of the developed simulator.

The aims of this chapter are to:

- Answer the question ‘does poor quality road network data in car satellite navigation systems have an impact on driver safety?’
- Review the research objectives
- Review the future uses of the simulator and;
- Outline future research required.

The aims for this chapter will be achieved by evaluating all findings in this thesis, compare all outcomes against the research objectives, consider and analyse other uses for the simulator and review what has been achieved and what future research remains after the completion of this project.

6.2 Review of Research Objectives

The research objectives for this project were prepared in section 1.4 of this dissertation.

1) Review GPS car satellite navigation systems, the suppliers of road network data to satellite navigation systems available in Australia and the sources of this data.

This review was conducted and reported in chapter 2 of this thesis. Investigations were conducted to identify the suppliers of road network data in Australia and their methods of obtaining this data. The functions available in modern satellite navigation systems were reviewed along with the basic functioning of a GPS system.

2) Investigate the data formats that can be used in simulation of GPS signals (both pre-processed and post-processed) and the use of this data in specific stages of simulation.

Thorough investigations and testing was completed to understand the capabilities of NMEA GPS data. The use of this data is extended throughout pre-processed and post-processed stages of simulation. This NMEA data was collected as part of the pre-processed stage; then sent through the simulator and transmitted using Bluetooth signals, which reflects the forward movement of simulation technology.

3) Assess the quality of different road network data sources and compare the data in different geographic areas.

As anticipated, the assessment of different road network data sources was not possible, as only one set of maps were available to us in the satellite navigation system that was purchased for this project. The testing of one road network data source (Navteq) was achieved and this data was tested in different geographic areas (mainly in the Northern New South Wales and Southern Queensland regions).

4) Simulate GPS signals through computer-based simulators to achieve a navigation path to a specific destination.

This stage of the project was completed four (4) months after the commencement of the simulation experiments. There were several achievements made in the development stage that contributed to its final completion. The final stage, the choosing of a suitable satellite navigation system, was critical in the successful operation of the simulator.

5) Analyse the impacts on safety by simulating a car navigation system along road networks with erroneous data.

This objective was completed by recording the errors made by the satellite navigation system and analysing the effects on driver safety. This was achieved by combining the findings with risk assessments of each road network data error example. Results varied for the different examples tested.

6) Report on these findings in an academic dissertation and project conference.

This completed dissertation fulfils the first requirements of this specification. The findings made in this project were presented at a project conference during the second semester 2008 residential school at the University of Southern Queensland, Toowoomba.

7) If time permits, Investigate advanced simulation to achieve a similar road path to driver's expectation.

Unfortunately sufficient time towards the due date of this project was not available in order to complete this additional specification.

6.3 Project Conclusion

This project started with two major aims, which were included in the title 'Simulation of GPS Car Navigation Systems in Evaluating the Impact of Poor Quality Road Data'. A simulator was to be developed so the testing of navigation routes could be conducted. Using this simulator, poor quality road network data was to be tested and used to evaluate its effects and impacts on driver safety. Both of these aims have been achieved.

The development of the simulator was completed using modern communication technology, like Bluetooth and was completed over a period of four (4) months. Its overall reliability can be improved but its operation in this project has been satisfactory. Unfortunately in this project, testing was only performed on one road network data source (Navteq), but the overall conclusion is that low quality road network data can affect driver safety. This conclusion can be made after testing only one map data source.

6.4 Future Research

Chapter 5 was mainly devoted to recommendations made to improve safety of drivers who use satellite navigation systems. Many of these recommendations can be researched further to analyse their overall effectiveness. The capture of road network data was discussed in chapter 2, but further research into these methods could demonstrate the overall effectiveness and affordability in the use of these data capture techniques.

Automated mapping was a recommendation put forward in chapter 5. Research into the methods and overall usefulness of this function would allow us to conclude whether or not it would improve the time taken to update road map databases. This research would require the combination of different fields of expertise, like computer programmers and spatial scientists.

The major programming function, snapping, was repeatedly discussed in this thesis. Further testing of this function, including the testing of the reduction in the snapping offset distance, is recommended. The potential assistance or deliberate interference of public mapping databases, like openstreetmap.org, is another issue that needs further research. The commencement of an online facility would attract interest from those who have a passion for using GPS and using it to locate features on the Earth’s surface, but the threat of deliberate sabotage is always a real threat when companies no longer rely on the expertise of spatial scientists to collect geographic data.

Other methods of road network data capture have been researched and conclusions have been presented in other papers in the past. Their effectiveness can however be utilised in different situations. For example, capture of roads using remote sensing is more effective in an area with minimal tree coverage, compared to capturing roads that exist in and through forests.

The frequency of road network errors can be combined with the findings in this thesis to provide an overall everyday impact on poor quality road network data on driver safety. Research can be conducted along sections of roads and record the errors that do exist and how often these errors occur.

