University of Southern Queensland

Faculty of Engineering and Surveying

Mapping Cycling Pathways and Route Selection Using GIS and GPS

A dissertation submitted by

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In fulfilment of the requirements of

Courses ENG4111 and 4112 Research Project

Towards the degree of

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Abstract

In today's society there have been many issues to do with the increase in fuel prices. This is all due to the world's increasing demand for crude oil. This makes it more expensive to operate a motor vehicle and it also has its affect on public transport prices. With the cost of fuel rising and the daunting fact that there is not an everlasting supply of oil, alternatives must be found. Alternative measures of transport in future could prove to be costly so the use of bicycles is going to become more common for local travel.

When riding a bicycle from A to B the shortest route is not always the easiest one. The terrain has more of an influence on how tired a person gets rather than the distance travelled. For a commuter travelling to work on a weekday they may know the shortest route to their location of employment. What they may not realise is that this route they are using actually requires more energy than another route that maybe longer. So how do we work out what is the easiest route from A to B?

This study works out the easiest route from the University (USQ) to the CBD in Toowoomba in terms of energy using GPS and other spatial data. This was done by collecting GPS data of cycling lanes and pedestrian paths for six different routes from USQ to the CBD. This data was then stored on GIS software and was then processed and analysed to ensure the data was suitable for computing energy usage. An energy equation was then formed to calculate the energy expenditure for a cyclist riding up and down terrain. Using this equation the energy for the six different routes could be calculated to find the route that used the least amount of energy and to also find the route that was the most energy efficient for USQ to the CBD.

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Certification

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

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

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CHAPTER 1

INTRODUCTION

1.1 Introduction

With the price of fuel rising and the cost to operate motorised vehicles becoming more expensive the use of bicycles will become a more common method of travel. Active transport is now being encouraged more to reduce the use of automobiles to save energy and to reduce pollution. Cycling has been around for over century and over time it has advanced dramatically. Not only is cycling a means of transportation but it is also a form of recreation. It is used for a range of applications such as competitive cycling, downhill mountain biking and many other sports. Study done on bicycle commuter routes in Guelo, Canada, (Aultman-Hall et al, 1997) found that most commuters travelled up to 5.5 kilometres from home to work. Most commuters didn't divert much from the minimum path and were found to use major road routes. The average variance was 0.4 kilometres (Aultman-Hall et al, 1997).

Figure 1.2: Bike pathway

Figure 1.1: Bike lanes

There is extensive planning from councils to design cycling and pedestrian networks in towns and cities. These networks can be made up of cycling and pedestrian pathways or they can be made up of bike lanes. Pathways consist of paths that go through parks and open spaces (Figure 1.2) whereas bike lanes are designated on streets and roads (as seen in Figure 1.1). Council's try to create routes that are (IBI Group, 2000); continuous, reasonably direct, functional (serving a variety of destinations), part of a network, safe, and passing through parks and open spaces where possible.

These pathways also need to have smooth surfaces, be well marked and be easily accessible. Creating a network that incorporates all the above factors, takes considerable time and planning (Association of New Jersey Environmental Commission (ANJEC)). They are however essential as they connect residents to their community (Bikeways & Pathways Master Plan). A way of encouraging cycling and making it more convenient is to have

Figure 1.3: Shows bike facilities at Monash University

facilities such as bike racks and lockers, amenities (showers and toilets) at desired locations and along the way and lastly for it to be aesthetically pleasing. To do this, authorities must find the most popular routes and develop these facilities. The illustration above (Figure 1.3) shows how facilities can be mapped. The blue circles represent bicycle lockers, the red squares represent bicycle hoops and the green pentagons represent wheel racks. One way in which the local councils can find the most common routes of the commuters and recreational cyclists is to survey the community. This gives the council insight into what paths people like to travel to work or what paths are available. This can help the council to plan or update networks. The authorities must also ensure that the networks provide sufficient access to the most important areas such as; schools, businesses, shopping centres, churches, libraries and other community facilities.

By incorporating all this factors into how people use, need and feel about cycling pathways can help increase the use of cycling.

A way of managing this is to have the active transport networks on a Geographic Information System (GIS). Users can view all the different pathways and can also see the inventory and facilities (toilets and parking) of routes (Gray M et al, 2005). Viewers can decide whether they want to take a route that has bike paths or whether they want to use bike lanes on a street. Today, most methods of choosing cycling routes are determined on the shortest and safest routes. This however is a poor way of determining a route as these routes may mean that more energy is expended.

1.2 Aims and Objectives

1.2.1 Aim

The aim of this project is to map cycling paths from the University of Southern Queensland to the central business district of Toowoomba using GIS and GPS. This data will then be processed in a Geographic Information System (GIS) and a formula will be found to calculate on energy expenditure and to find the easiest route from A to B.

1.2.2 Objectives

1. To collect data for cycling pathways from USQ to the CBD using GPS
2. Put this data into a GIS for processing and analysis
3. Work out a formula suitable for calculating energy usage for bicycles up and down slopes
4. To apply to the formula to the GPS data and calculate the energy
5. To apply the formula to the gathered data to find the easiest route (route that requires the least energy)

1.3 Expected Benefits

There are a number of expected benefits from this project. It will assist people in finding the easiest way from A to B and therefore giving more incentive to use a bicycle. The mapping of pathways will be a big benefit as it allows the community to view the cycling pathways available to them and this can also promote bicycle use. This can be a great tool for cycling groups as it allows them to view these routes and if necessary work out how hard the route will be depending on the cyclist's level of ability. This project would also be useful in weight loss programs as it gives the person an idea of how much energy they are using. For professional cyclists the project allows them to pick the hardest route as well and this can be very useful. Another aspect where this research could benefit is in the area of replenishing energy. Professional athletes or even recreational cyclist can use the information provided by this system to determine what energy would need to be consumed to replenish the energy used throughout a trip.

1.4 Dissertation Overview

This dissertation has 6 main chapters. These chapters have a brief description below.

Chapter 1 Introduction – Gives an introduction to the topic and what the aim and objectives are. This chapter also discusses the background of the topic and the expected benefits of the project.

Chapter 2 Literature Review– Is a literature for the project. It looks at a number of areas such as:

- Mapping of Cycling Pathways
- Geographic Information Systems
- Global Positioning Systems
- Data Collection
- Data Analysis and Route Selection
- Energy Equations

Chapter 3 Methodology – Involves looking at the Methodology used in the project. It looks at the data collection processes including the unseen areas in data collection. It looks at the data processing and analysis as well as how the energy formula was put together and how it was all calculated.

Chapter 4 Results – Shows the results that were found for the project. This includes graphs of energy usage and terrain profiles.

Chapter 5 Results Discussion – Is the discussion of the results. Each route is analysed individually and the efficiency is determined. There is then a recommendation made for which route is the selected route. The last aspect discussed in chapter 5 is the problems that were faced throughout the project.

Chapter 6 Conclusion – Provides a conclusion to the project.

1.5 Conclusion

From this chapter a number of aspects of the dissertation were addressed. Aspects such as the background of the project this included why the project was conducted. The aim and objectives were then discussed giving a clear idea of what is wanted to be achieved from the project. The expected benefits of the project were then discussed and lastly an overview of the project was given to outline what will be covered in each chapter of the dissertation. The next chapter is the literature review which will help form an understanding of some of the different aspects involved with the project.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The literature review was broken up into a number of different parts. Mapping of cycling pathways, Geographic Information Systems (GIS), Global Positioning Systems (GPS), Data Collection, Data Analysis and Route Selection, and Energy Equations. This chapter hopes to give an insight into what has been covered in this area before and to give a basic knowledge of some of the elements in this area of study.

2.2 Mapping Cycling Pathways

Mapping of cyclist and pedestrian pathways is becoming more common in today's society. This is because data can be gathered, stored and viewed much more efficiently because of better technology. Maps of cycling pathways are used in a number of different applications such as:

- Viewing current transport routes for asset management
- Ensuring connectivity of the pathways
- Planning for future active transport
- For public use
- To find the most common pedestrian and bicycle routes
- To plan for the effects of facility construction of levels on cycling and walking
- To know what pedestrian and bicycle facilities are available and exist

- For mapping pedestrian and cyclist crash zones

Figure 2.1: Digitalisation of a hard-copy map

This data can be collected, presented and analysed in a number of different ways. The data can be acquired by manually collecting field data, through community surveys or can be obtained through other organisations. Using a Geographic Information System the data can be presented in different formats and this can depend on how it is needed to be analysed. Over time there have been different needs and ideas of what must be mapped for a cycle and pedestrian survey. Depending on what the map is needed for depends on what information is needed to be mapped. In the past maps of cycle ways were made by writing hard-copy maps and then transferring it into digital data (Shomowsky R). Figure 2.1 shows a hard copy map being digitalised. These days data is either collected manually using specialised equipment and then exported digitally. It can also be acquired by taking small segments of data from other resources as seen in Figure 2.2.

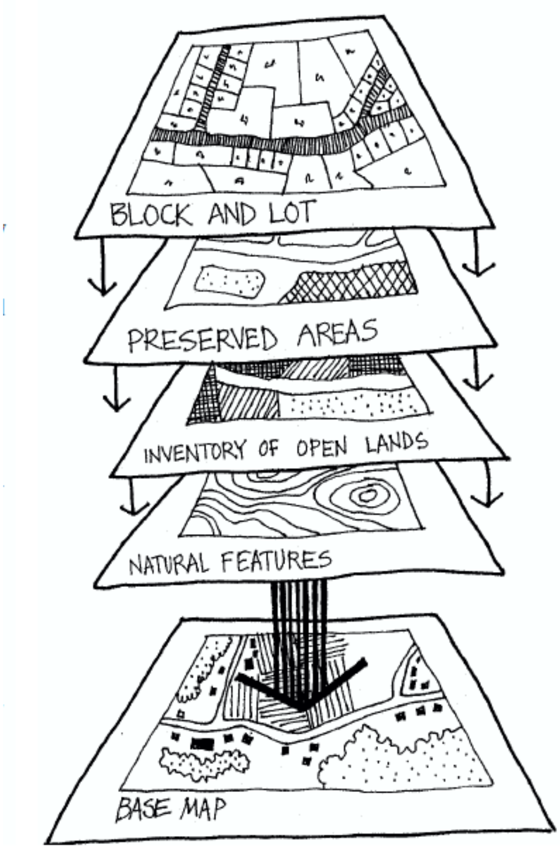


Figure 2.2: Combining information to form a

In the past town planning was more focused on road planning for vehicles. There was not enough attention paid to the pedestrian networks. Cycling paths were mapped as where the main streets were. Public transport was also neglected to a degree when planning a town or city. In recent years the importance of active transport and public transport has been noticed and is a key factor in the planning process. When active transport is mapped today, there is a great deal of information that must be gathered. There are a number of requirements and guidelines that can be used to ensure that sufficient information is collected. Along with mapping the actual pathways, the following

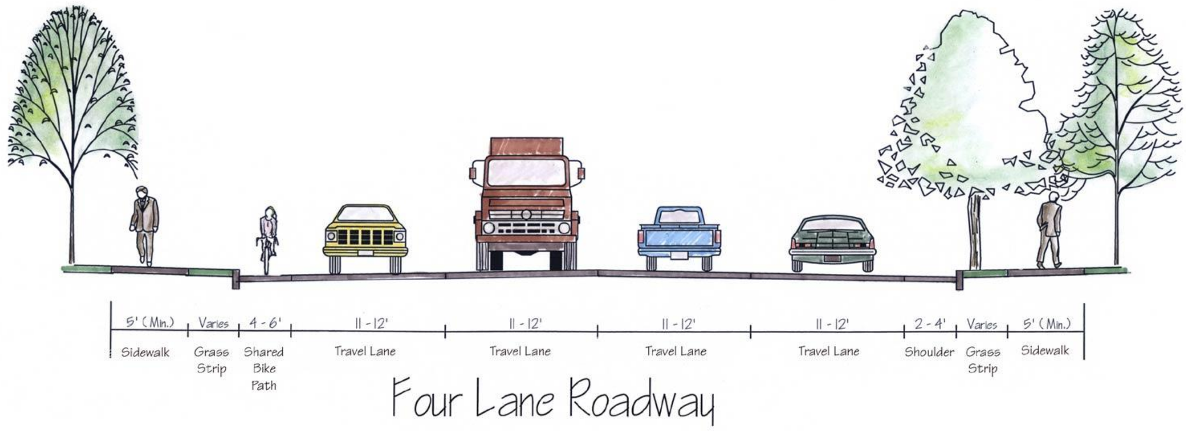


Figure 2.3: Roadway Diagram

information is gathered: actual pathways, speed of the traffic, number of lanes, traffic volumes, number of heavy vehicles, shoulder width, shoulder surface, surface condition, lane width, and crossings such as bridges and railways, and facilities and amenities. Figure 2.3 (above) shows the different features of a roadway using a cross section.

In future more information will be required for the mapping of cycle pathways. This additional information will include: public transport time tables, public transport stop information, type of amenities, street lighting, traffic lights, and major intersections.

All this information can be used to determine the ideal location for a cycling network and ensuring that it can be incorporated with other methods of transport. Study done by Gray M and Bunker J (2005) on the Kelvin Grove Urban Village incorporated all of these aspects into selecting the best routes for cyclist pathways. Also incorporating these factors allowed them to identify areas that needed improvements in terms of active transport.

Some of these factors discussed above were also incorporated by Leigh C, Peterson J and Chandra S (2009) for Monash University. Using these factors the cycling facilities of the university were located with the aim of creating a bike-friendly university. They were also able to use this data and other research to work out what improvements were needed for the network and the best places for new facilities.

Aultman-Hall et al (1997) and the Road and Traffic Authority (RTA) both look at improving cycle ways. Significant amounts of their data and research is done using community surveys. Surveys of education groups, tourists, sports groups, commuters, recreational cyclist and residents help to find what the public likes about cycling routes and to find out the potential routes that need to be looked at.

2.3 Geographic Information Systems

A Geographic Information System (GIS) in an interactive computer-based mapping tool that is able to store, display, and analyse spatial data (USGS Eastern Region PSC 4). It is very unique because it is able to integrate different information into one map. Figure 2.4 shows the process of integrating all the information and producing a final map. Another benefit of GIS is that it has a number of functions and tools that the viewer can use to interact with the data.

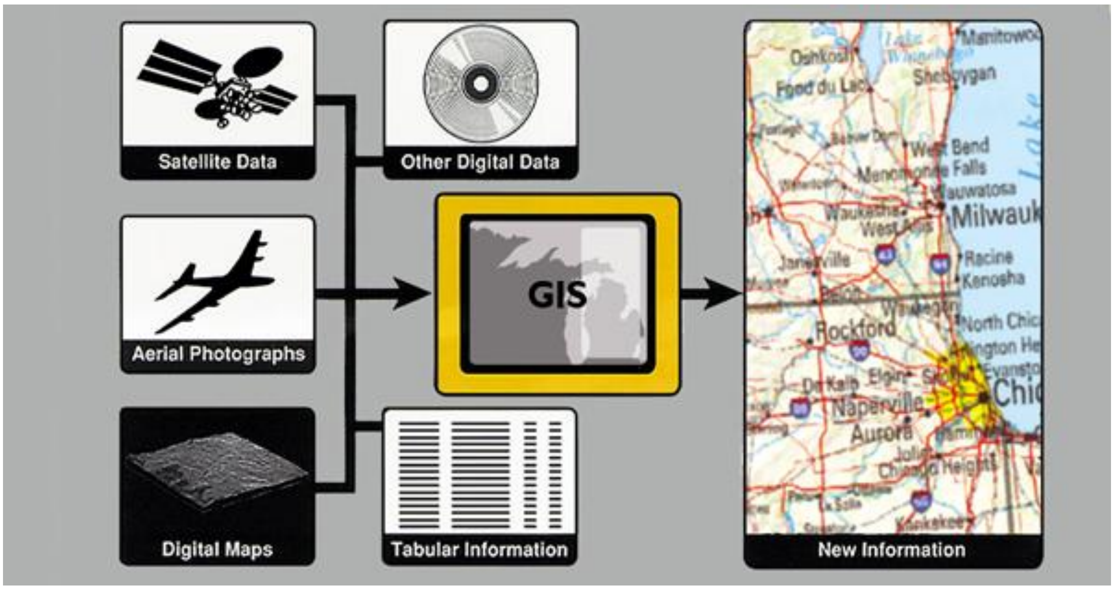


Figure 2.4: Basic process of GIS

One of the tools that assist in analysis enables the user to enquire information about the data. By clicking on a point feature such as a tree, can give you information as to the tree type, size and spread. It is also possible to enquire distances and areas using this tool. Other tools are; Topological Modelling, Network, Overlay, and Data output.

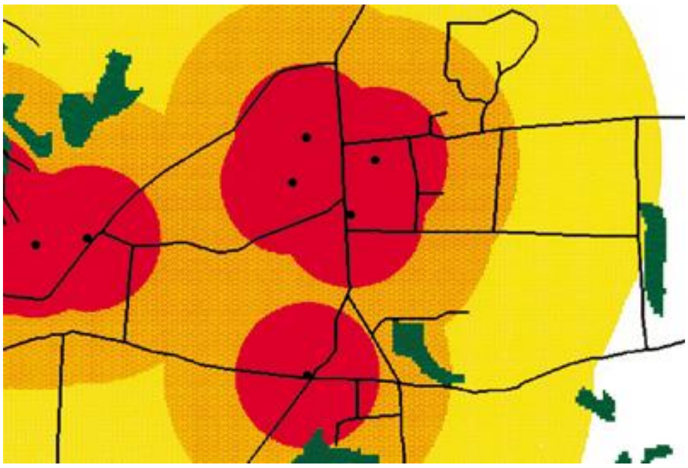


Figure 2.5: Topological Modelling

Topological Modelling involves being able to determine spatial relationships. It is possible to find factories that are upstream of a river through using this function (Ellis F). An example of topological modelling can be seen in Figure 2.5 where there are red buffers are around the factories. The Network function allows the system to combine information about a specific path. Google Maps uses this function to calculate the quickest route from A to B. Overlay is a function that is a benefit for looking at waterways that are potentially sensitive to nutrient run off (Ellis F). It does this by overlaying all the sets of data and then it creates a buffer zone for the waterways at risk. The Data Output function is the ability of the system to put the information the analyst needs into a screen map or as a map on paper. All these functions make it the ideal system for gathering information and making decisions based on this information. They also allow the user to create an output with a particular section of information being displayed.

These tools make GIS a very useful resource for many different industries and occupations (Ellis F). It is used in an array of different applications such as;

- Town Planning
- Asset Management
- Real Estate
- Environmental Impact Assessment
- Disaster Management

GIS has also provided many benefits in transport industry in areas such as transport planning. It provides benefits for; data collection, data storage, model building and validation, prediction of impacts and strategic evaluation, public consultation and participation, and continuous transport system monitoring.

The New Jersey Environmental Commission talks about how GIS is so valuable in depicting layers of geographic information such as roadways and lot formations. Aultman-Hall et al (1997) also says that "GIS is a valuable tool in route analysis". When looking at the best routes from one place to another, the information researched proves that GIS is an ideal tool for doing this function.

2.4 Global Positioning Systems

Global Positioning Systems or GPS is used to determine a person's location on the earth's surface. It uses a coordinate which is called the World Geodetic System of 1984, also known as WGS84. GPS basically consists of satellites in space and a satellite receiver on earth. GPS works by the satellites in space sending out signals which are picked up by the user's receiver. These signals picked up by the receiver are then used to calculate the position of the user. Using the range or the distance from a four satellites as a radius, an intersection point can be calculated and the result being the position of the user on the earth's surface.

GPS is a very relied upon tool in modern day society. GPS [**NAV**igation **S**ystem with **T**iming and **R**anging Global Positioning System (NAVSTAR GPS)] is used in a range of applications such as navigation and mapping. The United States Department of Defence developed the system for the use of the military and also the civilians (Zogg J M, 2002). The U.S launched

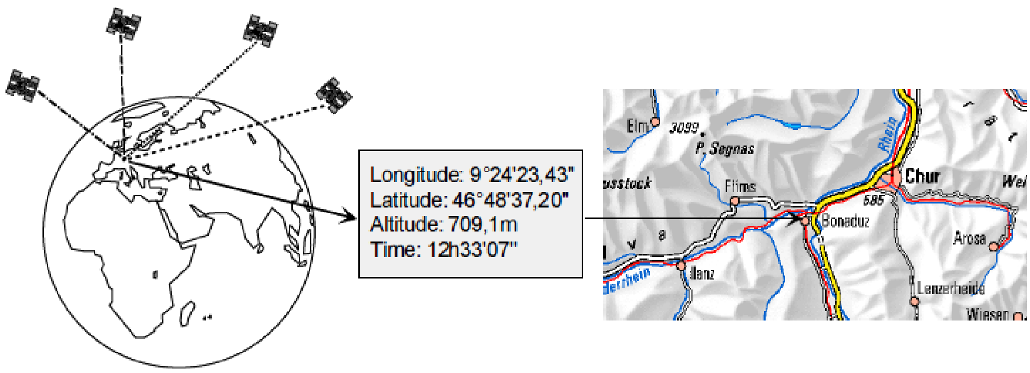


Figure 2.6: Basic function of GPS

their first satellite in February 1978 and since then a number of countries have begun to launch their own. Currently in space there are 28 NAVSTAR GPS satellites orbiting the earth approximately 20,000km away. The other countries to launch satellites are; Russia, China, Japan, France, India, Israel, Australia and the United Kingdom (Butterworth P, Palmer D). GPS can determine a position on the earth with the accuracy of 20 metres to 1mm. The diagram above (Figure 2.6) illustrates the basic function of GPS discussed earlier. Onboard the GPS satellites are atomic clocks that keep track of time very accurately. By being able to keep track o time accurately provides the opportunity for better accuracy.

As discussed above, a 3D position is calculated using a minimum of 4 satellites. The way the 28 satellites orbit around the earth means that at any one location there is a minimum of four satellites available. The satellites transmit data to the GPS receivers regarding its location and the present time (National Air and Space Museum). The satellites are all in tune with one another and all transmit signals at the same time. When the signals reach the receiver there will be differences in when the signals arrive. This is because the satellites are different distances away (National Air and Space Museum). The receivers can then calculate how far away the satellites are by the time it took the signal to reach the receiver. Using the distances from the four satellites the location can then be determined. The diagram below (Figure 2.7) illustrates how the satellites calculate a position.

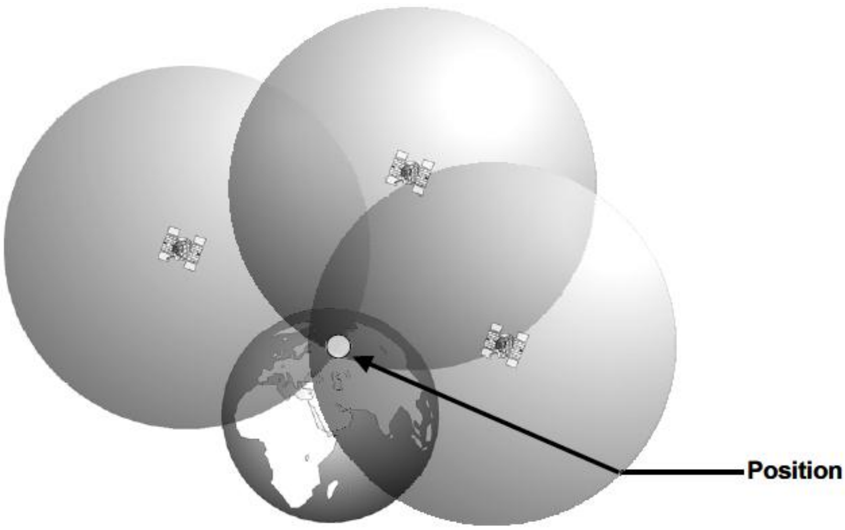


Figure 2.7: Calculating a GPS position

GPS accuracy is depended on what type of receiver is used, the visibility of the satellites and the geometry of the satellites. Basic handheld receivers get an accuracy of approximately 5-15 metres depending on the number of satellites available. By using better quality receivers the accuracy can be increase. Higher accuracy can be increased by using Differential GPS (DGPS) which involves the use of at least two receivers. One used as a base station and other as a rover that collects all the data. Between the two receivers errors such as; satellite clock errors, ephemeris errors (when the satellite transmits wrong information about its location), and atmospheric error (when the troposphere and ionosphere affect the signal) can be eliminated (Gibbings P, 2007). These corrections can also be applied in real-time or it can be post-processed.

Most industries in today's society use GPS is some form or another. An area that GPS is very valuable in is the Surveying industry. GPS is used in the surveying industry predominantly for mapping. The software that can be used with GPS is very useful for locating points, lines and area features. A function that the GPS has is the ability to log data at particular intervals. The logging interval can be set to take a measurement every time the GPS travels a certain distance or it can be set to take a measurement based on time such as 5 second intervals. This is a very useful tool in mapping.

2.5 Data Collection

Past research has shown that most data collection to do with mapping of cycling pathways was performed in a number of different ways. The Transportation Research Board's (2000)

Figure 2.8: GPS, INS, and Cameras

research on data collection showed that the data was usually collected in three different ways; by van, backpack or satellite. The method of using a van to collect the data involves using GPS equipment or the combination of distance measurement instruments (DMI) and inertial navigation systems (INS). A DMI is much like a speedometer in a car and measures distances based on wheel rotation. INS uses motion sensors to determine the orientation of where the van is heading. Some vans also have cameras installed to collect data that can later be processed using photogrammetric software (Orvets G, 2000). Figure 2.8 shows the unit on top of a van that has GPS, INS and two progressive scan CCD cameras (one colour, one black and white).

When using a backpack to collect the data, GPS is the primary tool. GPS equipment is attached in the backpack and the data is collected by walking. The GPS data is usually collected using two receivers with one being a base station. This means that data can be post-processed for better accuracy. The backpack method of collection can also be integrated with the use of a golf cart or bicycle. Lastly, using satellites to collect the data is done using satellite imagery. The correct images of the area are chosen and the image is then geo-referenced. This ensures the accuracy of the image. These images can then be used in GIS software and the relevant information can be collected.

The following table (Figure 2.9) shows the advantages and disadvantages of the three methods of collecting the data.

Means of Transport	Relative Advantages	Relative Disadvantages
Van	• Can be collected at near highway speeds • More choice in technologies • Can carry redundant systems • High accuracy possible	• Requires a minimum crew of two • Skilled crew required • If buying, then very expensive to start • Can be slow in bad weather and traffic conditions
Backpack	• Efficient in data collection • Lower initial costs	• Slow collection process • Little choice in technologies • Physically demanding • Collection stops in adverse weather
Satellite	• Potential for high level of automation for inventory extraction	• Cost depends on size of image, not on the size of the roadway network

	• No collection crew required • Covers a large area inexpensively	• Cannot collect many inventory elements • Lack of fully automated extraction techniques • Adverse weather affect image quality • No control over collection schedule

(Transportation Research Board, 2000) **Figure 2.9**: Data Collection

There are also other ways in which data can be collected without the field work. Data sets from other sources can be combined together into a GIS to form a map. Data can be obtained through councils, small firms and community surveys consisting of: road network data, digital elevation models (DEMs), bike trail maps (off road), and paths drawn by survey participants (confirmed by site inspections). Using the wide range of data available a map can be produced for further analysis.

2.6 Data Analysis and Route Selection

Previous research on analysis of cycling routes using GIS shows some of the processes used when analysing data (Aultman-Hall et al, 1997). The data was collected using surveys of the community and digitalising all the data into a GIS. Using the surveys filled out by the commuters, a number of possible routes were established. Attributes were then given to the different routes for further analysis. The attributes used were things such as;

- What intersections had traffic lights
- Major intersections (Two major highways)
- Grades (only grades significant to cycling, greater than 7%)
- Speed limits
- Bridges & Railway crossings

With all this data known the routes are then analysed to determine the best route. When selecting the best route Aultman-Hall et al (1997) looked at factors such as; overall distance, number of turns, turns at signals, turns at major signalised intersection, speed of the traffic on the road, volume of traffic, and grades.

Shumowsky et al (2005) discuss the process of creating a map of the pedestrian and bike pathways using GIS software. This map would also be used for planning for future pathways. A key element in the pathway design was the traffic volumes. '*Keeping away from roads that were too busy was important so that bikers and pedestrians would both feel and be safe when enjoying the routes'* (Shumowsky et al, 2005). This is information that needs to be noted in the analysis of routes. Routes that followed creeks and rivers were also a key element in the planning. Using all the information from the GIS system and the public input the best routes around the city were determined.

Gray M et al (2005) used GIS as a tool to analyse data and select common routes of commuters. There were many sources of data used to do this:

- Public transport route and stop data
- Public transport timetables
- Street, park, topography, bikeway data
- Public domain aerial photographs from Google
- Kelvin Grove Urban Village layout
- Population data
- Employment data
- Infrastructure and services benchmarks

By analysing all this data Gray et al (2005) was able to determine a number of things in the transport industry. Some of these factors were; the best routes to the CBD, the unsafe bicycle routes, and the best locations for new routes. The study was also able to show what areas needed more public transport service.

2.7 Energy Equations

There are many different factors that must be taken into account when forming an equation for energy usage for push bikes (Abbiss Dr C R et al, 2009). Some of these factors are;

- Rolling resistance
- Wind
- Riders weight
- Bicycle weight
- Speed
- Distance
- Time
- Revolutions per minute (RPM)
- Aerodynamics
- Slope
- Crank size and angle

With all these factors it makes it extremely difficult to incorporate all these factors into one formula. Another important aspect of the formula is the output (Atkinson G, Davison R, Jeukendrup A, Passfield L, 2003). There are a number of different units that energy can be displayed as. It can be displayed as; watts, kilojoules, calories, and horsepower.

Depending on what output is required determines what the equation will be like. There are three main factors that need to be considered when creating a formula for calculating energy. The first is what output is required, second, what will the equation be based on (time or distance), and lastly what other factors will be taken into account.

From previous research most equations calculate the energy on flat terrain rather than slopes and are based on time rather than distance. This makes it very difficult when trying to formulate an equation including slope and distance. Muhammad H Al-Haboubi's (1999) research on 'Modelling energy expenditure during cycling' gives information as to working out the caloric energy used when cycling. What Al-Haboubi (1999) does not look at however is applying this formula to slope and distance. The equations he looks at involve speed, technique, RPM and cyclist weight. His equation looks as follows and the output is in Oxygen Consumption;

$$\boldsymbol{V_{O_2} = 00494\,(0.261\,V^3 + 0.671\,W_T V)^{0.589}\,S^{0.168}}$$

Where,

V_{O_2} = Oxygen Consumption

V = Velocity

W_T = Weight

S = RPM

With the results being in oxygen consumption they can be converted into calories. For the purpose of this project variables such as slope, speed, and weight will be very important. Other research done by Swain (1998) investigates how important air resistance and gravity is on cycling up and down hills. He looks at a number of different equations for going uphill and downhill. The formula he discusses is for going uphill is;

W = krMs + kaAsv2 + giMs

Where,

W = Power

Kr = Rolling resistance coefficient

M = Mass of cyclist and bike

s = Speed on ground

Ka = Air resistance coefficient

A = Combined frontal area of cyclist

V = Air speed

G = Gravitational Acceleration

i = incline

This equation holds some advantages when computing energy expenditure. The main benefit being that it takes so many factors into account which makes it much more accurate than other formulas. A drawback for this equation is the fact that it is quite complex to use and some of these factors would be hard to determine for a final equation. The equation that Swain (1998) uses for downhill cycling energy is;

$$s = (-giM/kaA)1/2 \qquad \text{When } W = 0$$

Another drawback of using this research is that there are two different equations for travelling uphill and downhill. This can make it difficult to apply two different equations to a GIS.

Mueller K came up with a way to calculate calories for uphill terrain. She used a number of factors such as the average speed of the cyclist, the body weight of the cyclist, time, and the height difference. Using a speed coefficient she was able to compute the amount of calories used for a certain route. She calculated her results in the following steps.

1. The hourly cycling rate expenditure is calculated by multiplying the speed coefficient by the cyclist's weight and by 60 minutes. (eg. 0.0811 x 70kg x 60 minutes)

2. The next step involved calculating the total energy expenditure using time. The answer from step one was multiplied by the estimated time or time taken. (eg. 730 calories x 6.74hrs)

3. Energy is then added to compensate for elevation in the terrain. 22 calories were added for every 100 feet gained in elevation

Mueller K then goes on to talk about what energy is required to be eaten to replenish the energy used when cycling for long periods. The disadvantage of this study was that there was no research into the effect of downhill terrain on the energy expenditure. Downhill terrain would use less energy than travelling on flat ground therefore the energy usage must be adjusted.

Other drawbacks of all the research undertaken for energy equations are that none of these equations have been applied through a Geographic Information System. This makes the research in this project very unique and useful.

2.8 Conclusion

Throughout this chapter a number of things were discussed and the relevant literature was reviewed. The mapping of cycling pathways was the first item looked at in the chapter and it produced knowledge on what is involved in planning cycling pathways and what is mapped for different situations. There are a number of examples also given of what the data is used for. Geographic Information Systems (GIS) were then touched on and the different tools available to the users were discussed. The applications that GIS can be applied to were also explained along with how it is used in transport planning. The next area discussed in the literature review was Global Positioning Systems (GPS). It was explained how GPS works and what different applications it is used for. The analysis and route selection was another item that was researched and explained. It was found how previous studies had found the easiest route from A to B and what factors were considered in this process. Lastly, previous research into energy equations were looked at and the different factors that were included into the formulas were explained. This chapter forms basis knowledge to help give more understanding for the methodology.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This Chapter will look at the number of different stages in the process of planning, collecting, and the analysis of data in the project. It will cover;

- Data Collection
    - Preparation and Planning
    - Testing Equipment
    - Field Work
- Data Processing
- Data Analysis
- Researching Energy Equations
- Testing Energy Equations
- Route Selection

3.2 Data Collection

There were a number of steps involved with data collection. The steps involved are the preparation and planning, testing the equipment and lastly the field work. The processes of each step are described in detail as the work was performed.

3.2.1 Preparation and Planning

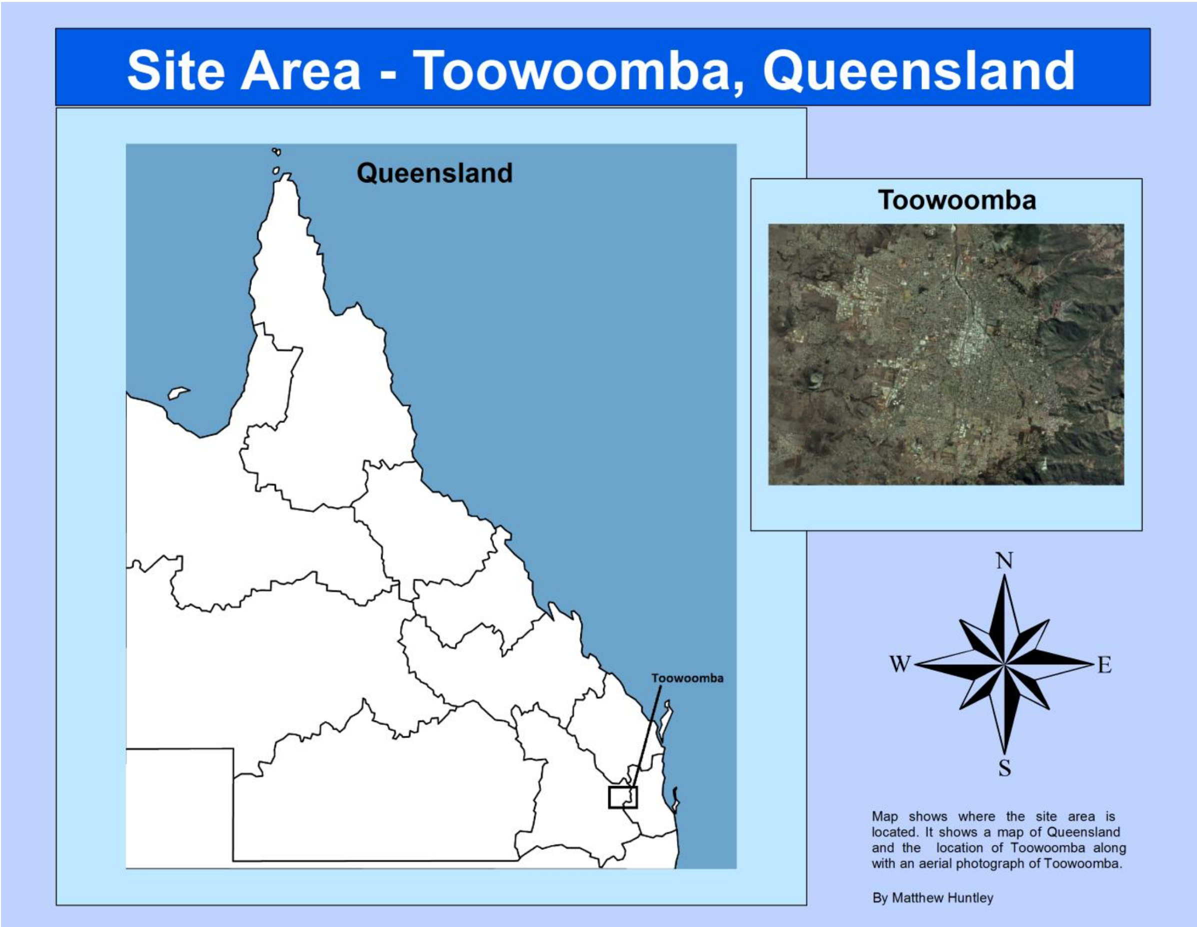


Figure 3.1: Site Area

The first step in the preparation and planning process was to select a study area. The area selected was Toowoomba which can be seen in Figure 3.1. A start and finish point for the survey then had to be found. It was decided that the start and finish point would be from the University of Southern Queensland (USQ) to the Toowoomba Regional Council offices in the Central Business District (CBD). With the start and finish point decided on, the different routes could then be selected. A minimum of three routes were needed to be selected. Using the selected routes the streets that needed to be data logged could then be worked out. Figures 3.2 to 3.7 show the six different routes selected from USQ to the CBD.

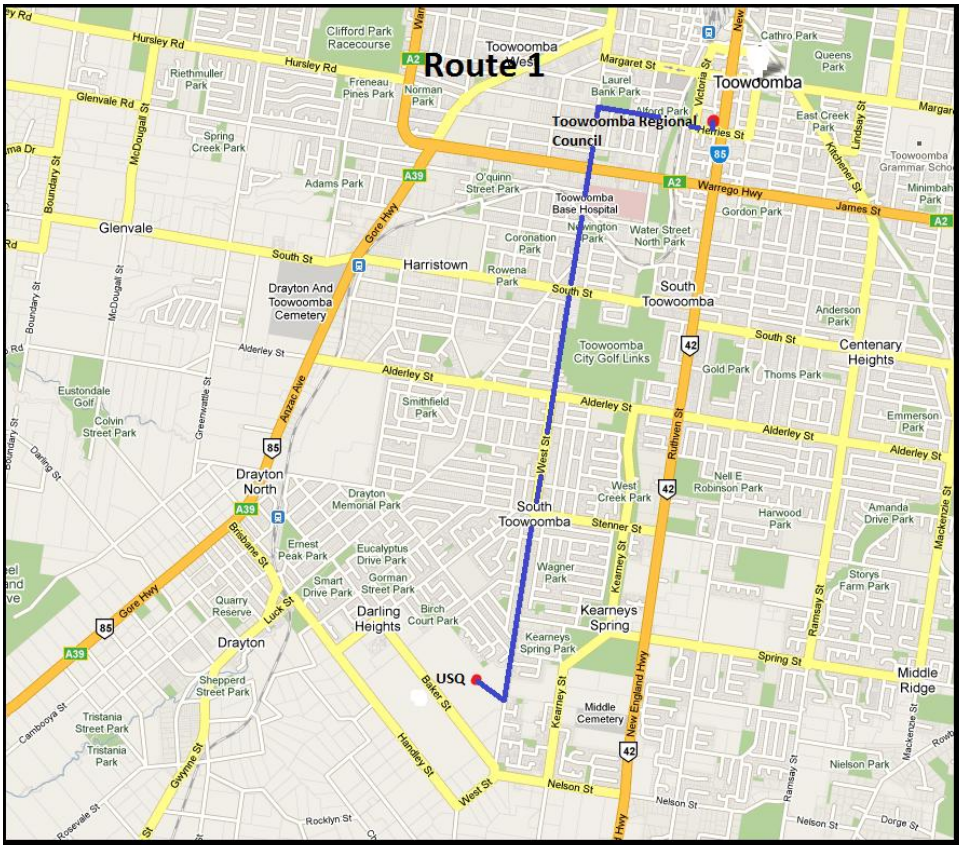
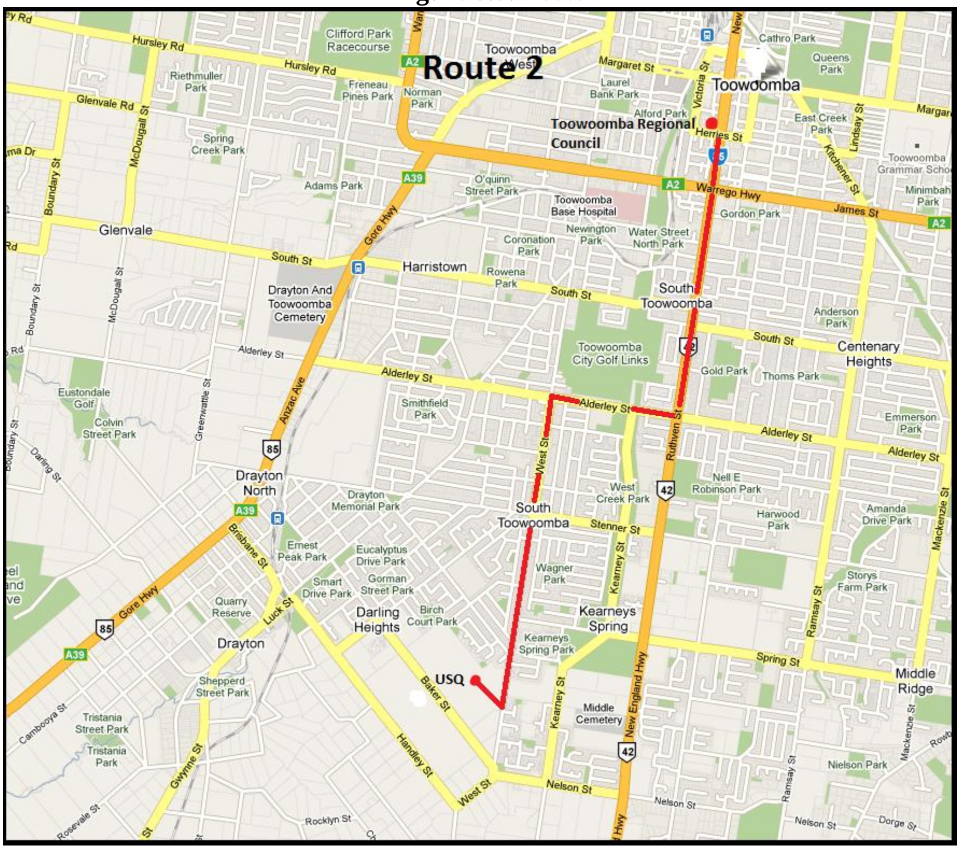


Figure 3.2: Route 1

Figure 3.3: Route 2



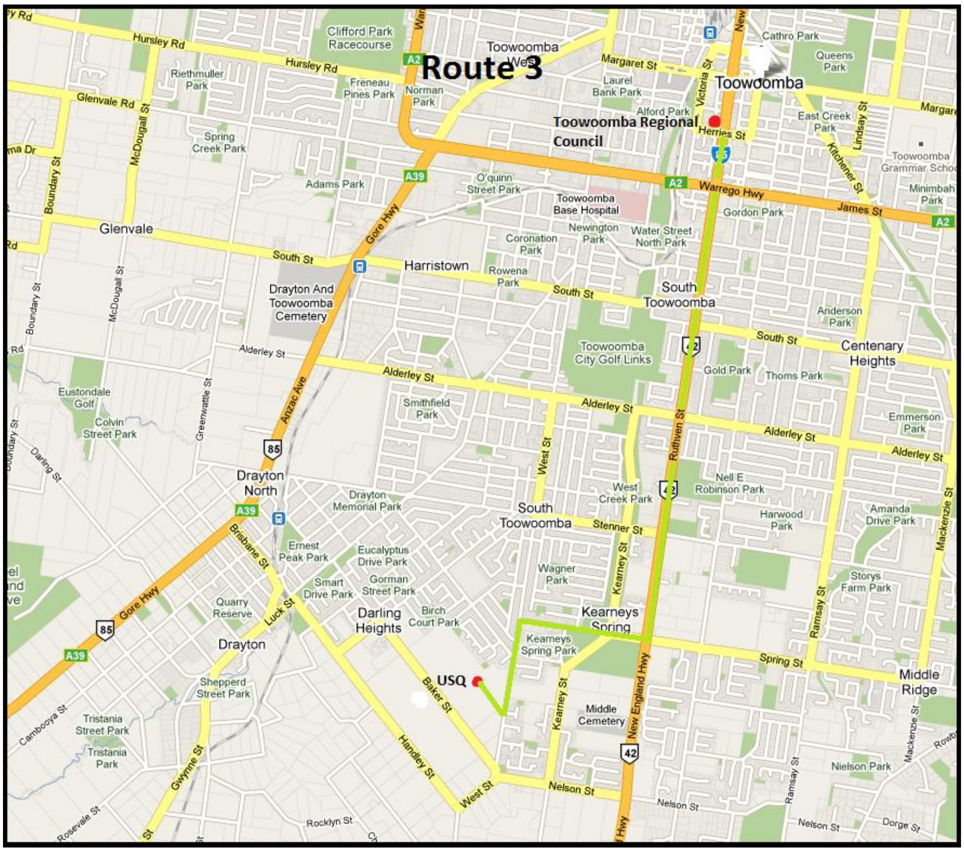
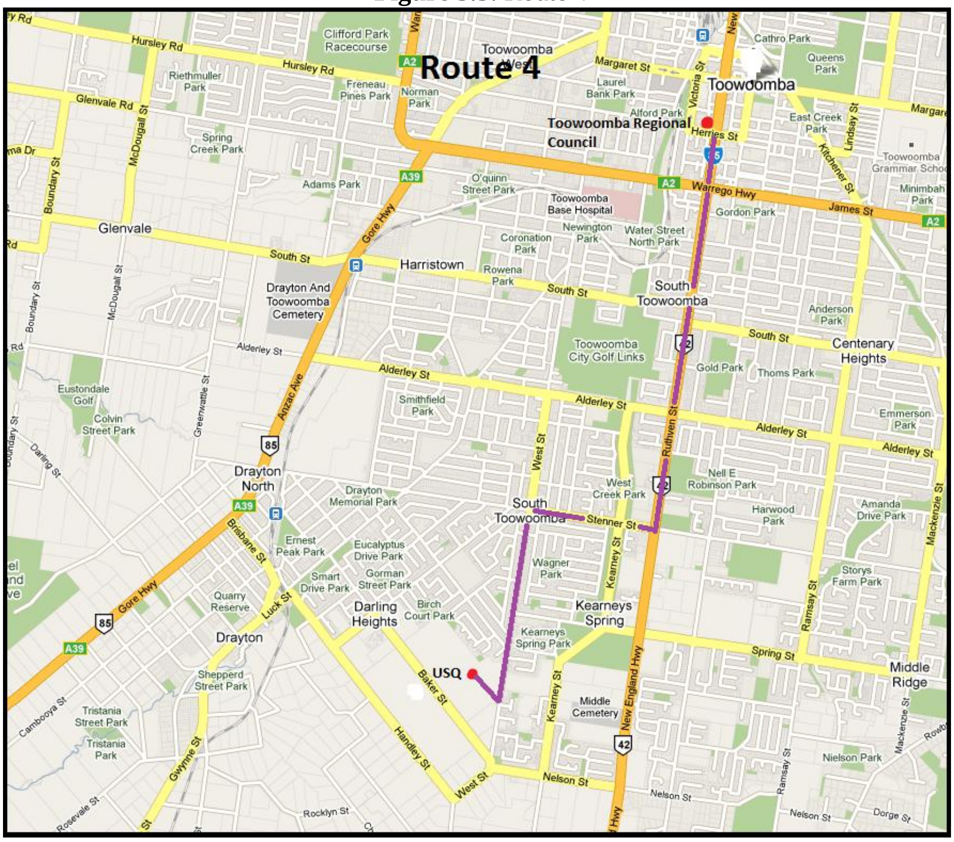