6.5 Potential Future Uses of the Simulator

With respect to GPS NMEA data, the simulator can be used in many different situations. Outside of the realm of GPS, other fields of engineering, such as electrical or mechanical engineers can find a similar simulator design helpful with specific experiments, like circuit designs and mechanical performance of new and used vehicles. In term of using GPS NMEA data, the simulation of location data can definitely be used in areas outside the use of satellite navigations systems. GPS NMEA data can be used to investigate the movements of aircraft where this data could be retrieved from the black box after a crash. Car racing teams can also use GPS NMEA data to analyse the performance of their cars and suggest better driving methods to drivers.

Any data of real-world processes that can be collected into readable data can possibly be used in a simulator that uses similar components, such as a program designed to deliver this data and Bluetooth communication to any external modules.

6.6 Closure

The overall focus of electrical retailers today is to retail satellite navigation systems at the lowest cost, so that sales can be maximised. This method of sales overlooks the overall importance of the accuracy of onboard maps. Many stakeholder groups need to be engaged together to assist in reducing the impact of poor quality road network data.

The errors that were encountered in the highest-risk examples can cause serious accidents. Therefore, rapid updating of new road data is necessary, especially on busy and major roads, like highways, freeways and inner city streets.

Roads that exist at locations where traffic volumes and vehicle speeds are high have a greater negative effect on driver safety. This is particularly the case when a driver is following navigation paths that are based upon low quality road network data. Therefore, the impact of poor quality road data can potentially have a large effect on driver safety.

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Appendix A

Project Specification

University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

ENG 4111/4112 Research Project
PROJECT SPECIFICATION

FOR: **BENJAMIN TART**

TOPIC: SIMULATION OF GPS CAR NAVIGATION SYSTEMS IN EVALUATING THE IMPACT OF POOR QUALITY ROAD DATA

SUPERVISOR: A/ Prof. Kevin McDougall
Mr Peter Gibbings

ENROLMENT: ENG 4111 – S1, X, 2008
ENG 4112 – S2, X, 2008
ENG 4903 – S2, X, 2008

PROJECT AIM: This project seeks to assess the impact of poor quality network road data in car satellite navigation systems. This will be achieved by simulating GPS navigation systems along pre-determined routes, focussing on routes that have low quality data.

PROGRAMME: **Issue C, 20th March 2008**

1) Review GPS car satellite navigation systems, the suppliers of road network data to satellite navigation systems available in Australia and the sources of this data.

2) Investigate the data formats that can be used in simulation of GPS signals (both pre-processed and post-processed) and the use of this data in specific stages of simulation.

3) Assess the quality of different road network data sources and compare the data in different geographic areas.

4) Simulate GPS signals through computer-based simulators to achieve a navigation path to a specific destination.

5) Analyse the impacts on safety by simulating a car navigation system along road networks with erroneous data.

6) Report on these findings in an academic dissertation and project conference.

As time permits:

7) Investigate advanced simulation to achieve a similar road path to driver's expectation.

AGREED:

_________ (Student) _________, _________ (Supervisors)

Date: 25/ 3/ 2008 Date: 31 / 3 / 2008 Date: 1 / 4 / 2008

Examiner/Co-examiner: _________

Appendix B

Google Earth Coordinate Data

Acacia Street, Killarney

Coordinates for Navigated Route along Acacia Street, from North-west Entry

Lat1=-28 20 07.120
Lon1=152 16 12.770
Alt1=503
Spd1=100
Lat2=-28 20 04.270
Lon2=152 17 19.520
Alt2=509
Spd2=80
Lat3=-28 20 16.910
Lon3=152 17 23.960
Alt3=509
Spd3=60
Lat4=-28 20 24.390
Lon4=152 17 39.120
Alt4=508
Spd4=

Coordinates for Continued Route along Warwick- Killarney Road

Lat1=-28 20 04.840
Lon1=152 17 04.810
Alt1=503
Spd1=80
Lat2=-28 20 04.580
Lon2=152 17 19.700
Alt2=508
Spd2=70
Lat3=-28 20 04.300
Lon3=152 17 19.530
Alt3=509
Spd3=60
Lat4=-28 19 58.290
Lon4=152 17 41.640
Alt4=508
Spd4=60
Lat5=-28 19 59.400
Lon5=152 17 46.310
Alt5=514
Spd5=

First Avenue, Lismore

Coordinates for Navigated Route along Bruxner Highway and First Avenue

Lat1=-28 48 53.900
Lon1=153 17 03.380
Alt1=12
Spd1=60
Lat2=-28 48 55.160
Lon2=153 17 12.560
Alt2=20
Spd2=50
Lat3=-28 48 57.590
Lon3=153 17 12.120
Alt3=20
Spd3=

Coordinates for Continued Route along Bruxner Highway (bypass First Avenue)

Lat1=-28 48 53.900
Lon1=153 17 03.380
Alt1=12
Spd1=60
Lat2=-28 48 55.160
Lon2=153 17 12.560
Alt2=20
Spd2=50
Lat3=-28 48 59.240
Lon3=153 17 38.760
Alt3=70
Spd3=