Figure 3.4: Route 3

Figure 3.5: Route 4



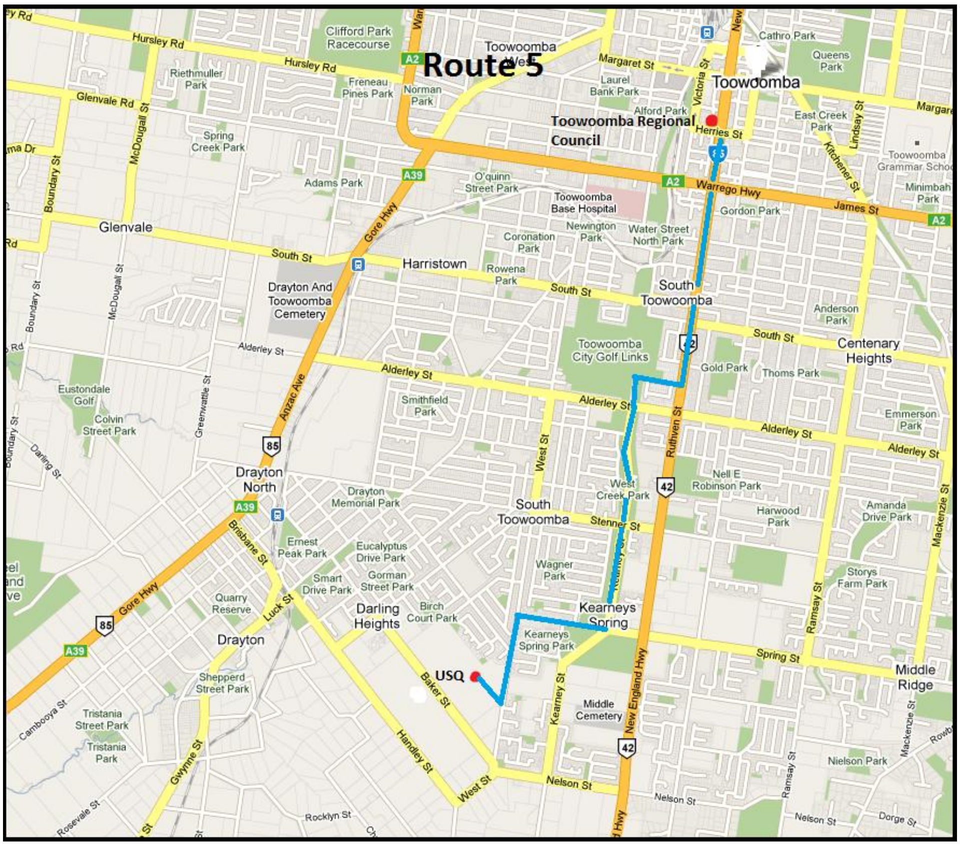
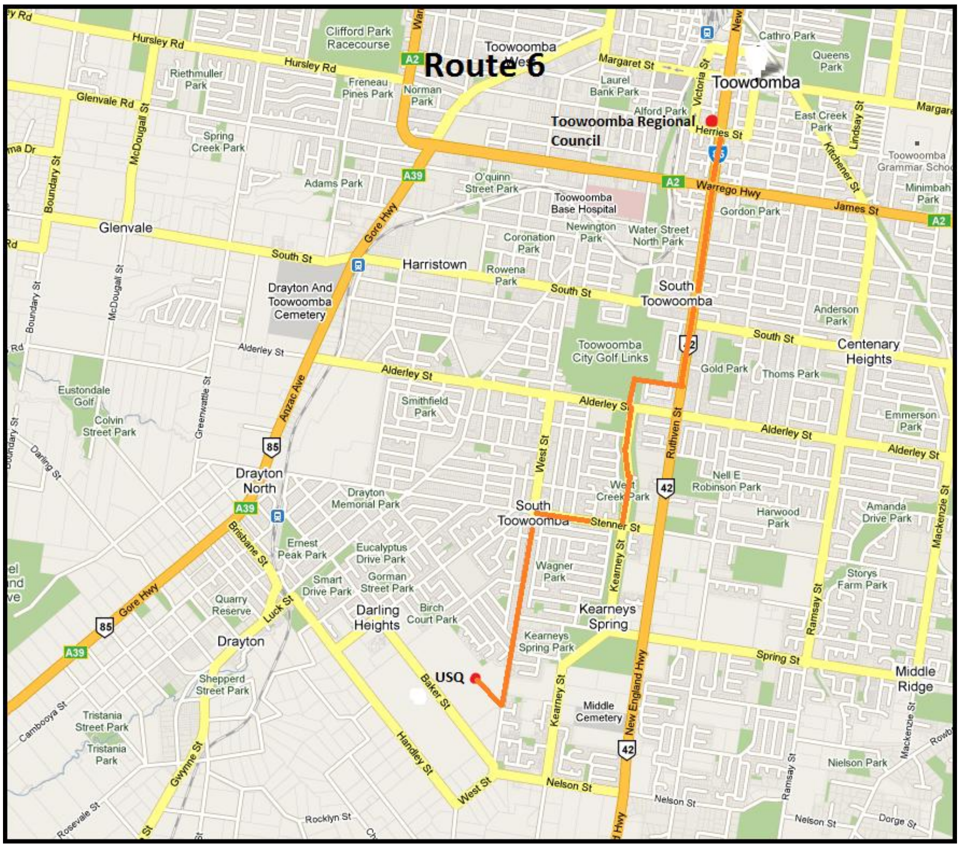


Figure 3.6: Route 5

Figure 3.7: Route 6



With the site and route selection completed the required accuracy for the data was then needed to be established. It was worked out that 0.5 metres in horizontal accuracy and 0.9

Figure 3.8: Pro XH GPS Receiver

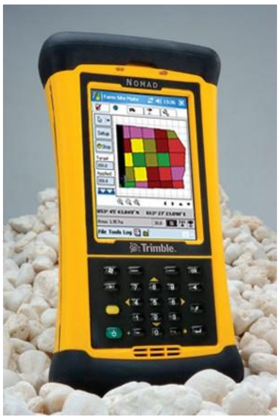


Figure 3.9: Nomad Data recorder

metres in vertical accuracy would be sufficient for computing energy usage. Using a Trimble Pro XH GPS receiver and a Trimble Nomad data recorder (Figure 3.8 & 3.9), raw data could be collected and post processed to get the desired accuracy. The next decision that was

Figure 3.10: Bike Frame Setup (left)

Figure 3.11: Magnetic Screw Plate

needed to be made was how the data would be collected. A frame was made up for a bicycle which the GPS could then be mounted onto. The bike and frame can be seen above in Figure 3.10. On top of the black plate on the frame sits a magnet that the GPS receiver screws on to (Figure 3.11). With the method of collection, accuracy, and the equipment decided on the logging interval was then chosen. A logging interval of five metres was picked for most of the terrain but in some areas with steep slopes and at corners, a logging interval of one second would be used. A time frame on completing the field work was also needed to assist in the rest of the planning process. It was expected that to complete the field work for this area it would take around six hours. It was estimated that there was approximately twenty kilometres of road logging to be collected.

The next step was to work out when the optimum time was to collect the field data. This was done by looking at factors such as: satellite configuration, peak traffic times and weather forecasts. Using different graphs and charts, the best time to collect data in terms of the number of satellites and their configuration could be determined. There were three main graphs that were used to work out the best time to collect data. The first was to show the number of satellites available in the sky at any one time. The more satellites in the sky generally meant better accuracy. An example of this graph can be seen below (Figure 3.12).

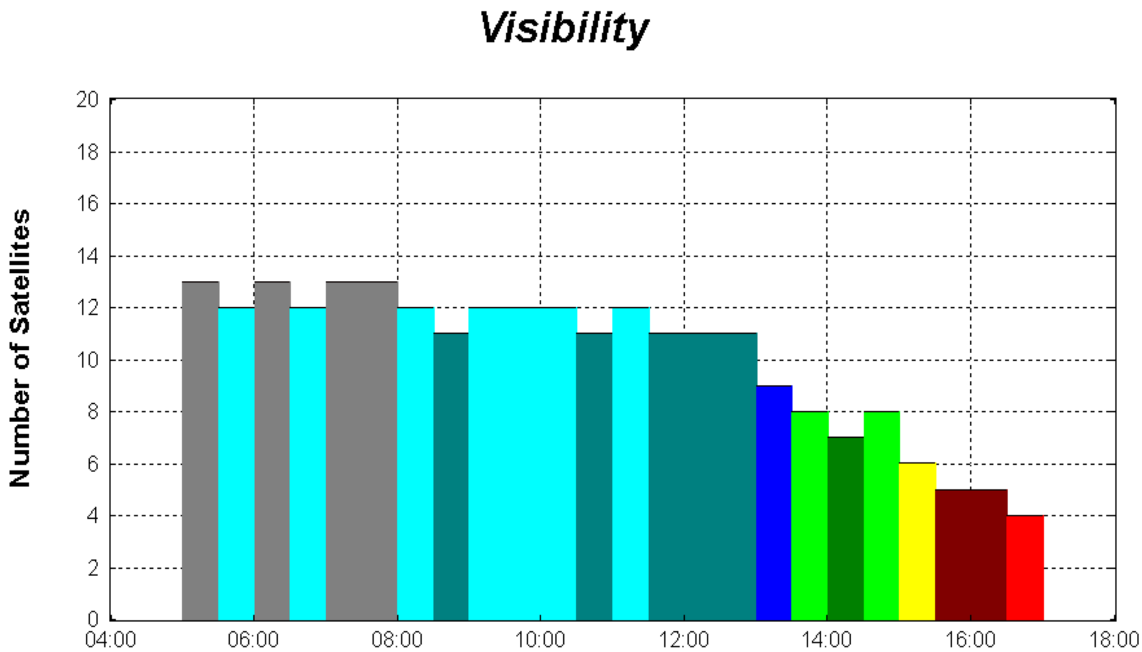


Figure 3.12: Satellite Numbers

Station Default North 0° 0' East 0° 0' Height 0m Elevation cutoff 10° Obstacles 0% Time 13/05/2010 05:00 - 13/05/2010 17:00 (GMT+10.0h)
Satellites 28 GPS 28 [Almanac.alm]

This graph shows that there are more satellites available from 5:30am til around 1:00pm. After 1:00pm the satellite numbers begin to fall to a point where there is not enough satellites to guarantee good accuracy.

Figure 3.12 then needed to be checked against another graph to check the Dilution of Precision (DOP). This graph can be seen below in Figure 3.13.

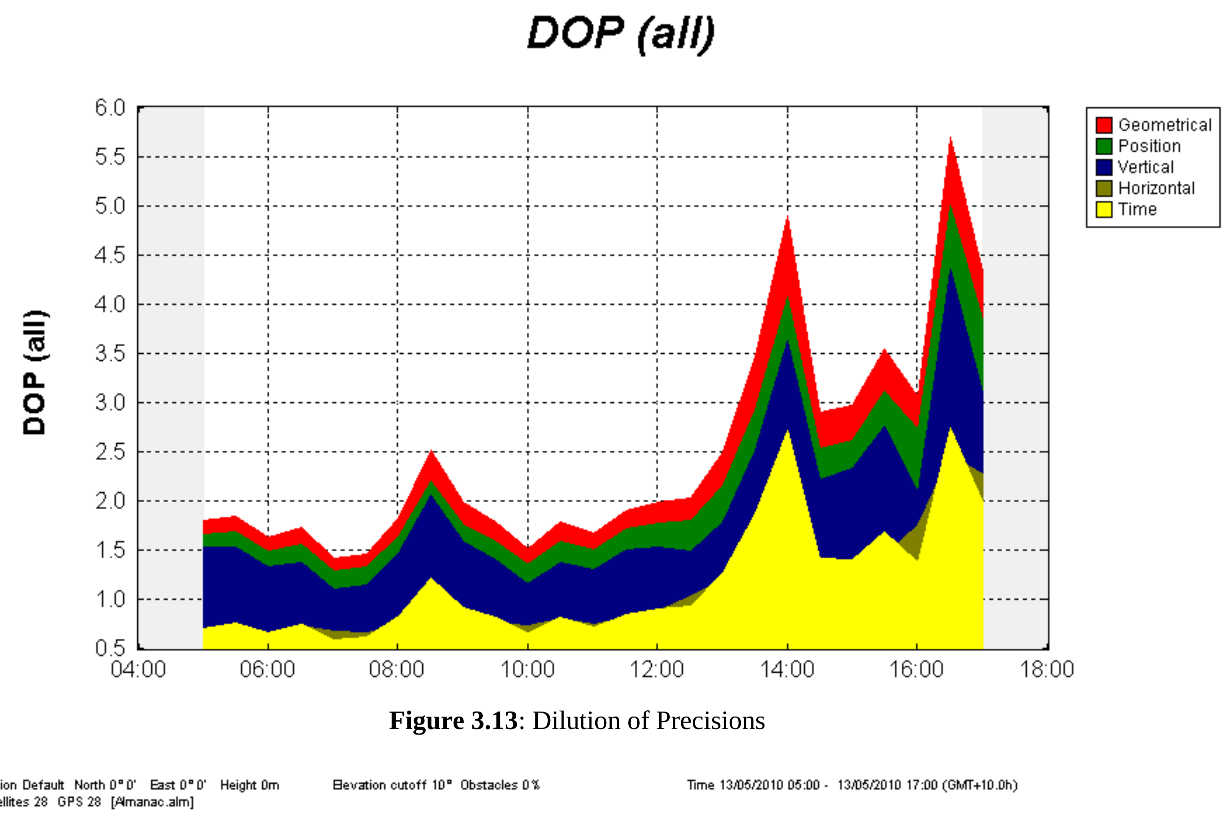


Figure 3.13: Dilution of Precisions

Again this graph shows that the DOP is good from 5:30am to about 1:00pm. However, when trying to maintain a DOP of two or better, between 8:00am and 9:00am data should not be collected due to the spike in the DOP. It could also be seen that after 1:00pm that the DOP blows out and the accuracy would not be very good during these times. After analysing the best times in terms of number of satellites and DOP, these optimum times can then be cross referenced with the sky plot chart.

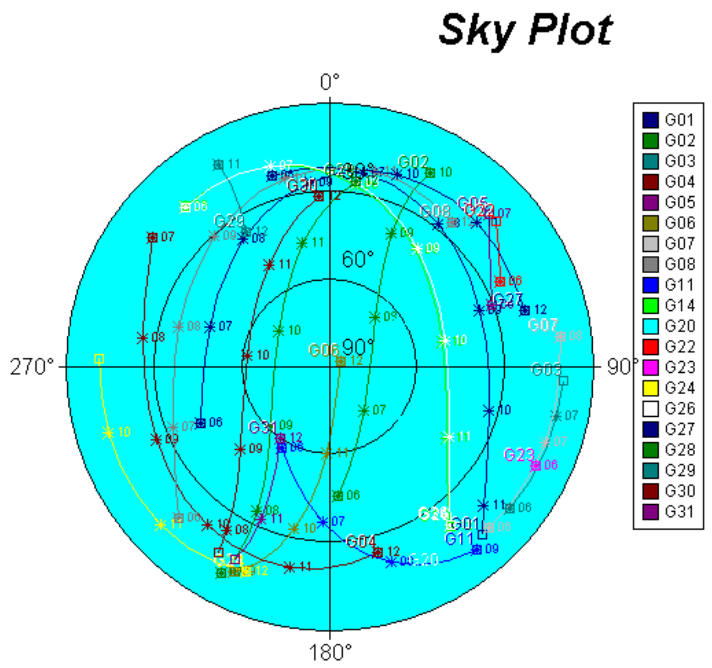


Figure 3.14: Sky Plot

Station Default North 0° 0' East 0° 0' Height 0m Elevation cutoff 10° Obstacles 0% Time 13/05/2010 06:00 - 13/05/2010 12:00 (GMT+10.0h)
Satellites 28 GPS 28 [Almanac.alm]

This sky plot chart (Figure 3.14) shows the satellite configuration for the times decided on using the previous two graphs, from 6:00am to 12:00pm. This chart shows that the satellites are wide spread across the sky so there will be satellites available even if there are obstructions such as trees and buildings. The configuration of the satellites during this time will give good geometry and therefore will give relatively good accuracy.

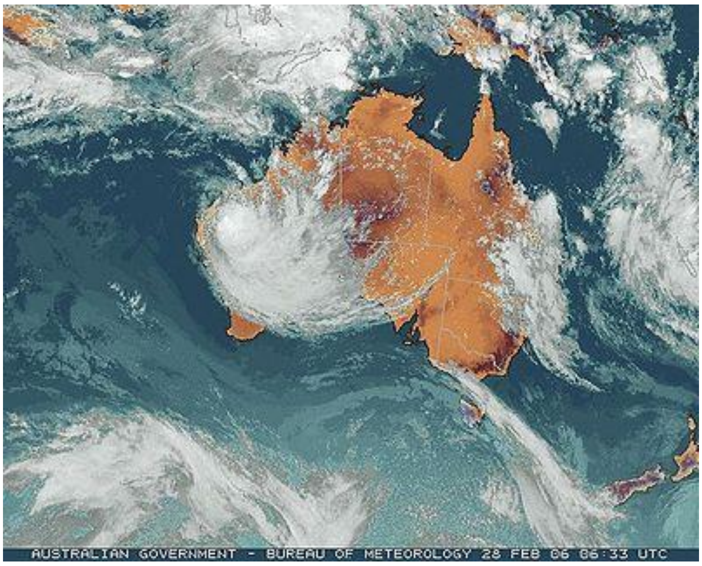


Figure 3.15: Weather Map

With the ideal times for data collection in terms of satellites these times must then be cross referenced with traffic times. In Toowoomba the peak traffic times are from about 8:00am til around 9:30am and from 2:30pm til 4:30pm. When taking these statistics into account it was clear that the best time to collect the data would be either from 6:00am til 8:00am or from 9:30am til 12:30am. Also considered in the data preparation and planning were the weather conditions. Clear weather is obviously the best weather for collecting the data as it provides comfortable weather and increases safety.

The last step in the preparation step was to ensure that appropriate safety precautions were in place for the survey. Ensuring that the following equipment was used and checked: high visibility clothing, helmet, appropriate footwear, ensuring the bicycle is in good shape (brakes etc), and knowing the road rules.

Figure 3.16: Hi-Viz Clothing

3.2.2 Testing Equipment

Before any data could be collected the equipment needed to be tested to ensure that it worked and so that it could be downloaded properly and into the right format. The GPS equipment

Figure 3.18: Testing Equipment

was hooked up to the bicycle and bracket. Figure 3.18 and 3.19 show the set up used for testing and collecting the field data. The Trimble ProXH receiver can be seen mounted on top of the black frame at the back of the bike and the Trimble Nomad data controller can be seen in the harness around the shoulder. After hooking up the equipment, a small amount of data was collected. This data was then post-processed and exported as a shape file (.shp) so it could be viewed in Arc Map. Base data files were downloaded from the USQ base station on

Figure 3.19: Equipment testing

top of Z block to post process the data. By completing this process it ensured that the equipment was working appropriately and that the data would be able to be used in Arc Map. This process was also good practice in using the equipment and producing useful field data. With the testing complete and confidence in the equipment and the process was felt, the field work could then be undertaken.

3.2.3 Risk Assessment

There are a number of risks that could cause personal harm or injury in this project. With a significant component of field work these risks are always present. The following table shows the hazards that are present in this project and the controls to minimise the risks.

Hazard	**Risk**	**Likelihood**	**Consequences**	**Controls**
Working on or near a road (streets & highways)	Getting clipped or hit by a car	Possible	High	Working at times when there is minimal traffic Wearing PPE (helmet, High Visibility clothing, appropriate clothing)
Riding a Bicycle	Falling off or crashing	Possible	Medium	Wearing PPE (helmet, appropriate clothing, closed in shoes)
Exhaustion	Extreme tiredness causing injury to self or others	Unlikely	Low	Take regular breaks Break the job up into parts
Dehydration	Headaches, nausea, vomiting	Possible	Medium	Take regular drink breaks Check urine
Pot holes and low branches	Crashing and hit head on branches	Unlikely	Low	Wearing PPE (helmet, appropriate clothing, closed in shoes)
Flat Tyre	Crashing	Possible	Medium	Wearing PPE, Checking Bicycle before leaving
Sun	Sunburn	Possible	Low	Wear Sunscreen and appropriate clothing

Figure 3.20: Risk Assessment

3.2.4 Field Work

Figure 3.21: Cycling Pathway

Figure 3.22: Cycling Lane

The data was collected in three different sections. This was because there was a large amount of data to be collected (approximately 20km) and to work in with the ideal times collect data found in the planning process. Once again the equipment was mounted on the bike and the safety equipment worn. A few checks were also made to ensure the data was working efficiently. The time was noted for the start of the survey so the respective base data files could be downloaded after completing the section. With everything in order the data was collected.

The data was collected over a range of different paths from cyclist lanes to pedestrian paths which were considered to be the most common paths for cyclists. Figure 3.21 shows the path through the cycling pathways along West Creek which offers wide open spaces for riding. Figure 3.22 shows the cycling lanes along West street while Figure 3.23 shows pedestrian

Figure 3.23: Pedestrian Path

pathways where the data was collected. The data was collected using a five metre logging interval but on steep roads and at sharp corners the logging interval was changed to a one second interval to eliminate gaps in the data. Once the data was collected it was then downloaded onto a computer using Active sync software and stored at an appropriate location. The base station data was also downloaded online for post processing later. This process was repeated until all the field data was collected.

3.2.5 Other Data Collection

Along with the GPS data logged on the pathways a digital elevation model (DEM) and road network data were needed to check the data and to assist in making a better output map. This data was able to be acquired through my project supervisor Dr. Xiaoye Liu. This data was collected in 2006 via orthorectified digital colour aerial photography at one metre grid elevation points. The diagram on the next page (Figure 3.24) shows a map of the DEM and road network data of the site area acquired from Dr. Xiaoye Liu.

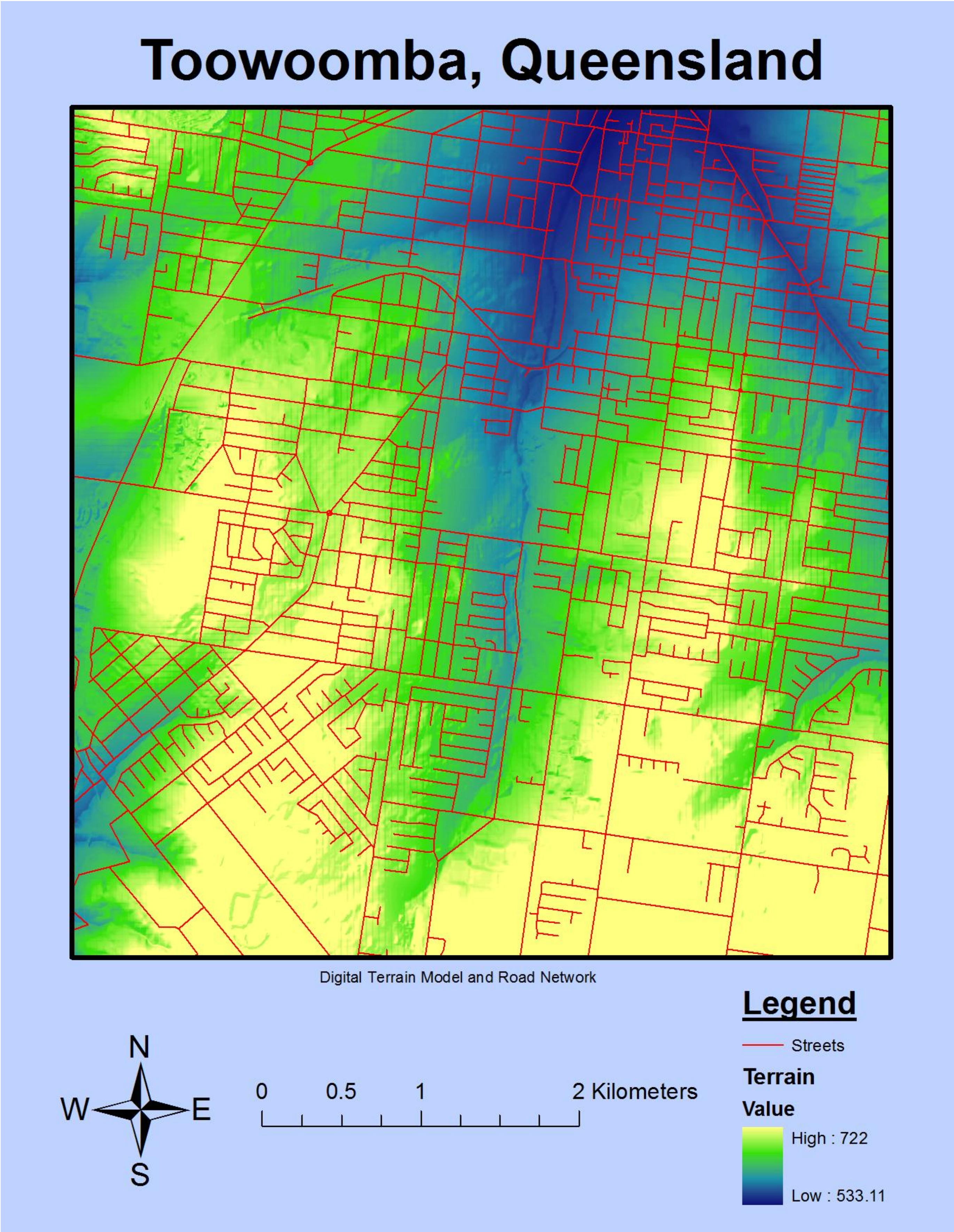


Figure 3.24: Acquired Data

3.3 Data Processing and Analysis

The first step in the data processing and analysis stage was to post-process the GPS data. This was done by downloading the GPS data using Active sync and data transfer software (Figure

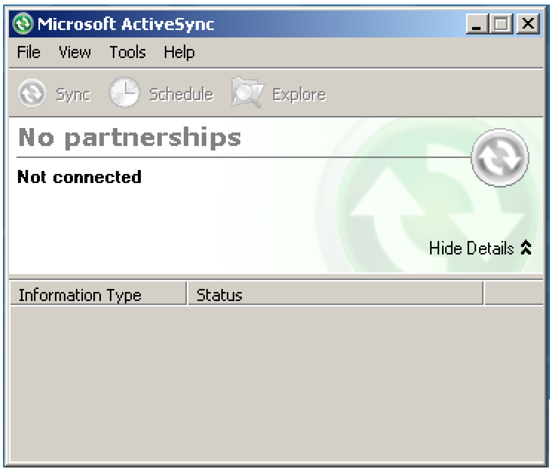


Figure 3.25: ActiveSync Program

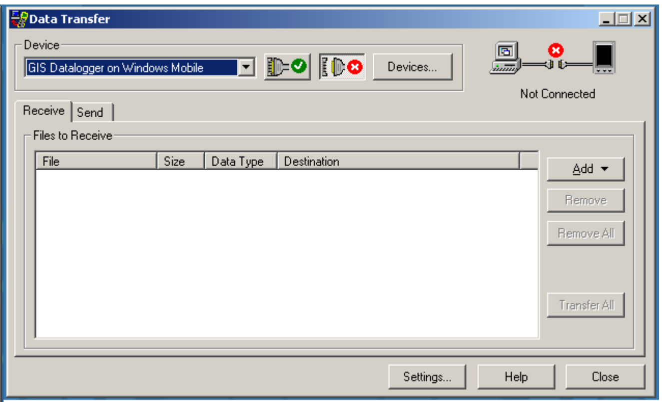


Figure 3.26: Data Transfer Program

3.25 and 3.26) and storing it onto the computer. The files were then opened in Trimble Pathfinder Office and it was post-process (seen in Figure 3.27 below). The accuracy of the data before post-processing was ±5 metres in horizontal and ±6 metres in vertical. After post-

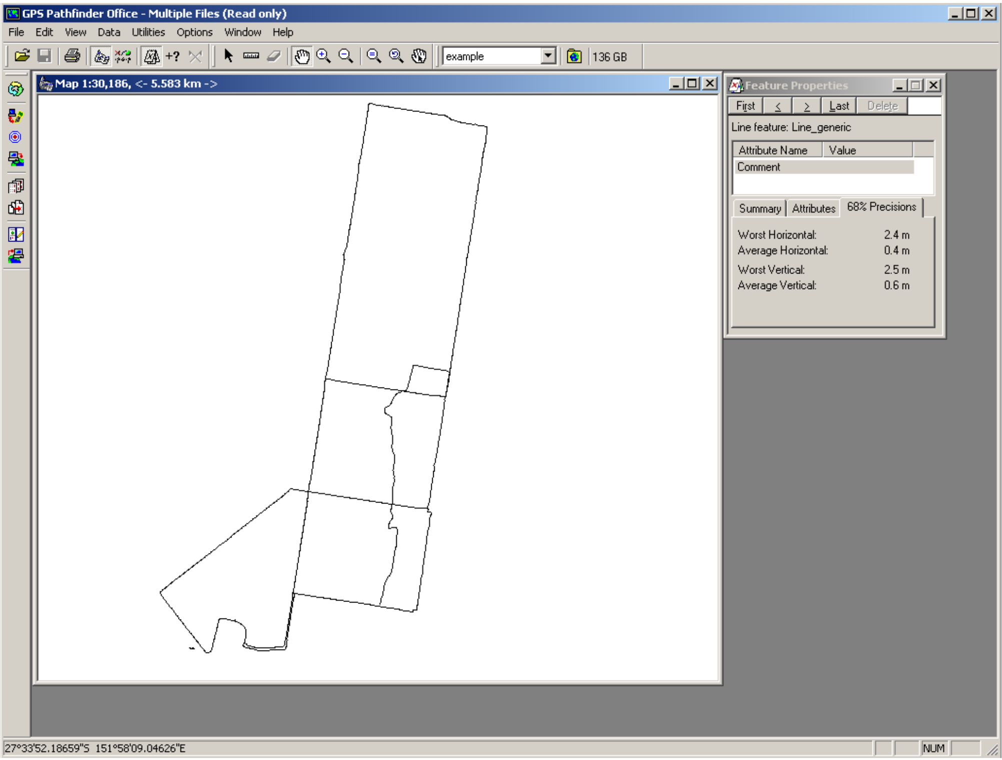


Figure 3.27: GP Pathfinder Office Post-Processing

processing the accuracy was ±0.3 metres in horizontal and ±0.8 in vertical in the worst cases. Most of the data was below 0.5 metres in accuracy. This was well and truly good enough for what the data was needed for. Once the data was post-processes and the accuracy was checked, the data was then exported as a shape (.shp) file so it could be used in ArcGIS software.

Within ArcGIS the program Arc Map was opened and the DEM data, road network data and the GPS data was imported. From here checks could be made to ensure that the data collected matched the terrain of the DEM and also was accurate with the road network data. Figure 3.28 shows all the data combined together using Arc Map.

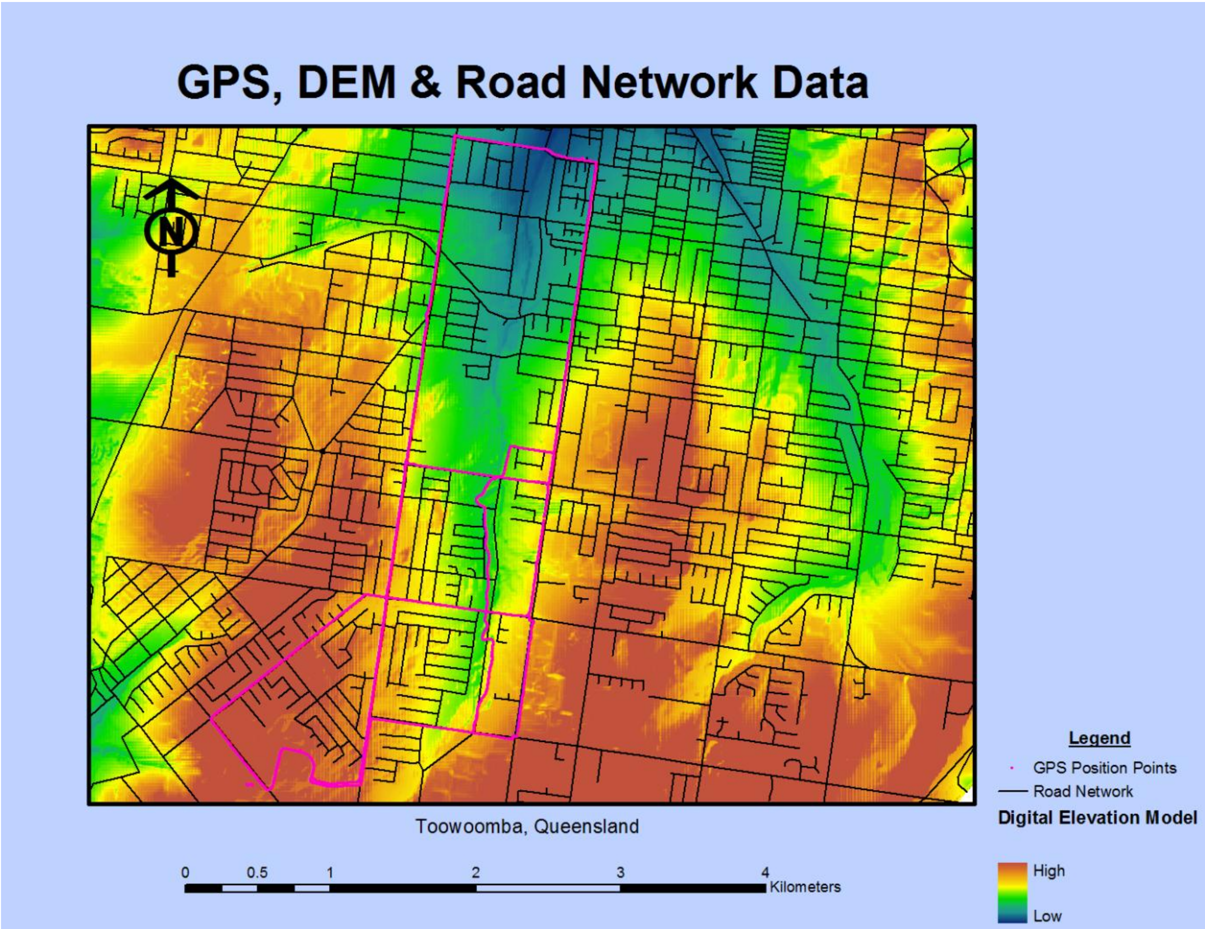


Figure 3.28: GPS, DEM & road network data used

With the checks completed the next step was to create a slope map from the DEM. This involved creating categories for the different slope to assist in calculating energy expenditure. Firstly, a slope map was created and this map was then reclassified to specific parameters to make it more useful for determining grade change. The categories that were used in the reclassification of the slope map were:

0 – 1%

1 – 3%

3 – 5%

5 – 7%

7 – 10%

10 – 15%

15 – 30%

Each category was represented by a different colour on the DEM. This can be seen in Figure 3.29 (below) where slope classification is conducted and the final output shown. The red colours represent areas that are relatively flat while the bluer colours represent steep terrain. With the post-processing, checks and the slope classification complete, the data was then ready to be used in the calculations.

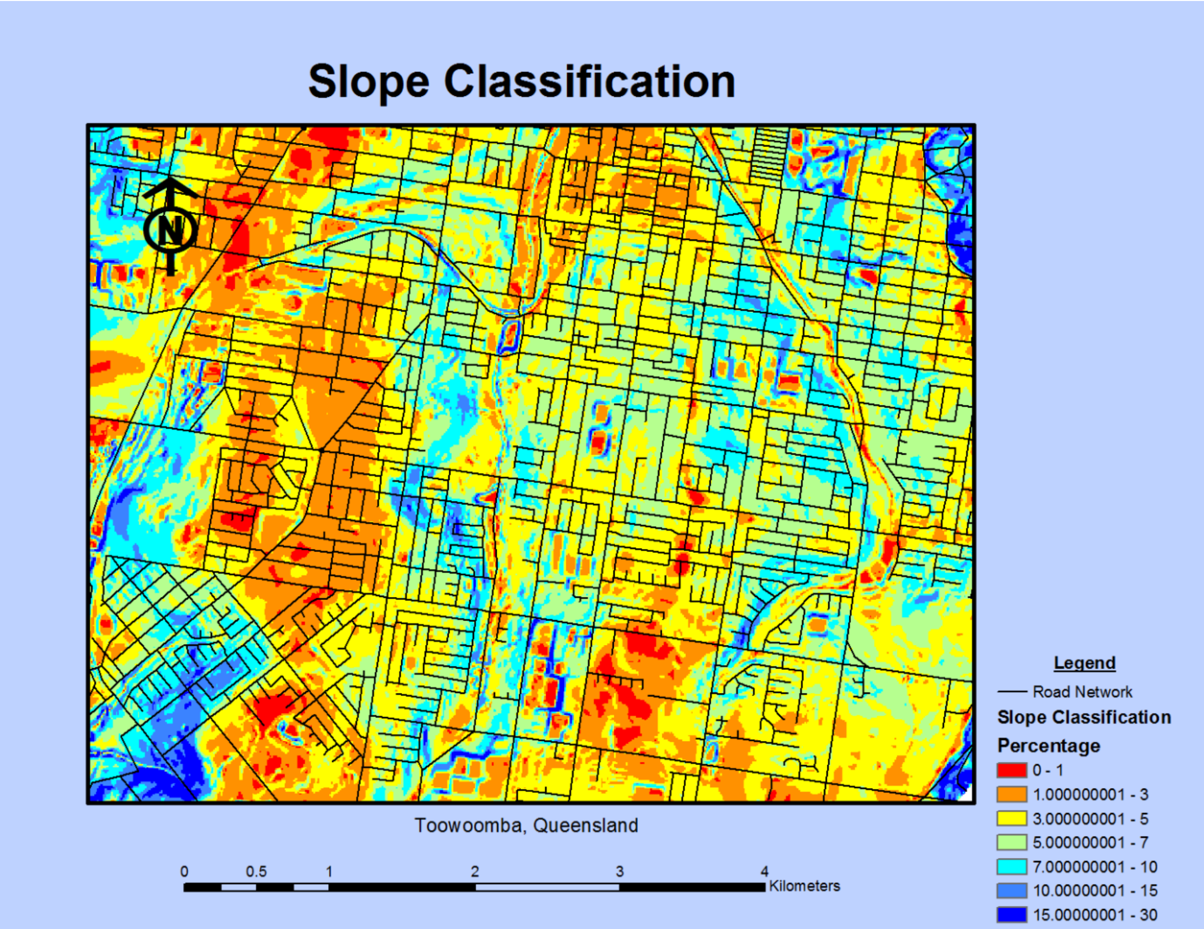


Figure 3.29: Slope Classification

3.4 Computing Energy Usage

There were two equations formulated to calculate the energy for bicycles on slopes. There was one equation that calculated the energy going uphill and the other was used for calculating energy going downhill. The formulas were a modified version of the Mueller K research into energy equations. The equation was changed so that it was in metric units and different values for speed coefficients were used. The final formulas and the variable information can be seen below;

Uphill

$$Calories = \left[(S_c \times (BW \times 2.2) \times 60) \times \left(\frac{D}{S}\right)\right] + (0.22 \times (HD \times 3.28))$$

Downhill

$$Calories = \left[(S_c \times (BW \times 2.2) \times 60) \times \left(\frac{D}{S}\right)\right] - \left(0.1 \times (HD \times 3.28)\right)$$

Where,

S = Speed (average)

S_c = Speed Coefficient

BW = Body Weight (kg)

D = Distance (km)

HD = Height Difference (metres)

These formulas were formed by using a combination of information from other sources and adjusted to produce an equation for what was needed. When looking at the first equation for calculating energy uphill it can be divided into two sections. The first section is within the large set of parentheses. This first section computes the energy use for riding a bike on level terrain. The second part is adding energy to compensate for travelling uphill because of course it takes more energy to ride up a hill. The second equation is similar to the first and it calculates the energy usage of riding downhill. It can also be divided into two separate parts. Again the first section computes the energy on level terrain while the second part subtracts energy to compensate for riding downhill.

Before any calculations could be conducted on the data, the equations had to be tested to ensure that they were going to work. A small section of data was taken from Arc Map and was used to check the formulas. The uphill formula was applied first to the data from A to B. This produced a result that could then be used to compare later. The downhill formula was then applied to the same data but in the opposite direction, from B to A. For the formula to work efficiently the results had to be different. A second test was then conducted by taking the first part of the formula and testing it to calorie calculators on the internet. The sources used were Fitness2live (2010) and CSG network (2010). When comparing the answers there was a small difference and was considered not be an issue. This will be discussed later in the dissertation.

The calculations begun by collecting relevant information using Arc Map and inputting it into a Microsoft Excel spreadsheet. Using this program the above formulas were applied to the

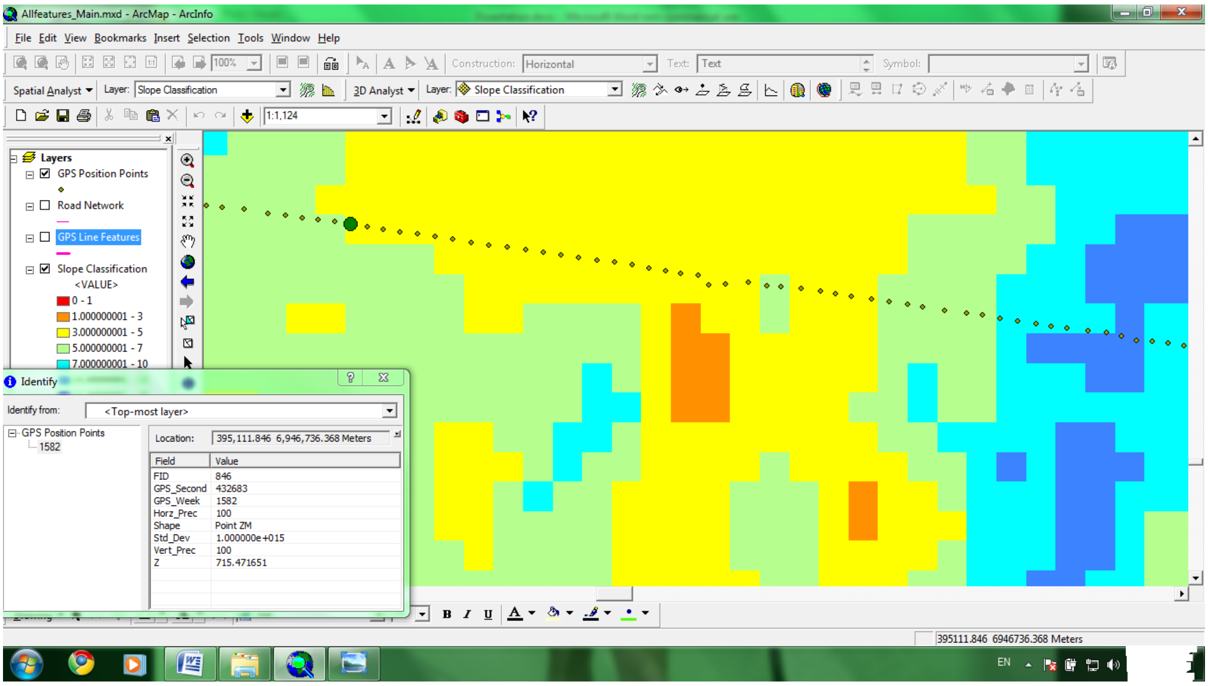


Figure 3.30: Point Selection and Calculations

data. The routes were divided up into a number of small sections to make it easier to calculate the energy and also to avoid having two calculated sections on routes twice. The information gathered using Arc Map was collected by using the slope classification layer and the collected GPS point data. Where a grade started a point would be selected and the point number and its height were noted (Figure 3.30).

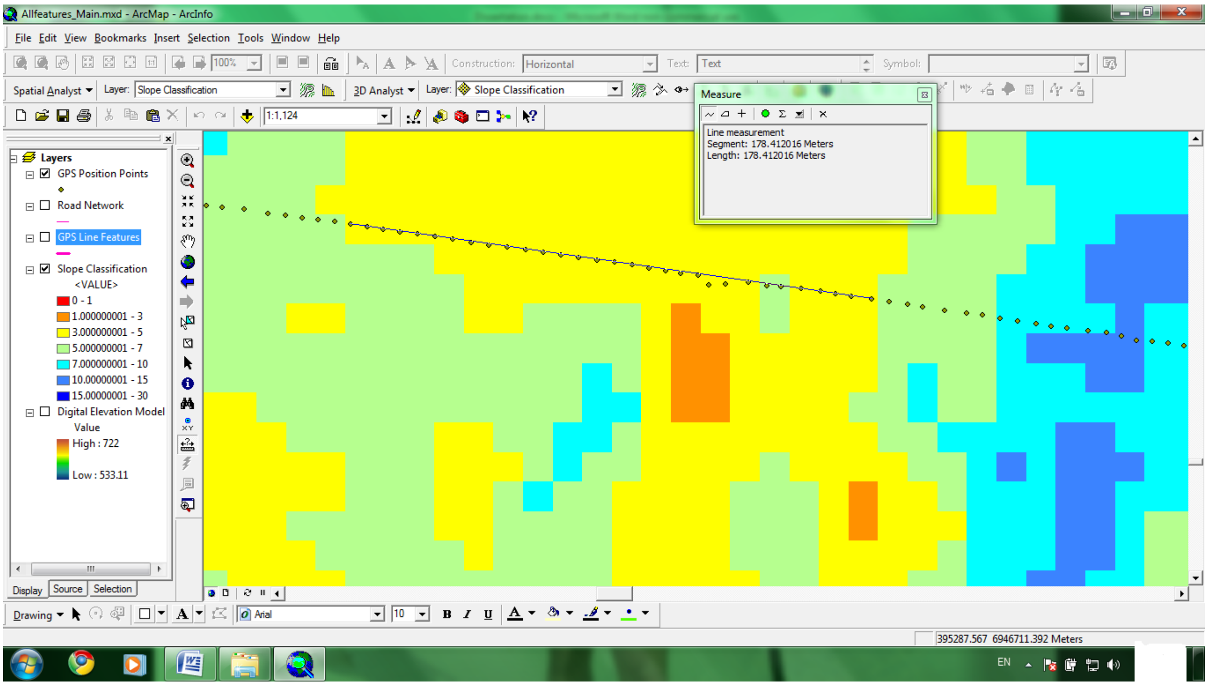


Figure 3.31: Measuring between points

Where there was another change in grade another point was selected and again the number and height was noted. A distance between these two points was then calculated using the inquire function and all this information was stored in the spreadsheet (Figure 3.31).

The data was put into respective columns and calculations were made to determine the height difference between two points. Depending on weather the answer was positive or negative determined which formula was used, the downhill or uphill equation. When the height difference was negative the terrain was going downhill so the respected formula was used. When the height difference was positive the terrain was uphill and therefore the uphill equation was applied. This was done in turn for each route until the results were found. These results were then tested by applying the formula for the start and finish point for all the different distances. The results were then all put together and graphs were made to help show present and analyse the results.