Loveday Road, Cooby Dam

Coordinates for Dirt Road towards dam and right bend away from road

Lat1=-27 23 36.060
Lon1=151 56 28.240
Alt1=511
Spd1=50
Lat2=-27 23 21.910
Lon2=151 56 30.540
Alt2=486
Spd2=20
Lat3=-27 23 20.640
Lon3=151 56 27.290
Alt3=488
Spd3=20
Lat4=-27 23 21.910
Lon4=151 56 30.540
Alt4=486
Spd4=20
Lat5=-27 23 36.060
Lon5=151 56 28.240
Alt5=511
Spd5=

Snapping Testing- New England Hwy, Missen Flat, QLD

20 metres offset

Lat1=-27 53 39.300
Lon1=151 58 28.230
Alt1=500
Spd1=60
Lat2=-27 54 12.980
Lon2=151 58 39.200
Alt2=500
Spd2=

30 metres offset

Lat1=-27 53 39.770
Lon1=151 58 28.000
Alt1=500
Spd1=60
Lat2=-27 54 13.390
Lon2=151 58 38.970
Alt2=500
Spd2=

50 metres offset

Lat1=-27 53 40.240
Lon1=151 58 27.390
Alt1=500
Spd1=60
Lat2=-27 54 13.920
Lon2=151 58 38.390
Alt2=500
Spd2=

100 metres offset

Lat1=-27 53 40.100
Lon1=151 58 25.430
Alt1=500
Spd1=60
Lat2=-27 54 13.590
Lon2=151 58 36.360
Alt2=500
Spd2=

200 metres offset

Lat1=-27 53 40.970
Lon1=151 58 21.920
Alt1=500
Spd1=60
Lat2=-27 54 15.880
Lon2=151 58 33.350
Alt2=500
Spd2=

225 metres offset

Lat1=-27 53 43.390
Lon1=151 58 21.770
Alt1=465
Spd1=60
Lat2=-27 55 00.090
Lon2=151 58 45.570
Alt2=466
Spd2=

250 metres offset

Lat1=-27 53 42.710
Lon1=151 58 20.520
Alt1=465
Spd1=60
Lat2=-27 55 00.040
Lon2=151 58 45.570
Alt2=466
Spd2=

Appendix C

Questions from Driver Survey

Example 1- Brunswick Heads

Begin Brunswick2.nmea simulation

Driver on freeway (dual-carriageway), speed 110km/h, traffic volume med-high, trucks and buses regularly use road, terrain undulating, sight distances are good.

1st- snapping section:
What would you do if you saw this happening on the freeway?
How would you react with your driving?

2nd- Roundabout:
What would you do when you were told there's a roundabout ahead?
There is no roundabout. What do you do now?

Example 2- Elevation & Aspects

Begin Elevation-Aspects.nmea simulation

Driver on normal road (single-carriageway), speed 20-60km/h, traffic volume low, small trucks and buses regularly use road, terrain steep sections, sight distances are ok-dodge.

1st- turn into subdivision, stops navigation:
What would you do if you saw this happening?
How would you react with your driving?

2nd- turn into subdivision, stop navigation:
Would you do anything different here?

Example 3- Hogbin Drive, Coffs Harbour

Begin Hogbindriveext1.nmea simulation

Driver on normal road (single-carriageway), speed 40-60km/h, traffic volume med-high, small trucks and buses use road, terrain flat-undulating, sight distances are good.

1st- snapping onto Watsonia Avenue:
What would you do if you were here?
You realise you can't turn right, what do you do now?
What do you do when you see the sat-nav doing this?

2nd- no navigation:
What would you do here?

3rd- drive over creek:
If you saw there was a creek approaching what would you do?
There is a bridge across creek. Would you continue on ahead?

Example 4- Acacia Street, Killarney

Insert reality west data into config file, Begin NMEA generator

Driver on normal road (single-carriageway), speed slowing down from 100 to 60km/h, trucks sometimes use road, terrain flat, and sight distances are good.

1st- Approach Acacia Street:
What would you do when you approach Acacia street?
You realise there is no road and you can't turn right; what do you do now?

2nd- Past Acacia Street:
Would you turn around when instructed?
Would you want to continue and calculate a new route?

Example 5- First Avenue, Lismore

Insert navigation from west data into config file, Begin NMEA generator

Driver on urban highway (dual-carriageway), speed 60km/h, traffic volume is high, trucks and buses regularly use road, terrain steep then flat, sight distances are good.

1st- Approach First Avenue:
What do you do when you approach the intersection?
This intersection is a set of traffic lights. You realise that entrance is restricted by barriers, but it has a small narrow entrance. Do you proceed to turn right? You drive through and notice that you cannot proceed along First Avenue because of a concrete drain that runs across the road. What do you do to get to your destination?

Example 6- Loveday Road, Cooby Dam

Insert reality from south data into config file, Begin NMEA generator

Driver on bitumen- dirt road (single-carriageway), speed 20-50km/h, trucks and buses very rarely use road, terrain flat, sight distances are good.

1st- Approach Dam: You drive along the dirt track towards the dam. You realise that the road goes through the dam but the dirt track bends to the left. What do you do?