3.5 Conclusion

This chapter covered how the method of the project was carried out. It looked at what was required in the planning, testing, and data collection. The risks of collecting the data were assessed and the method of data processing and analysis was discussed. Maps were made to help understand the terrain and the process of computing energy expenditure was explained. With the method of the project described the results can then be presented and the easiest route discovered.

CHAPTER 4

RESULTS

4.1 Introduction

In this chapter the results of the project will be presented. The Microsoft Excel spreadsheet tables used to calculate the energy usage for each route will be displayed along with a table showing the final results of the energy expenditure. There are also graphs within this chapter that show the terrain of each route and also showing the energy usage in a number of different ways.

4.2 Results

The results for the different routes were calculated using Microsoft Excel and are seen below in tables for each route. The following variables were also used in the calculations.

S = 25km/h

S_c = 0.075

BW = 70kg

Figure 4.1: Route 1 Energy calculations

Route 1

Distance	RL	Calories	Acquired Distance	Acquired Calories
0.00	735.72	0.00	0.00	0.00
0.08	733.88	1.65	0.08	1.65
0.15	733.46	4.15	0.24	5.80
0.21	726.78	3.62	0.45	9.43
0.10	724.00	1.96	0.55	11.39
0.04	723.30	0.90	0.59	12.29
0.24	720.46	5.59	0.83	17.87
0.08	719.95	2.05	0.91	19.92
0.11	718.08	2.34	1.01	22.26
0.33	712.71	7.43	1.34	29.69
0.25	708.34	5.61	1.60	35.30
0.13	707.73	3.46	1.73	38.76
0.13	711.83	6.57	1.86	45.33
0.20	712.42	5.96	2.06	51.30
0.20	710.22	4.95	2.26	56.25
0.14	707.77	3.12	2.41	59.37
0.11	699.24	0.38	2.52	59.76
0.11	695.03	1.74	2.63	61.49
0.16	698.77	7.19	2.80	68.68
0.07	697.25	1.51	2.87	70.19
0.12	694.18	2.34	2.99	72.53
0.11	692.12	2.45	3.10	74.98
0.19	684.43	2.68	3.29	77.66
0.19	682.75	4.61	3.48	82.27
0.15	681.45	3.79	3.63	86.06
0.10	676.71	1.20	3.73	87.26
0.12	675.83	2.94	3.84	90.20
0.13	676.70	4.18	3.97	94.38
0.04	676.96	1.35	4.01	95.73
0.05	676.47	1.30	4.07	97.03
0.15	672.48	2.88	4.22	99.91
0.12	670.11	2.59	4.34	102.50
0.18	661.23	2.21	4.52	104.71
0.10	656.97	1.35	4.62	106.06
0.17	652.15	3.09	4.79	109.15
0.12	655.41	5.71	4.91	114.86
0.09	658.95	5.15	5.01	120.01
0.11	660.21	3.90	5.11	123.91
0.11	658.65	2.48	5.22	126.39
0.24	646.86	2.80	5.46	129.19
0.07	643.66	0.84	5.53	130.03
0.14	635.72	1.16	5.67	131.19
0.09	633.64	1.88	5.76	133.07
0.10	635.51	4.11	5.86	137.17
0.09	639.50	5.37	5.95	142.54
0.08	639.64	2.43	6.03	144.97
6.03		**144.97**	**6.03**	**144.97**

Figure 4.2: Route 2 Energy calculations

Route 2

Distance	RL	Calories	Acquired Distance	Acquired Calories
0.00	735.72	0.00	0.00	0.00
0.08	733.88	1.65	0.08	1.65
0.15	733.46	4.15	0.24	5.80
0.21	726.78	3.62	0.45	9.43
0.10	724.00	1.96	0.55	11.39
0.04	723.30	0.90	0.59	12.29
0.24	720.46	5.59	0.83	17.87
0.08	719.95	2.05	0.91	19.92
0.11	718.08	2.34	1.01	22.26
0.33	712.71	7.43	1.34	29.69
0.25	708.34	5.61	1.60	35.30
0.13	707.73	3.46	1.73	38.76
0.13	711.83	6.57	1.86	45.33
0.20	712.42	5.96	2.06	51.30
0.20	710.22	4.95	2.26	56.25
0.14	707.77	3.12	2.41	59.37
0.11	699.24	0.38	2.52	59.76
0.11	695.03	1.74	2.63	61.49
0.16	698.77	7.19	2.80	68.68
0.27	678.86	1.02	3.07	69.70
0.39	666.46	6.80	3.46	76.50
0.09	669.66	4.75	3.55	81.25
0.19	683.10	14.97	3.74	96.21
0.06	686.24	3.85	3.79	100.06
0.15	684.74	3.65	3.94	103.71
0.06	683.70	1.42	4.01	105.13
0.10	681.73	2.17	4.11	107.30
0.30	674.63	5.90	4.41	113.21
0.11	672.99	2.41	4.51	115.62
0.38	660.46	6.31	4.89	121.93
0.39	656.03	9.24	5.27	131.17
0.33	650.35	7.21	5.60	138.38
0.11	646.45	1.78	5.71	140.16
0.33	639.73	7.04	6.05	147.20
0.10	639.64	2.79	6.15	149.99
6.15		**149.99**	**6.15**	**149.99**

Figure 4.3: Route 3 Energy calculations

Route 3

Distance	RL	Calories	Acquired Distance	Acquired Calories
0.00	735.72	0.00	0.00	0.00
0.08	733.88	1.65	0.08	1.65
0.15	733.46	4.15	0.24	5.80
0.21	726.78	3.62	0.45	9.43
0.10	724.00	1.96	0.55	11.39
0.04	723.30	0.90	0.59	12.29
0.24	720.46	5.59	0.83	17.87
0.08	719.95	2.05	0.91	19.92
0.11	718.08	2.34	1.01	22.26
0.08	715.47	1.28	1.09	23.54
0.20	707.61	3.03	1.29	26.57
0.22	690.75	0.57	1.51	27.14
0.23	688.29	5.56	1.74	32.69
0.32	704.19	20.38	2.06	53.08
0.10	701.53	1.92	2.16	55.00
0.10	695.61	0.96	2.27	55.96
0.12	694.32	2.96	2.39	58.92
0.10	695.51	3.17	2.49	62.08
0.10	694.03	2.39	2.59	64.48
0.10	691.24	1.92	2.70	66.40
0.12	686.94	2.05	2.82	68.45
0.11	683.98	1.97	2.93	70.42
0.26	680.45	4.76	3.19	75.19
0.20	683.41	7.75	3.39	82.94
0.12	681.92	2.15	3.51	85.09
0.20	683.45	6.57	3.71	91.66
0.18	686.24	6.87	3.88	98.53
0.15	684.74	3.65	4.03	102.18
0.06	683.70	1.42	4.09	103.60
0.10	681.73	2.17	4.20	105.77
0.30	674.63	5.90	4.49	111.67
0.11	672.99	2.41	4.60	114.09
0.38	660.46	6.31	4.98	120.40
0.39	656.03	9.24	5.36	129.64
0.33	650.35	7.21	5.69	136.85
0.11	646.45	1.78	5.80	138.63
0.33	639.73	7.04	6.13	145.67
0.10	639.64	2.79	6.23	148.46
6.23		**148.46**	**6.23**	**148.46**

Figure 4.4: Route 4 Energy calculations

Route 4

Distance	RL	Calories	Acquired Distance	Acquired Calories
0.00	735.72	0.00	0.00	0.00
0.08	733.88	1.65	0.08	1.65
0.15	733.46	4.15	0.24	5.80
0.21	726.78	3.62	0.45	9.43
0.10	724.00	1.96	0.55	11.39
0.04	723.30	0.90	0.59	12.29
0.24	720.46	5.59	0.83	17.87
0.08	719.95	2.05	0.91	19.92
0.11	718.08	2.34	1.01	22.26
0.33	712.71	7.43	1.34	29.69
0.25	708.34	5.61	1.60	35.30
0.13	707.73	3.46	1.73	38.76
0.13	711.83	6.57	1.86	45.33
0.26	700.87	3.52	2.12	48.85
0.24	690.06	3.17	2.36	52.02
0.20	675.70	0.70	2.55	52.71
0.08	675.10	1.97	2.63	54.68
0.14	678.79	6.44	2.77	61.12
0.08	682.86	5.03	2.84	66.16
0.26	680.45	4.76	3.11	70.92
0.20	683.41	7.75	3.31	78.67
0.12	681.92	2.15	3.43	80.82
0.20	683.45	6.57	3.62	87.39
0.18	686.24	6.87	3.80	94.26
0.15	684.74	3.65	3.95	97.91
0.06	683.70	1.42	4.01	99.33
0.10	681.73	2.17	4.11	101.50
0.30	674.63	5.90	4.41	107.41
0.11	672.99	2.41	4.52	109.82
0.38	660.46	6.31	4.89	116.13
0.39	656.03	9.24	5.28	125.37
0.33	650.35	7.21	5.61	132.58
0.11	646.45	1.78	5.72	134.36
0.33	639.73	7.04	6.05	141.40
0.10	639.64	2.79	6.15	144.19
6.15		**144.19**	**6.15**	**144.19**

Figure 4.5: Route 5 Energy calculations

Route 5

Distance	RL	Calories	Acquired Distance	Acquired Calories
0.00	735.72	0.00	0.00	0.00
0.08	733.88	1.65	0.08	1.65
0.15	733.46	4.15	0.24	5.80
0.21	726.78	3.62	0.45	9.43
0.10	724.00	1.96	0.55	11.39
0.04	723.30	0.90	0.59	12.29
0.24	720.46	5.59	0.83	17.87
0.08	719.95	2.05	0.91	19.92
0.11	718.08	2.34	1.01	22.26
0.08	715.47	1.28	1.09	23.54
0.20	707.61	3.03	1.29	26.57
0.22	690.75	0.57	1.51	27.14
0.23	688.29	5.56	1.74	32.69
0.12	686.28	2.63	1.86	35.32
0.14	682.82	2.80	2.00	38.13
0.10	682.05	2.53	2.10	40.66
0.13	679.28	2.56	2.23	43.21
0.13	679.05	3.63	2.36	46.85
0.15	677.73	3.71	2.51	50.55
0.18	675.97	4.43	2.69	54.98
0.13	674.36	3.08	2.82	58.07
0.20	670.03	4.16	3.02	62.23
0.14	669.39	3.77	3.17	66.00
0.11	669.22	3.05	3.28	69.06
0.15	669.11	4.13	3.43	73.18
0.16	668.74	4.28	3.59	77.46
0.14	666.61	3.27	3.73	80.74
0.07	665.32	1.54	3.80	82.28
0.10	663.80	2.37	3.90	84.65
0.14	666.93	6.10	4.04	90.74
0.14	676.75	11.00	4.18	101.75
0.11	683.70	8.06	4.29	109.81
0.10	681.73	2.17	4.40	111.98
0.30	674.63	5.90	4.69	117.89
0.11	672.99	2.41	4.80	120.30
0.38	660.46	6.31	5.18	126.61
0.39	656.03	9.24	5.56	135.85
0.33	650.35	7.21	5.89	143.06
0.11	646.45	1.78	6.00	144.84
0.33	639.73	7.04	6.33	151.88
0.10	639.64	2.79	6.43	154.67
6.43		**154.67**	**6.43**	**154.67**

Figure 4.6: Route 6 Energy calculations

Route 6

Distance	RL	Calories	Acquired Distance	Acquired Calories
0.00	735.72	0.00	0.00	0.00
0.08	733.88	1.65	0.08	1.65
0.15	733.46	4.15	0.24	5.80
0.21	726.78	3.62	0.45	9.43
0.10	724.00	1.96	0.55	11.39
0.04	723.30	0.90	0.59	12.29
0.24	720.46	5.59	0.83	17.87
0.08	719.95	2.05	0.91	19.92
0.11	718.08	2.34	1.01	22.26
0.33	712.71	7.43	1.34	29.69
0.25	708.34	5.61	1.60	35.30
0.13	707.73	3.46	1.73	38.76
0.13	711.83	6.57	1.86	45.33
0.26	700.87	3.52	2.12	48.85
0.24	690.06	3.17	2.36	52.02
0.20	675.70	0.70	2.55	52.71
0.13	674.36	3.08	2.68	55.79
0.20	670.03	4.16	2.89	59.96
0.14	669.39	3.77	3.03	63.73
0.11	669.22	3.05	3.14	66.78
0.15	669.11	4.13	3.29	70.91
0.16	668.74	4.28	3.45	75.19
0.14	666.61	3.27	3.59	78.46
0.07	665.32	1.54	3.66	80.00
0.10	663.80	2.37	3.77	82.37
0.14	666.93	6.10	3.91	88.47
0.14	676.75	11.00	4.05	99.47
0.11	683.70	8.06	4.16	107.54
0.10	681.73	2.17	4.26	109.71
0.30	674.63	5.90	4.56	115.61
0.11	672.99	2.41	4.66	118.03
0.38	660.46	6.31	5.04	124.34
0.39	656.03	9.24	5.42	133.58
0.33	650.35	7.21	5.75	140.79
0.11	646.45	1.78	5.86	142.56
0.33	639.73	7.04	6.20	149.61
0.10	639.64	2.79	6.30	152.40
6.30		**152.40**	**6.30**	**152.40**

The final results of the calculation can be seen below in Figure 4.7.

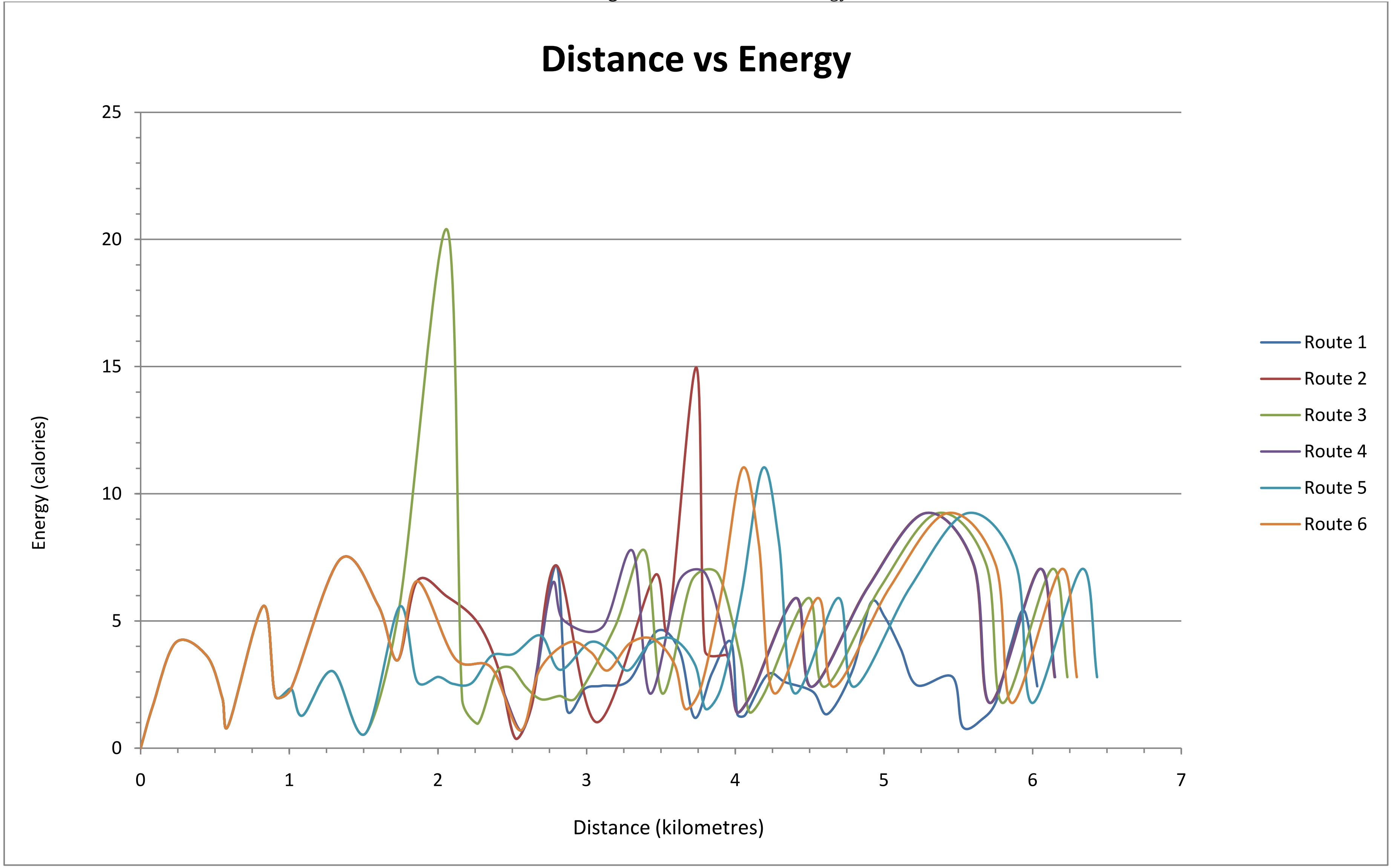
Route Energy and Distance

Route	Energy (calories)	Distance (kilometres)
1	144.9743	6.031
2	149.99234	6.147
3	148.4603	6.234
4	144.1930	6.151
5	154.6725	6.434
6	152.3994	6.297

Figure 4.7: Energy calculations results

The results show the six different routes and the total energy used in terms of calories and also the total distance of each route in terms of kilometres. The graphs below show the energy used over distance for all of the routes and also the profiles of all the routes.

Figure 4.8: Distance vs. Energy



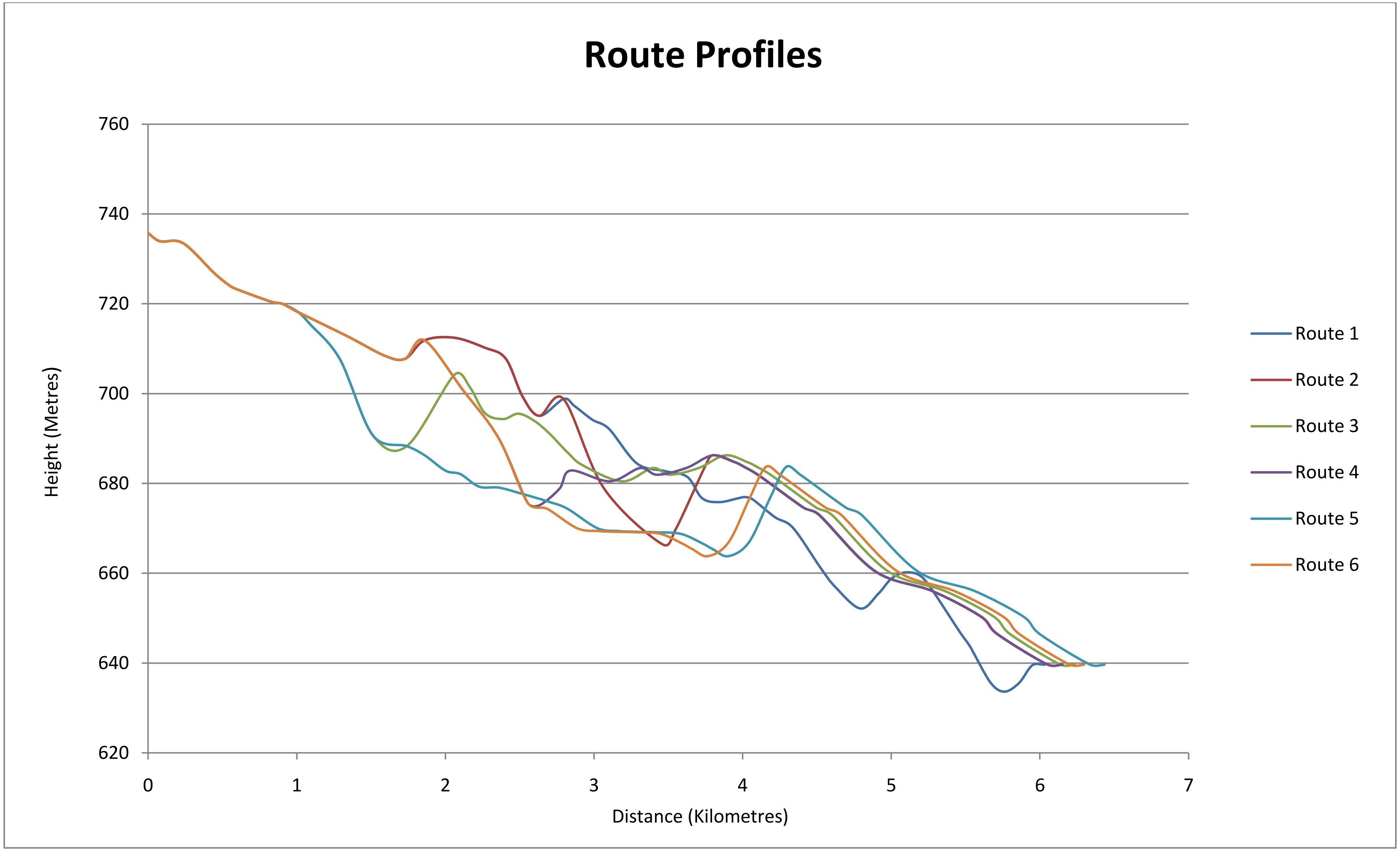


Figure 4.9: Route Profiles

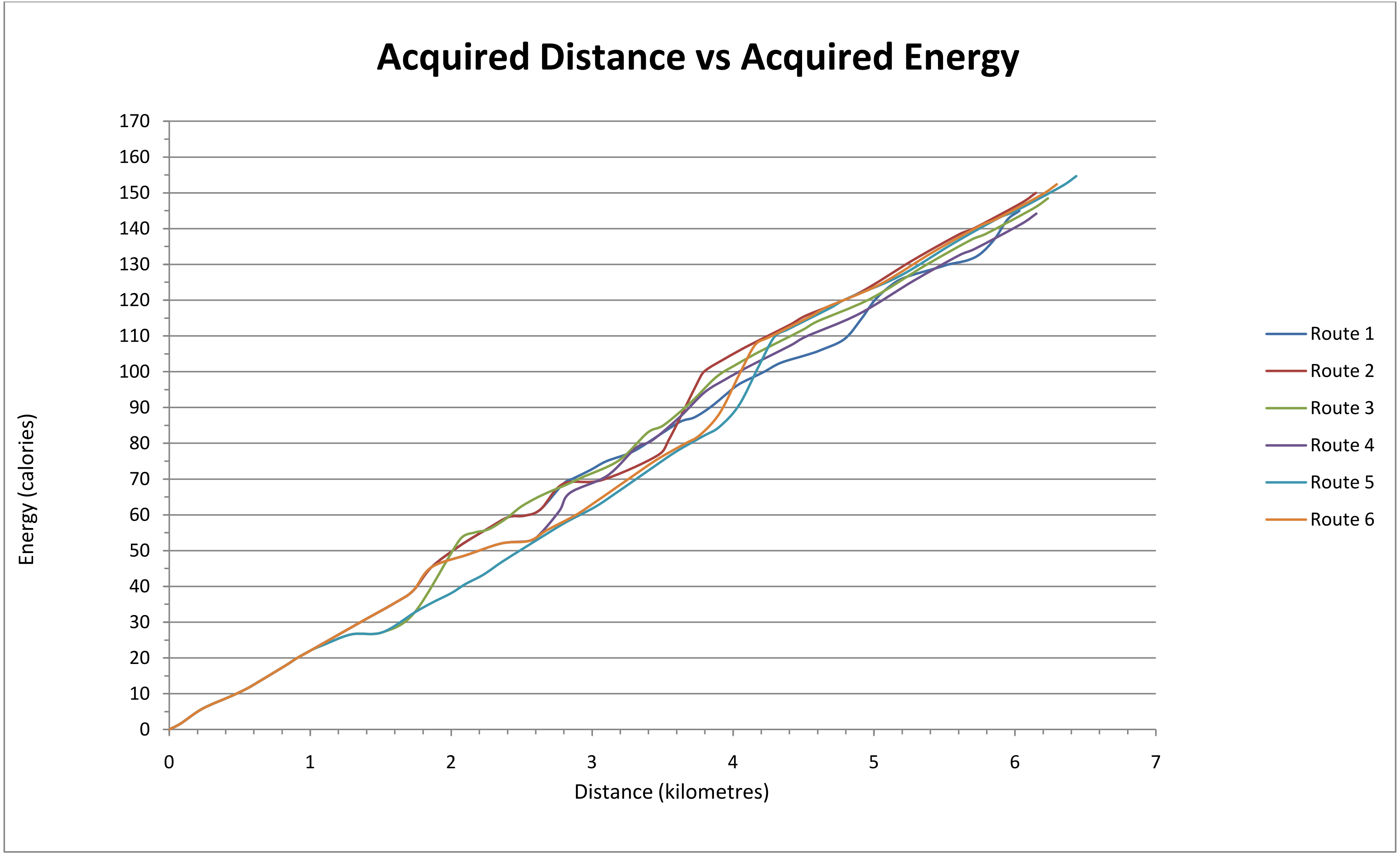


Figure 4.10: Acquired Distance vs.

4.3 Conclusion

This chapter has revealed the results of the project. The calculations on each route have been presented and the easiest route in terms of calories can be found. Graphs have been created to assist in displaying and understanding these results. These graphs will be discussed in more detail in the following chapter where the results are analysed and discussed.

CHAPTER 5

RESULTS DISCUSSION

5.1 Introduction

In this chapter the results are analysed. Each route is looked at individually and discussed. By analysing the results it can be explained why certain routes have used more energy than others. It will also help put in perspective how much each route differs from one another. The most energy efficient route is also calculated and discussed. A recommendation is then given as to which is the selected route. Lastly there will be a discussion about the problems faced throughout the project.

5.2 Discussion

When looking at the results produced, a number of different factors can be established. The longest and shortest routes can be determined as well as the routes that requires the least and the most energy. The results show that route 4 used the least amount of energy to get from USQ to the CBD, while route 5 used the most energy. Route one (1) was calculated to be the shortest route while route 5 was calculated to be the longest. Each route will now be broken down and viewed individually.

When looking at graphs of route one it can be broken down and determined where most of the energy was used. Below are graphs of route 1's profile and acquired distance vs. energy (Figures 5.1 & 5.2). Route 1 had a total distance of 6.031 kilometres and used a total of 144.9732 calories. This meant it was the shortest of the six routes.

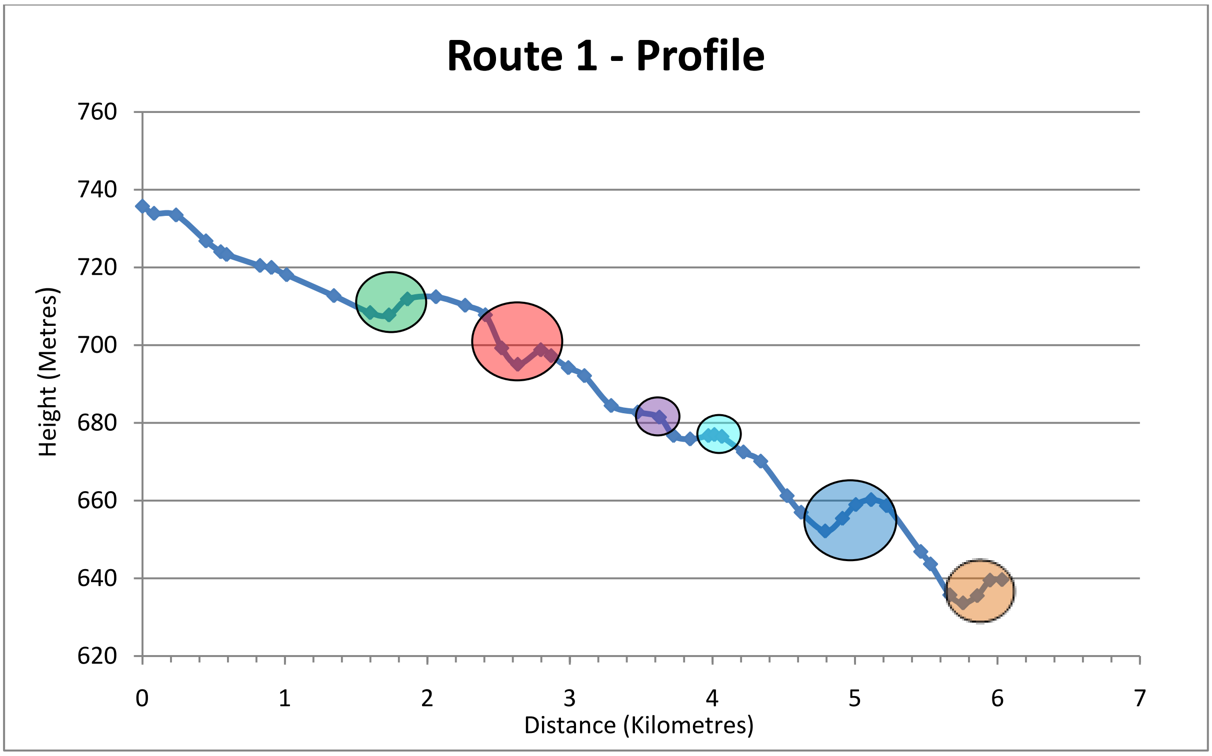


Figure 5.1: Route 1 Profile

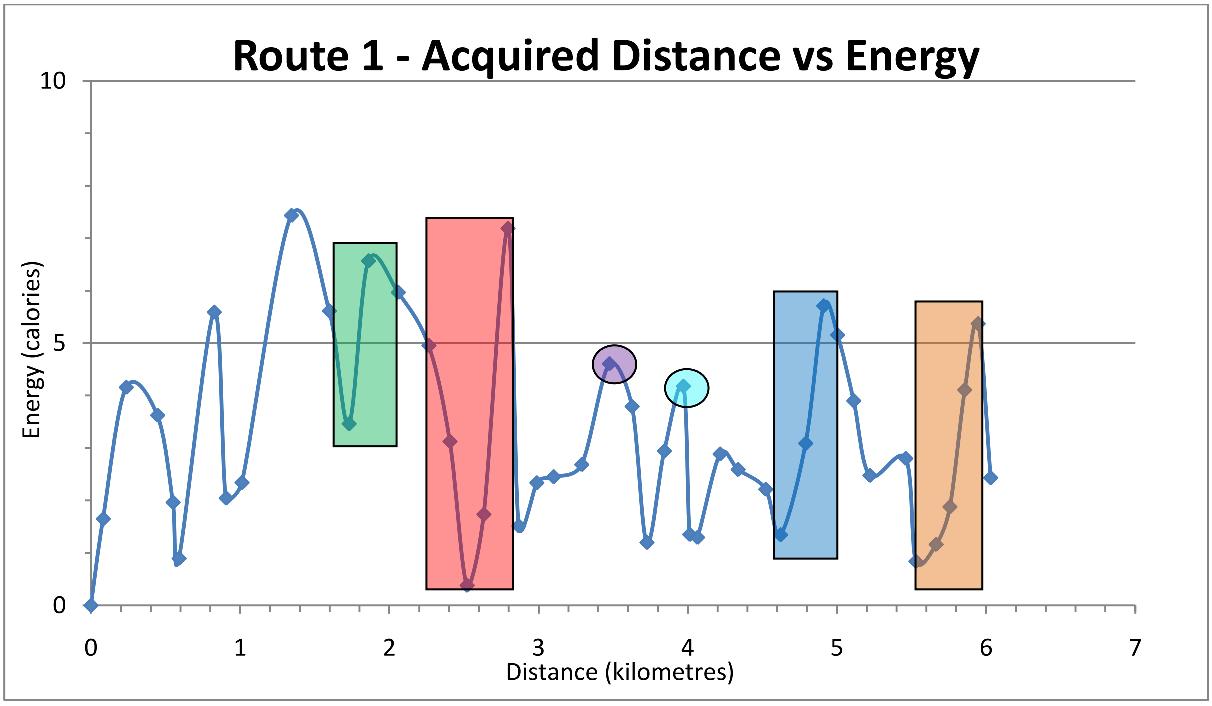


Figure 5.2: Route 1 Acquired Distance vs. Energy

When analysing these two graphs it can be seen that in the first kilometre that the energy fluctuates as the terrain slopes downhill. These fluctuations are due to the different distances between points. By the second kilometre the energy has built up to a small peak which can be seen in the green box. The green circle in the profile graph shows that there is a small rise in the terrain and this is what is causing this energy peak. The larger fluctuations before these points are cause by large distances between points which causes a build up of energy. From two kilometres to three, the energy drops all of a sudden and this is because of the steep slope in the terrain, which can be seen in the figure 5.1. These areas of interest are highlighted with the red rectangles and circles in each graph. From this point there is a large rise in energy use and this is because of the uphill section in the terrain which again can be seen in the graph. After the three kilometre mark the energy usage decreases and fluctuates again. This is because there are two small rises or ridges in the terrain which is causing the rises in energy usage. These peaks can be seen in the purple and cyan circles. As the graph reaches the five kilometres mark there is another spike in the energy seen in blue. This is because the terrain has reached a low point and there is a steep slope, which can be seen in the blue circle on the profile graph. The energy graph then shows a slow decline in the energy used from the five kilometre mark to approximately the five and a half kilometre mark. In this section the profile shows that the terrain is downhill before it rises from the five and a half kilometre mark to the finishing point. This small rise is reflected in the energy graph with another spike in the energy used which can be seen in orange.

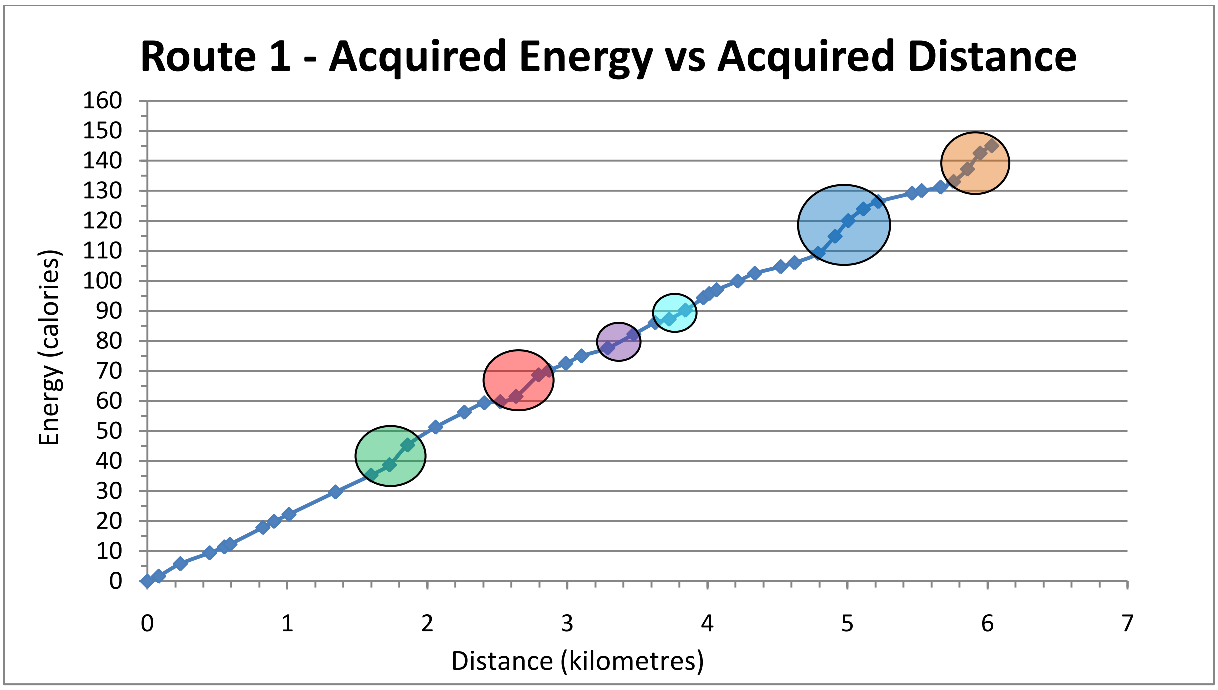


Figure 5.3: Route 1 Acquired Energy vs. Acquired Distance

Looking at the graph above (Figure 5.3) for the acquired energy vs. acquired distance for route 1, the effects of the terrain on energy usage can be seen. The coloured circles on this graph correspond to those in the previous graphs for route 1. Where the line gets steeper is where there is a rise in the terrain and where the line flattens out or dips the terrain declines. The red and the blue circles are areas in the route that require large portions of energy to complete and in turn having a major influence in the final outcome.

This same analysis can be done for route 2. This route used a total of 149.9923 calories over a total distance of 6.147 kilometres. Below is the profile and acquired distance vs. energy graph for route 2(Figures 5.4 and 5.5).

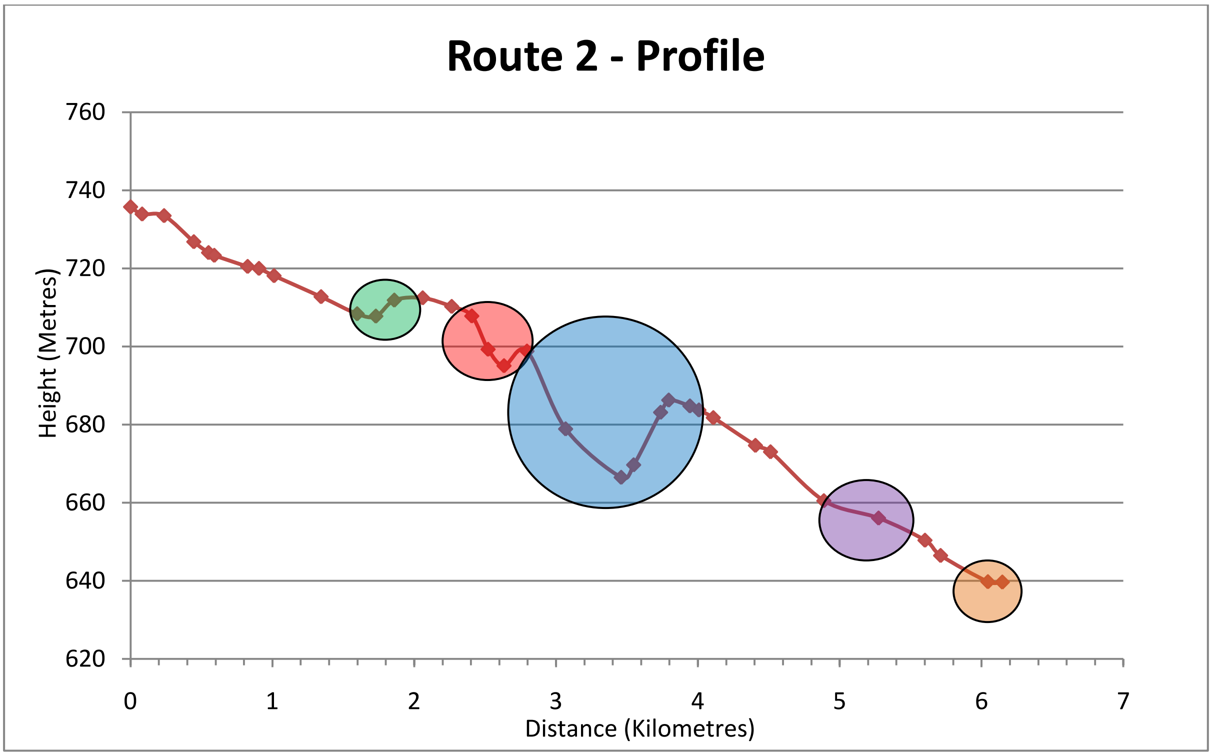


Figure 5.4: Route 2 Profile

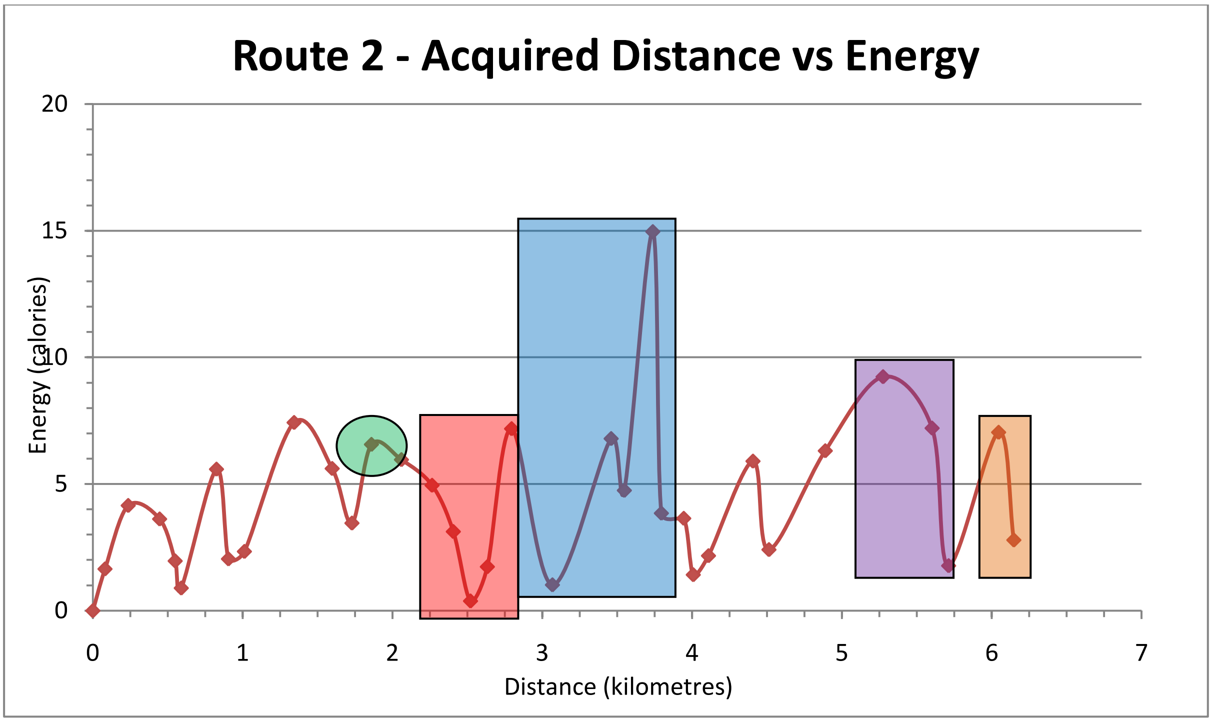


Figure 5.5: Route 2 Acquired Distance vs. Energy

Route 2's energy usage starts out similar to that of route 1 as it uses the same streets. It reaches a small peak in energy which is indicated by the green circle in the acquired distance vs. energy graph. When compared to the profile graph this small peak is due to the small rise which is also highlighted with a green circle. Again the fluctuations before this point are due to long distances between points which cause a build up of energy. From this point there is a large decline in energy and it drops close to zero. It then rises steeply back up and can be seen in the red rectangle in Figure 5.5. This dip and rise can be justified when looking at the profile as there is a steep decline and then another small incline. From the 2.9 kilometre mark there is another steep decline which can be seen in the blue rectangle. The energy usage then rises extremely steeply and this is because of the steep slope in the terrain. After this high peak there is another large drop. This is not due to a steep incline but it is due to a short distance by which the energy was calculated. From the four kilometre mark to the five kilometre mark the energy graph shows fluctuation and this is again due to different distances which influences the energy used. The terrain in this section descends at a relatively even rate. The purple rectangle in Figure 5.5 shows a small peak in the energy usage just after the five kilometre mark. This is due to the flatter section in terrain and therefore causing more energy to be used. As the terrain declines again the energy usage drops as well. Seen in the orange rectangle is a small peak as the terrain flattens out once again.

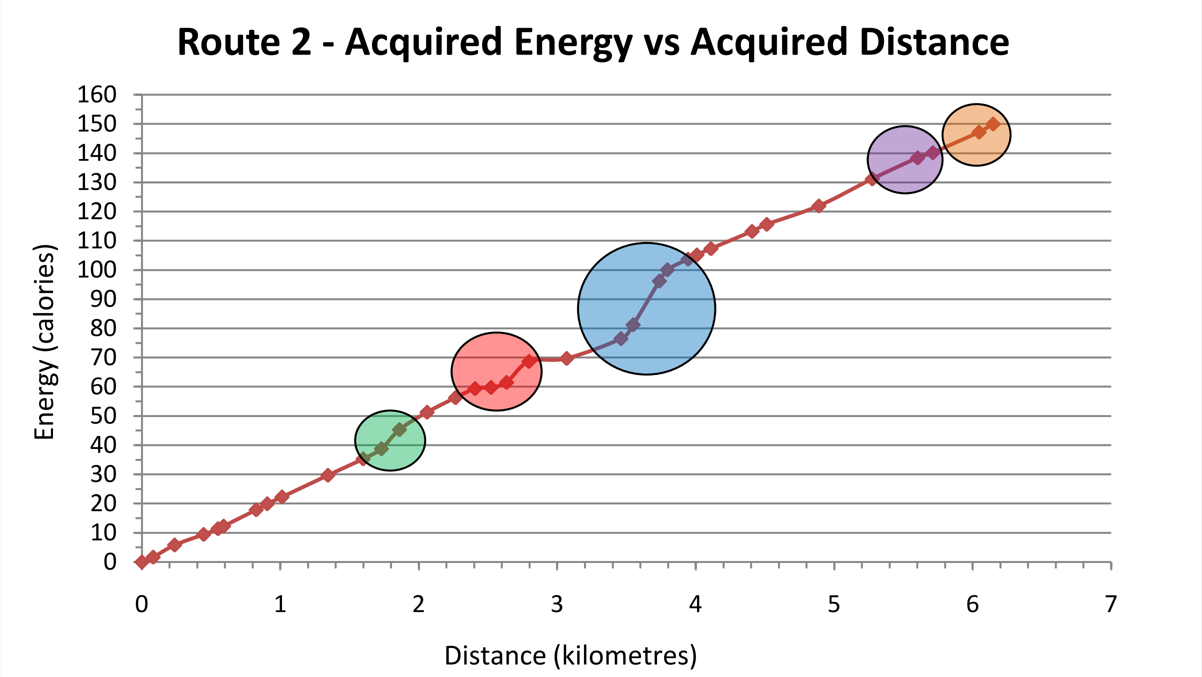


Figure 5.6: Route 2 Acquired Energy vs. Acquired Distance

Figure 5.6 also shows the energy changes when looking at the terrain. The coloured circles show the same areas that are highlighted in Figures 5.4 and 5.5. The red and the blue circles show the two most influential areas in the route that required large amounts of energy.

The profile and energy graphs for route 3 can be seen below in figures 5.7 and 5.8. Route 3 used a total energy of 148.4603 calories over a total distance of 6.234 kilometres.

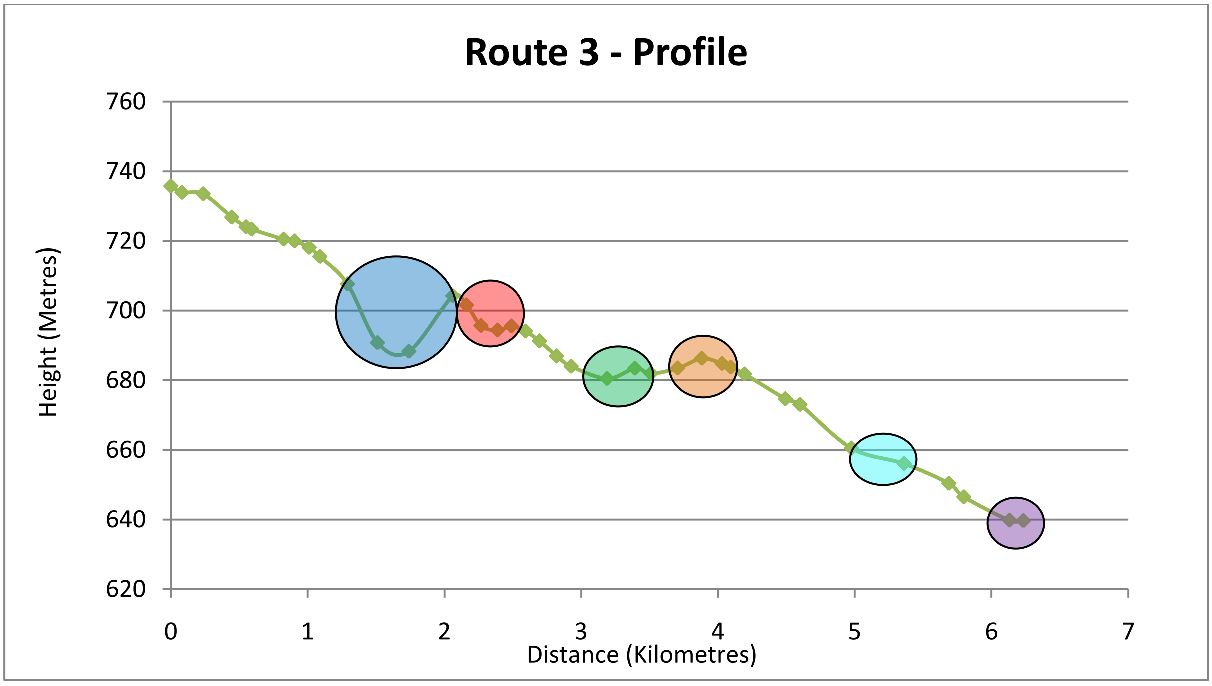


Figure 5.7: Route 3 Profile

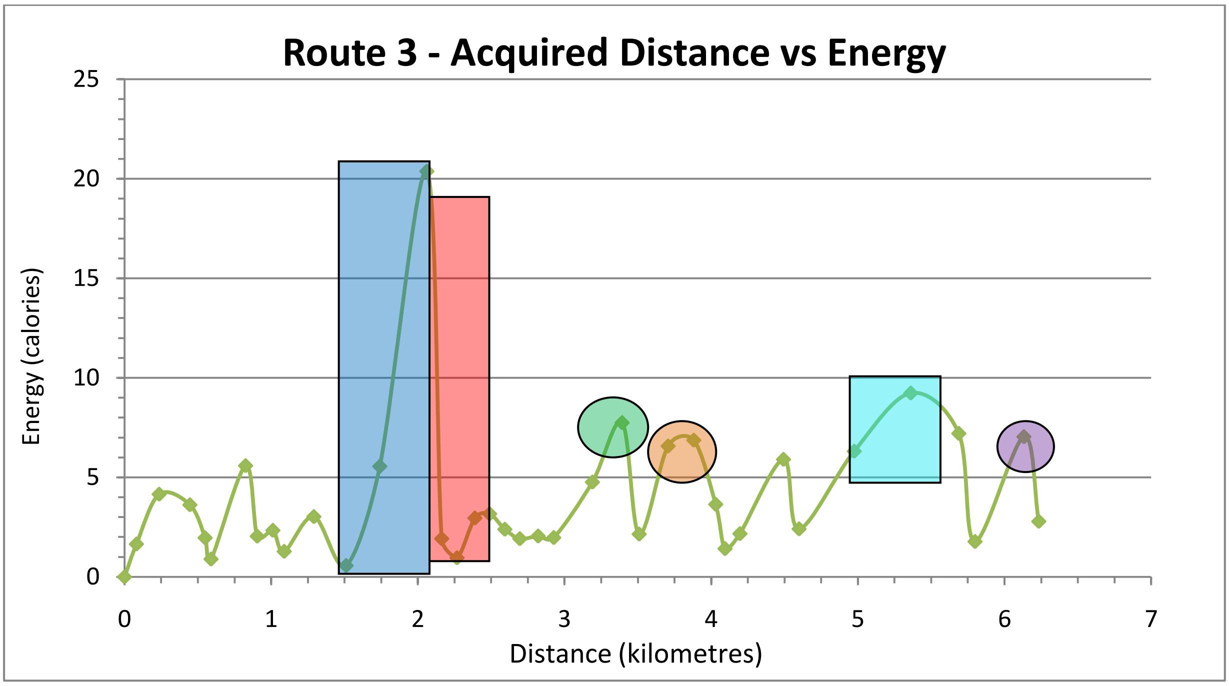


Figure 5.8: Route 3 Acquired Distance vs. Energy

When viewing the energy graph for route 3 from the start point to the one kilometre mark there are a number of small peaks and dips. This has occurred due to differences in distances but also due to the small changes in grade that are reflected in route 3's profile. As the energy usage reaches the 1.4 kilometre mark there is a slight dip and then a large rise which can be seen in the blue. This can be explained when looking at the blue circle in the route profile where there is a steep drop followed by a steep rise. Immediately after this rise there is another decline in the terrain and this is again reflected in red in the energy graph (figure 5.8). The energy then stays steady until the three kilometre mark before it again fluctuates. This can be seen in the green and orange circles. These fluctuations are caused by the terrain flattening out and coming to a ridge which causes more energy to be used. The wave in the graph after the five kilometre mark seen in cyan is caused by the combination of the terrain flattening out and the distance is longer causing a larger energy usage. The purple circle seen at the end of both Figure 5.7 and 5.8 shows where the terrain flattens out which causes a small rise in energy usage in this section. Lastly in the purple circle, there is an energy rise and again this is reflected when looking at the terrain in Figure 5.7. Below in Figure 5.9, the graph the build up of energy vs. the distance can be seen for route 3.

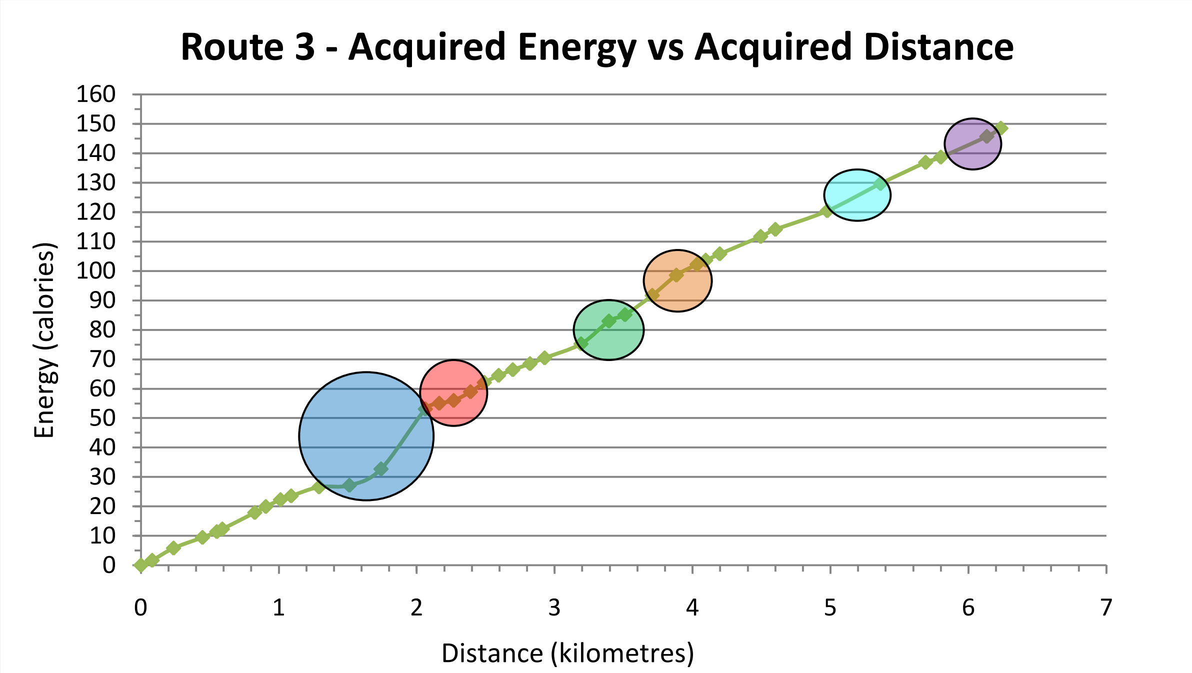


Figure 5.9: Route 3 Acquired Energy vs. Acquired Distance

The coloured circles seen here correspond with those seen in Figures 5.7 and 5.8. What this graph helps to illustrate is where there is significant uses in energy and also where energy is saved. It is evident from this graph for route 3 that the larger blue circle (1.6km mark) and the smaller green circle (3.2km mark), are areas that have significantly added to the energy usage. The graph also shows the red circle, which is just around the two kilometre mark, is an area where energy has been saved. This graph can then be compared with those for route 4.

Over the course of its route it used a total of 144.193 calories and its total distance was 6.151 kilometres. Route 4 was the route that used the least amount of energy from USQ to the CBD. Seen below is the profile graph and the acquired energy vs. distance graph for route 4 (Figure 5.10 & 5.11).

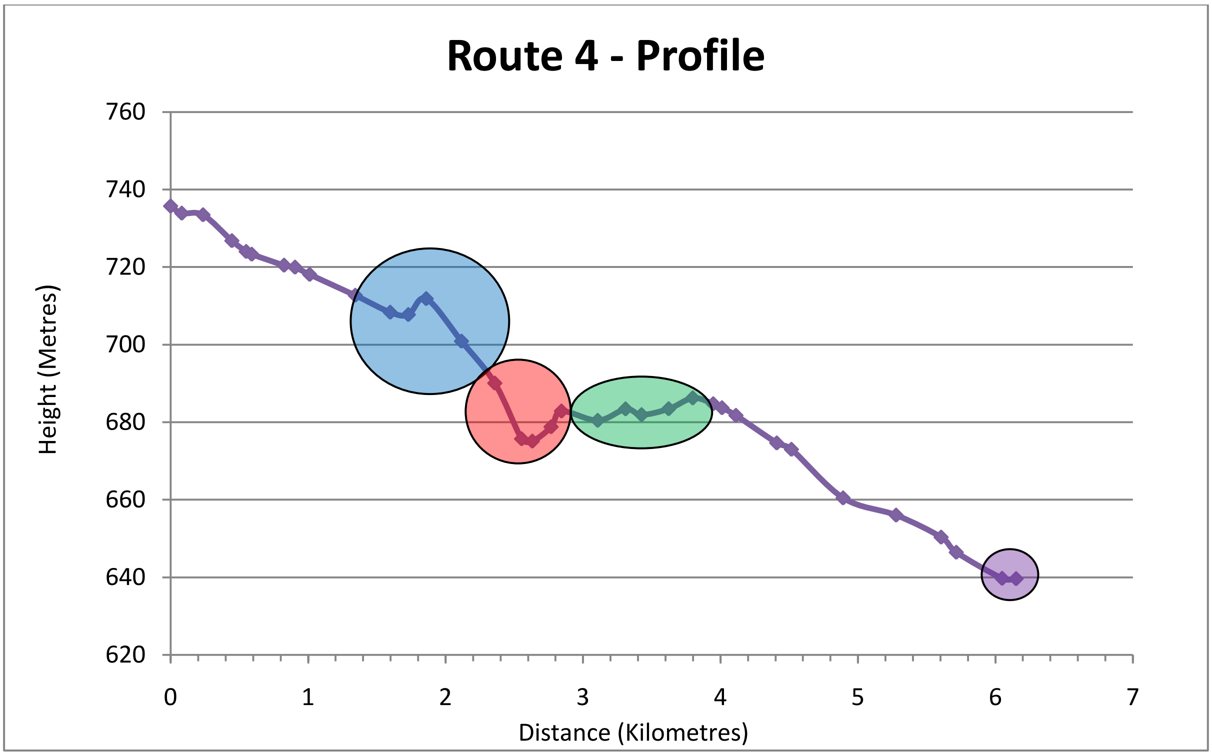


Figure 5.12: Route 4 Profile

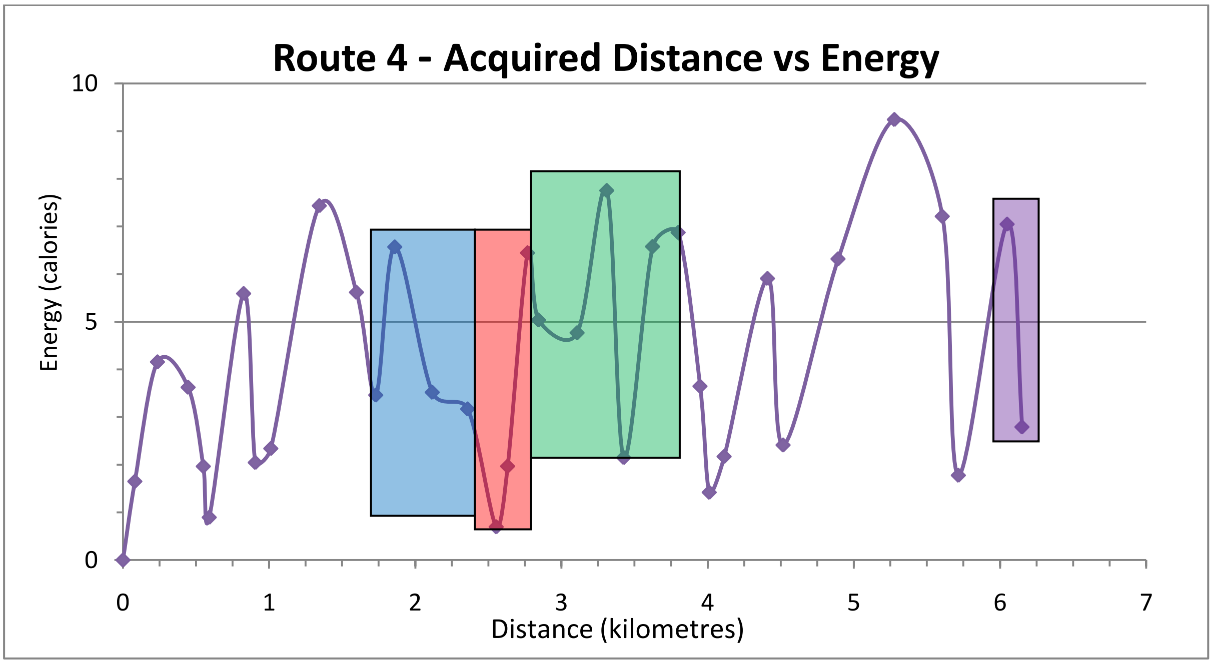


Figure 5.13: Route 4 Acquired Distance vs. Energy

When looking at the energy graph for route 4 it can be seen that the maximum of the graph only goes to 10 calories and there are no extremely large peaks in energy used. From the start point to the first kilometre mark there are fluctuations in the energy graph (Figure 5.13). This is not due to the terrain but it is due to longer distances used between grades resulting in more energy being used. Continuing along the route from the one kilometre mark the graph continues to fluctuate until it reaches the 2.6km mark. When looking at Figure 5.12 it can be seen in the blue circle that the terrain rises slightly followed by a long steep drop. When viewing the energy graph the blue rectangle represents the same area mentioned in the blue circle of the terrain graph. The energy rises up and then falls steeply before flattening out briefly. As seen in the red rectangle in Figure 5.13 the energy drops steeply again and then rises again very steeply. This is reflected in the red circle in Figure 5.12 where the terrain drops right down to a low and then rises again. From here the green circle in figure 5.12 shows a number of small peaks and ridges. The corresponding colour in the energy usage graph shows that there are rises and falls in energy where the terrain is alternating. From 3.75km mark the terrain declines at a continuous rate, flattening out in some areas. The energy graph however shows fluctuations and again this is mainly due to the different distances used between grades, however areas where the terrain flattens out contributes to these fluctuations. This continues until the 6km mark before the terrain levels out which can be seen in the purple circle. The energy graph again reflects this in the corresponding colour with a spike in the energy used.

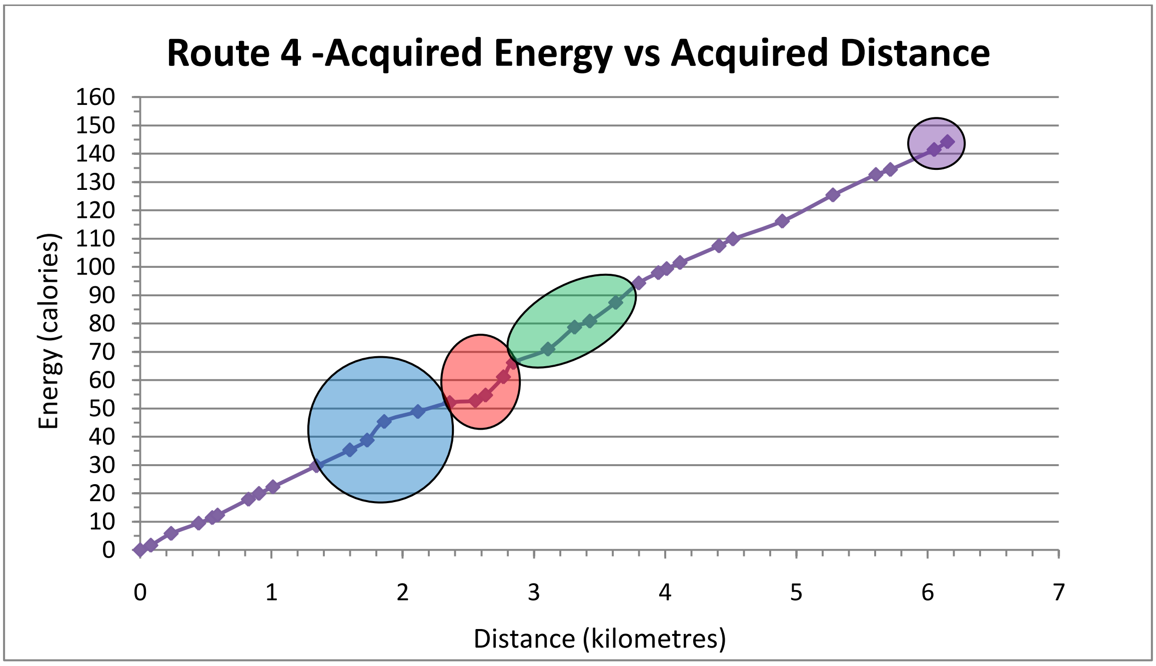


Figure 5.14: Route 4 Acquired Energy vs. Acquired Distance

The graph above, Figure 5.14, shows the corresponding colours of Figures 5.12 and 5.13. These coloured circles help to show which areas use large or small amounts of energy. It is evident that the areas in the blue circle (1.8km mark) and the red circle (2.6km mark) are sections of the route that influenced the total energy usage. The blue circle section is an area where a considerable amount of energy was saved due to the large downhill section. The red circle also saved some energy however there was a steep incline in the terrain which caused a large amount of energy to be used.

The next route to be analysed is route 5. This route was the route that required the most amount of energy and it was also the longest route. It used a total of 154.6725 calories over the total distance of 6.434 kilometres.

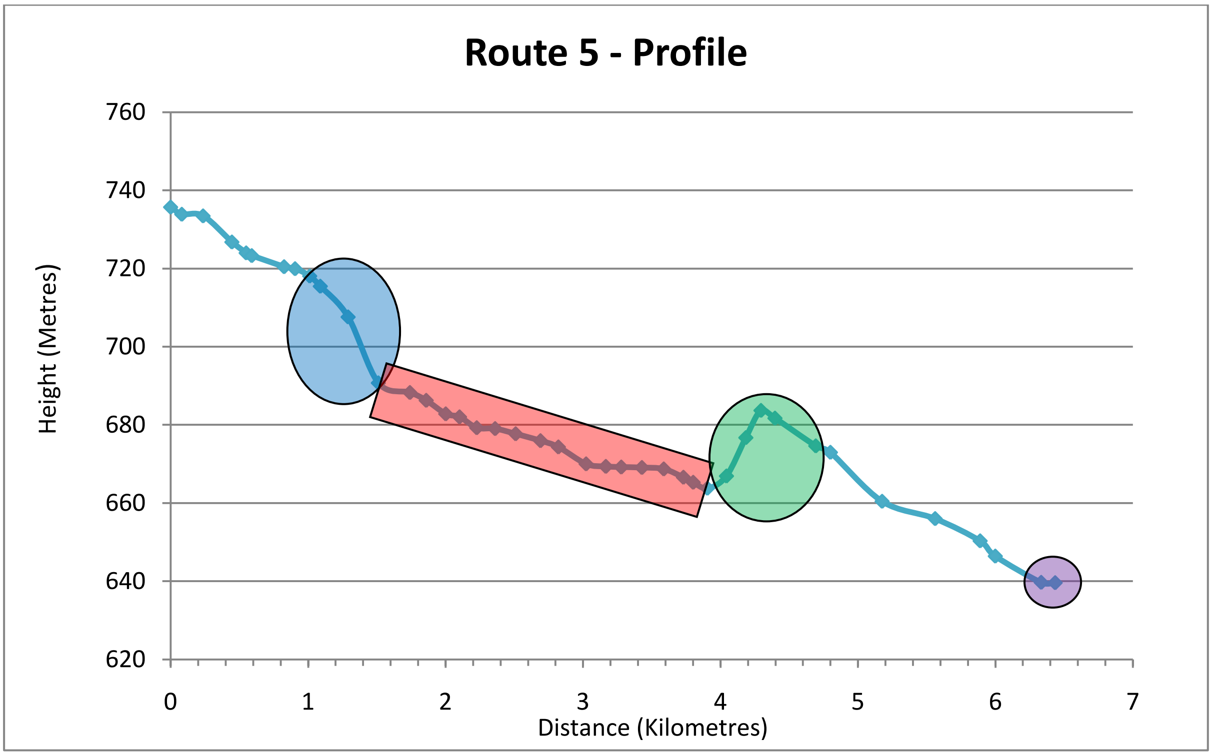


Figure 5.15: Route 5 Profile

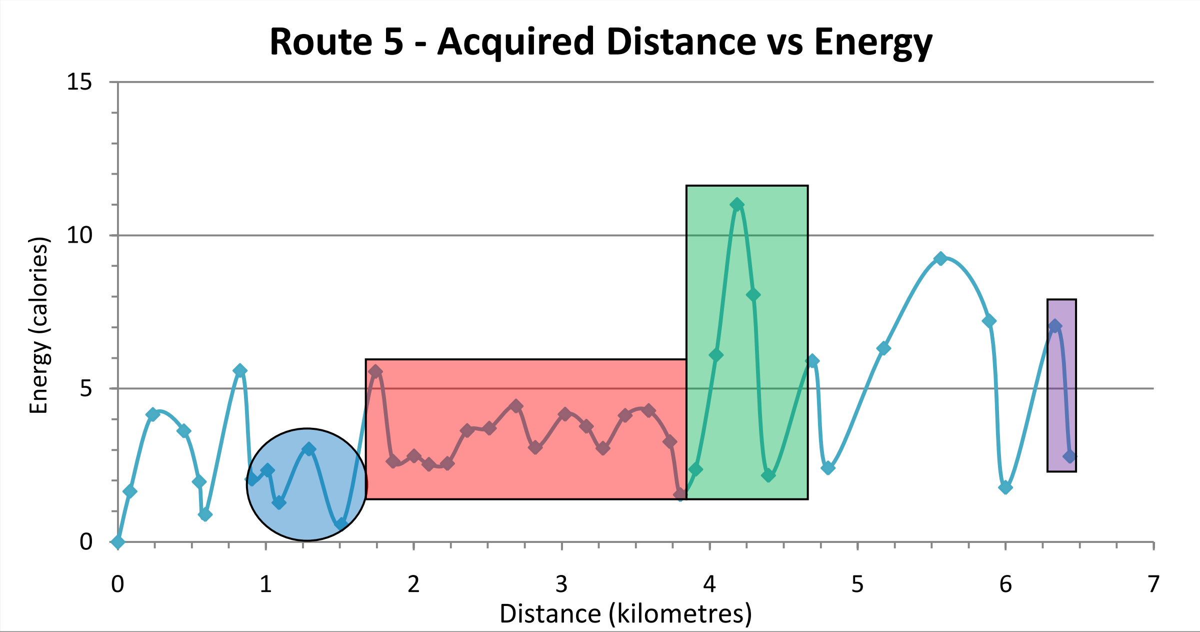


Figure 5.16: Route 5 Acquired Distance vs. Energy

Above are graphs that show the terrain (Figure 5.15) and the distance vs. energy (Figure 5.16). From the start point to the approximately the one kilometre mark there are fluctuations in the energy usage. Like the other routes this is due to the different distances used between grades amounting to spikes in energy. The blue circle seen in Figure 5.15 from the 1km mark to the 1.5km mark, shows that there is a steep decline in the terrain. This is reflected in Figure 5.16 where the energy used is very low around 2-3 calories. The terrain then goes into a continuous decline from 1.5km mark to the 3.75km mark and this is represented by the red rectangle in figure 5.15. Again Figure 5.16 reflects the terrain in the red rectangle showing the energy staying quite low and having small fluctuations. Figure 5.15 shows the green circle from the 3.75km mark to the 4.8km mark. This green circle illustrates where the terrain rises steeply. This is reflected in green in Figure 5.16 where the energy expenditure rises steeply as well. From this point to the 6.25km mark the terrain begins to decline again at a slightly steeper grade then the previous section. The grade changes fluctuate in areas before flattening out after the 6.25km mark seen in purple. Figure 5.16 shows that there are fluctuations in energy usage from the 4.8km mark to the 6.25km mark. This is because of the inconsistent distances used as well as areas where the grade changes slightly. The purple rectangle in Figure 5.16 also represents where the terrain flattens out and there is a spike in the energy.

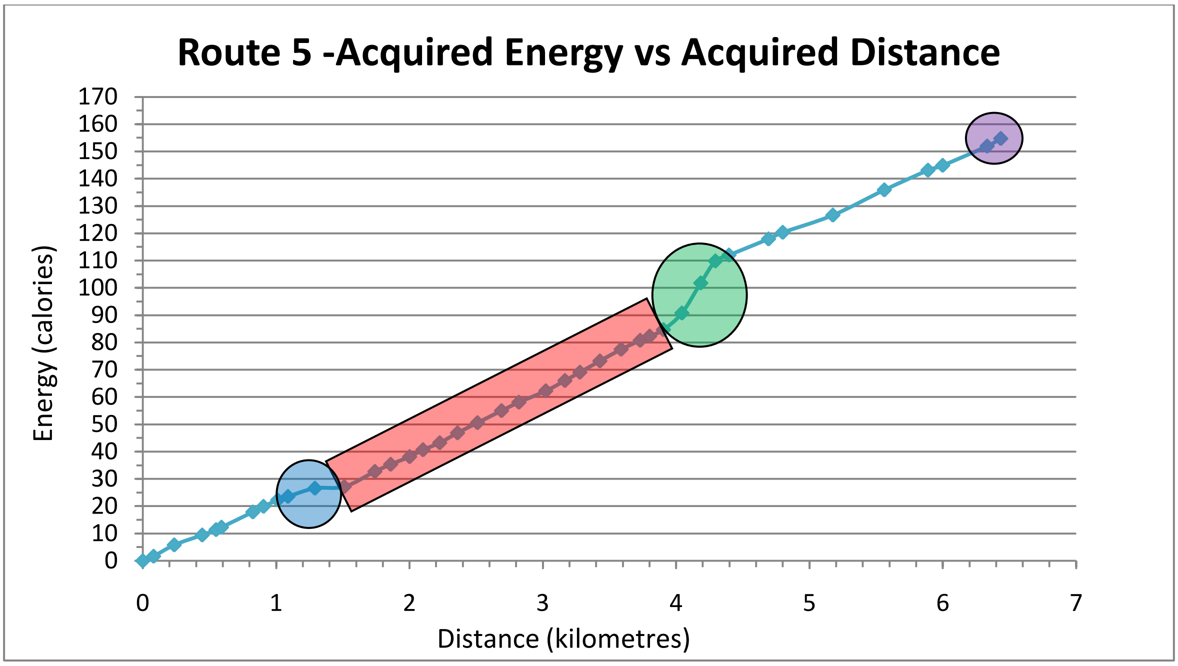


Figure 5.17: Route 5 Acquired Energy vs. Acquired Distance

Figure 5.17 seen above shows the acquired energy used along the route. It helps display where the energy was used and saved. The blue circle (1.2km mark) is an area where a large amount of energy was saved because of the decline in the terrain. Although the red rectangle shows an area where the energy is increasing this is also an area where energy has been saved. The grade of this section is not very steep which indicates that the terrain is downhill which it is when looking at Figure 5.15. The green circle (4.2km mark) in Figure 5.17 shows an area where the most energy of the route was used. This was caused by the steep incline in the terrain. Overall the route only had one major uphill section in the terrain, the rest was consistently downhill. The main reason for this route using so much energy is predominantly because it is approximately 250 metres longer than most of the other routes.

Route 6 used a total of 152.3994 calories over a total distance of 6.297 kilometres. This makes it the route that used the second most amount of energy. Below in figures 5.18 and 5.19 are the profile and acquired distance vs. energy graphs.

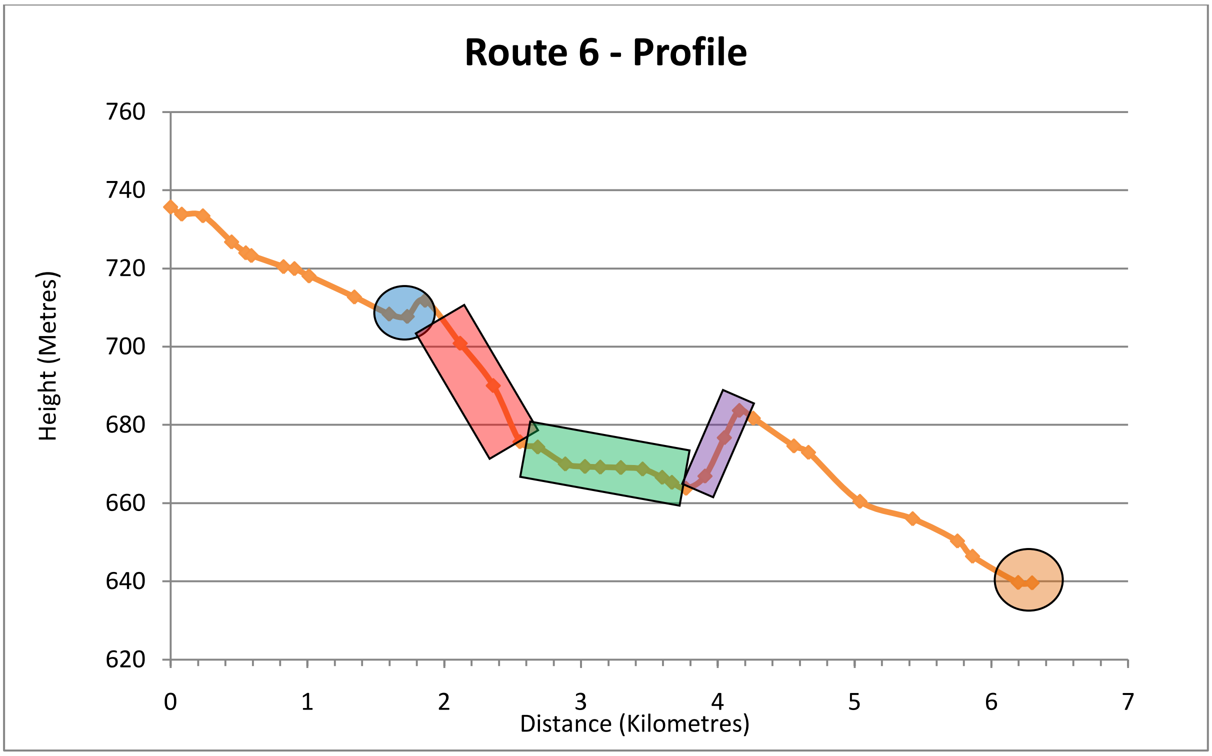


Figure 5.18: Route 6 Profile

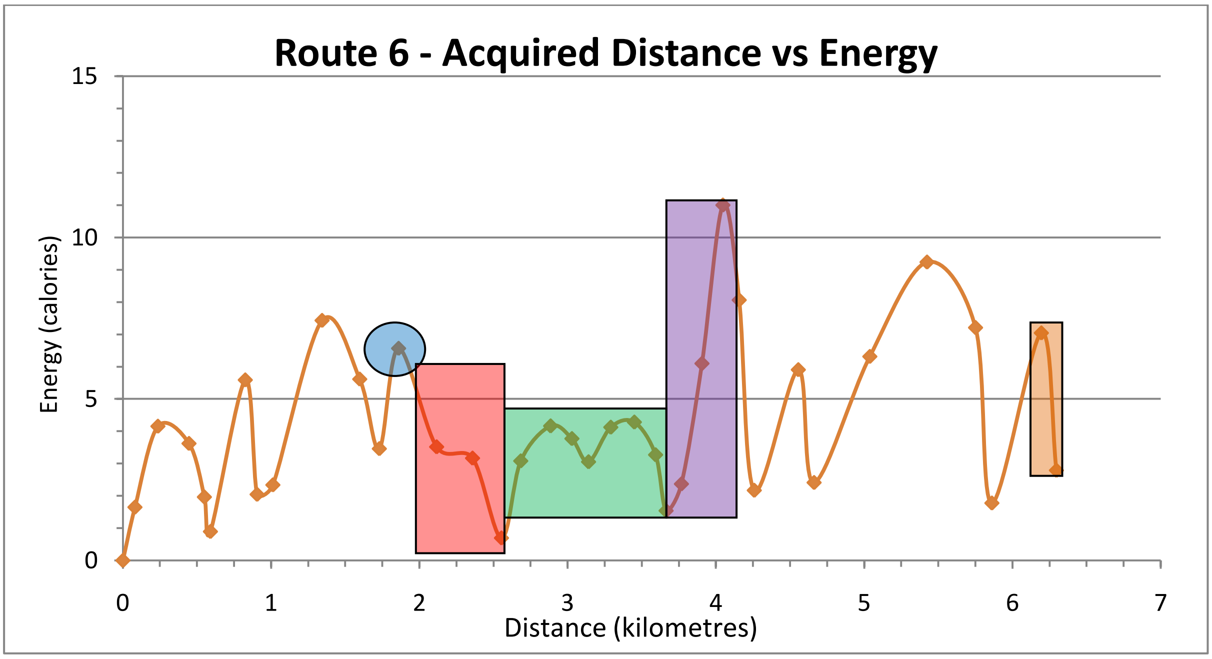


Figure 5.19: Route 6 Acquired Distance vs. Energy

Like the other five routes Figure 5.19 shows fluctuations at from the start to the around the 1.75km mark. Again these are caused by inconsistent distances between grades causing large energy usage. From the 1.75km mark it can be seen in Figure 5.18 that there is a small rise in the terrain which is highlighted by the blue circle. This is also reflected in Figure 5.19 where the blue circle represents the peak in energy where the terrain rises. From the peak of this rise the terrain declines steeply which can be seen in the red in both Figure 5.18 and 5.19. The energy graph shows how the energy usage responds to the decline of the terrain with hardly any energy being used. The terrain then levels out with a slight decline which can be seen in Figure 5.18 with the green rectangle. The energy graph also reacts to this terrain with not much energy being used during this period of the route. From the 3.6km mark to the 4.0km mark the terrain rises steeply and this is seen in the energy graph where the energy usage jumps up quite high, which can be seen in the purple. From this point the terrain slopes downwards for the next 2.2 kilometres. During this section the energy graph fluctuates in places and again this is due to the different distances between grades. The small changes in grade and where the terrain flattens out have also contributed to these fluctuations. The last section seen in the orange circle flattens out and this is seen in the energy graph where there is a small peak. Below in Figure 5.20 is a graph that shows the energy build up throughout the route.

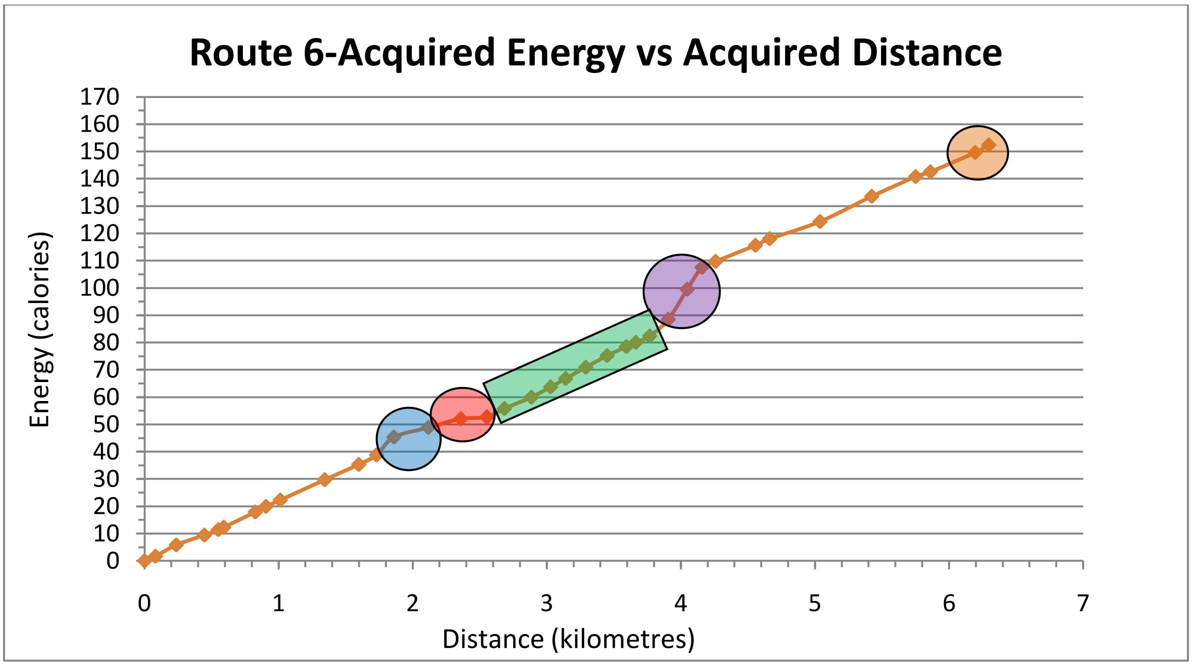


Figure 5.20: Route 6 Acquired Energy vs. Acquired Distance

Using this graph as well as Figure 5.18 and 5.19 the sections of the routes that influence the final results can be determined. It is clear that the areas of the blue circle (1.75km mark) and the purple circle (4km mark) are areas that required a lot of energy. These are areas where there is a rise in the terrain and therefore resulting in extra energy being used. This is evident with the steep rises in energy expenditure seen in Figure 5.19. The red circle and the green rectangle are areas where energy was saved. The red circle (2.25km mark) saved energy because of the downhill slope in the terrain. When looking at Figure 5.20 the energy flattens out, which indicates another area where energy was saved. The section represented by the green rectangle is also an area where energy was saved as it had a slight decline in the grade and therefore minimal energy was needed in this section. Overall this route did not use the least amount of energy however the extra length of the route may have slightly contributed to the extra energy used.

After analysing all the routes, areas that have influenced the energy expenditure have been identified. It was also discovered that different distances in the routes could also have contributed to the differences in energy used. By dividing the distance by the calories a ratio can be established that gives energy efficiency. This means that the energy efficiency can be determined for each route to work out which route was the most energy efficient. The table below shows these results (Figure 5.21).

Figure 5.21: Route Energy Efficiency

Route	Efficiency	Rating
1	0.04160	3
2	0.04098	5
3	0.04199	2
4	0.04266	1
5	0.04160	3
6	0.04132	4

As seen in the results, route 4 was not only the route that used the least amount of energy but it was also the route that was the most energy efficient. It can also be seen that route 3 was the next energy efficient route. Route 3 used the third lowest amount of energy and was also the fourth shortest route. The fact that this route has been identified as the second most energy efficient route really shows that if this route was the same length as other routes that it would be the route that requires the least amount of energy. The results also show that route 1 and 5 were both the third most efficient routes. This is a very interesting result as route 1 is 403 metres shorter than route 5. This proves that the shortest route is not always the easiest route. Route 5 is the longest route so by it being the third most efficient route also reinstates the fact the shortest route is not always the most easiest. Route 6 was the fourth most energy efficient route with it being the route that used the fifth least amount of energy and it was the second longest route. The least energy efficient route was route 2. Route 2 was the second shortest distance and used the fourth lowest energy. This reinstates the fact that the shorter the route doesn't mean it is easier.

5.3 Recommendation

By looking at all the information presented above it is evident that Route 4 is the ideal route. Not only was it the route that required the least amount of energy to get from the University to the CBD but it was also the most energy efficient route. Route 4 consists of riding from Z-block at USQ onto West Street. Along West Street and turning right onto Stenner Street and then turning left onto Ruthven Street. Continue up Ruthven Street until reaching Herries street. Turn left onto Herries Street and the council offices are on the right immediately after turning left. The route is majority downhill with minimal uphill terrain. Therefore I recommend that when travelling from USQ to the CBD route 4 should be used.

5.4 Problems

There were a number of different problems encountered throughout the project with most of them revolving around the formula for an energy equation. The first problem I had was working out how accurate my formula was. From the background research done it was found that so many other factors could have been included in the formula to create a more accurate result. These additional factors were things such as: wind, bearing load, bike weight, tyre tread, aerodynamics, rolling resistance, crank size, and crank angle.

Applying these additional factors would have made calculations more accurate and could have had the potential to change results. The final variables I used in my formulas were: speed, cyclist weight, distance, height difference, and speed coefficient.

These factors were relatively easy to determine and make assumptions about and were essential to the equation. Although the formula was missing other factors that would make it more accurate, these factors still helped in getting the desired results. This was because the formula made using these factors gave results that were relative to one another and therefore was able to determine which route was the easiest.

When creating the formula it was first tried by having a single equation that could calculate the energy usage up and down hills. A formula was created and tested but was found to be inaccurate and could not be used. The formula was then adjusted but there was still no success. From here it was decided that two separate equations were needed to calculate energy up and down hills. This proved to be an issue in itself, making it difficult to apply through the GIS.

Another Problem that was encountered when formulating the equation for energy usage was the calculations for downhill energy use. At first the equation was giving energy use in negatives when travelling down steep downhill sections. This wasn't seen to be to important because it was felt that the negative answer made up for where no pedalling was need and also for the momentum gained from riding downhill into the uphill or flatter sections. Although this was not seen to be an issue the formula was then adjusted to give results that were not negative as the thought of using negative energy can be a confusing concept and questions can also then be asked about the accuracy of the formula. With the formula adjusted it then gave more accurate results and would make more sense to a person with no experience in the area.

When viewing the results in graphs also seen previously, it can be difficult to determine information needed. These problems arose due to the distances between points being determined on the distance between grade changes. This caused fluctuations in the data and made it hard to read in places. One way to eliminate this issue would be to use a consistent distance throughout such as 10 metres or 20 metres. This may make it more time consuming and mean that there is more data required in the formula but it would mean the results would be able to be viewed more accurately. Making this system automated however could then eliminate the issue of time, making it much easier and again providing better results.

Better accuracy is another issue that arose. If better accuracy was achieved, would it have changed the results? The accuracy used in this project was plus or minus half a metre in horizontal accuracy and plus or minus 0.9 of a metre in vertical accuracy. Although the accuracy achieved provided relatively good results it can give some variance the longer the trip is. Options such as RTK GPS could potentially solve this issue if more accurate results were needed in future.

Another problem that was encountered was a height difference between the GPS data and the DEM ascertained through the Dr. Xiaoye Liu. In the checking of all the data it was found that there was a consistent 42 metre difference between data sets. At first this was seen to be a real issue but it was soon worked out that it was not. What had happened was that the DEM was based on ellipsoidal heights and the GPS data was based on geoid heights. This is what had created the 42 metre difference. Because the GPS data was all relative, calculations were still able to be made. Checks could also still be done on the data by checking the X and Y coordinates with each other.

5.5 Conclusion

This chapter has explored each route individually and worked out where each route used its energy. A number of graphs were used in this analysis and provide representation of important areas. The route energy efficiency was then explained and presented followed by a final recommendation of the selected route for USQ to the CBD. Lastly in this chapter the problems encountered during the project were talked about and how these problems were solved. The work covered in this chapter and the previous chapters will be summed up in the final chapter as a conclusion.

CHAPTER 6

CONCLUSION

6.1 Introduction

Overall in this project majority of the aims and objectives were achieved. The cycling pathways were mapped successfully from the University of Southern Queensland to the Toowoomba Regional Council Offices. GPS was used to collect this data and was then inputted into a geographic information system. From there the data was then processed and analysed forming a basis for calculations to be made. Considerable amounts of research were done and then formulas were made to determine energy expenditure up and down hills. This formula was then applied to the GPS data manually and the easiest route in terms of energy usage was found. Route 4 out of six routes was found to be the route that used the least amount of energy and was also the most energy efficient route. There were a number of problems that were encountered throughout the project however they were overcome and alternatives and solutions were found.

6.2 Future Work

To this point the energy formula has not been able to be applied to the data through the GIS. This is due to the fact that there are two different formulas which have created problems. To have the formula applied to the data through the GIS is a major objective in this project and will definitely be worked on in future. Another goal that is wanted to be achieved is to potentially adjust the energy equation to make it more accurate. The way in which the equation is now means that the equation is only giving a relative difference between routes which shows which route is easier. To have a more accurate energy equation means that there are potentially more benefits available to this process. Adjustments are also wanted to be done to the equation to make a single equation which makes the process much tidier and makes it easier to apply to the data through the GIS. Other future work that needs to be done is to use more consistent distances in the energy calculations as discussed in the problems section. This will provide much better results and in turn open another goal that has developed throughout the period of the project. This goal is to have graphs produced by the

GIS that show the profile and the energy usage for a selected route. This provides much more information for the user and lets them relate better to the route. The last goal to be achieved in future is the incorporation of ‘age’ into the energy equation. Age is a factor that was not included in the final formula but would have a significant impact on the final energy usage for a scheduled route. This in turn makes it an important factor in creating a more accurate and reliable energy equation which is the main aim of future work.

6.3 Conclusion

This study has produced a method by which has allowed the energy usage to be calculated using GPS data and other spatial data. The best or worst route can be determined in terms of calories which in turn benefitting a user. Continuing to develop this process of energy expenditure will provide better results and a much more reliable and user friendly information. This then can be implemented to the community and provide incentive and encouragement for cycling as a mode of transport.

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Appendices 1 - Project Specifications

University of southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

ENG 4111/4112 Research Project
PROJECT SPECIFICATIONS

FOR: **MATTHEW HUNTLEY**

TOPIC: MAPPING CYCLING PATHWAYS AND ROUTE SELECTION

SUPERVISORS: Dr. Xiaoye Liu

ENROLMENT: ENG 4111 – S1, D, 2010
ENG 4112 – S2, D, 2010

PROJECT AIM: The aim of this project is to map cycling paths from the University of Southern Queensland to the central business district of Toowoomba using GPS. This data will then be processed in a Geographic Information System (GIS) and a formula will be found to calculate on energy expenditure and to find the easiest route from A to B.

PROGRAMME: **Issue A, 23rd of April 2010**

1. Research the background information into previous study done on the topic.
2. Research equations and formulas that can be used to determine potential energy utilisation for bicycles on flat and hilly terrain.
3. Collect field data of the cycling pathways from the University to the CBD using GPS.
4. Analyse and apply field data to existing digital elevation models and road networks of the Toowoomba area.
5. Compute energy utilisations for the cycling pathways and program the GIS to apply the equations to the cycle ways chosen by the user.

AGREED:

__________________________ [Student] ___ / ___ / _____

__________________________ [Supervisor(s)] ___ / ___ / _____

__________________________ ___ / ___ / _____

Examiner/Co-examiner: __________________________ ___ / ___ / _____

Appendices 2 - Project Timeline

The following Table represents the timeline of the project.

Project Task	Dec-09	Jan-10	Feb-10	Mar-10	Apr-10	May-10	Jun-10	Jul-10	Aug-10	Sep-10	Oct-10
Submit Project Proposal											
Review literature for energy usage on bicycles											
Submit Project Specifications											
Plan for field work											
Collect Field Data											
Submit Project Appreciation											
Analyse Data											
Submit Progress report											
Determine a Formula for energy usage											
Work out how to apply a formula to GIS data											
Apply the Formula to data											
Prepare and Submit Dissertation											