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TrafficVis: Visualizing Road Traffic Volume Data

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Submitted in partial fulfilment of the requirements for
Bachelor of Engineering (Honours).

Abstract

Large quantities of traffic explored data are collected throughout the New Zealand State Highway network, and further analysis of this data could provide valuable insights into traffic behaviour in New Zealand. Understanding the the behaviour and limitations of the road network is key to ensuring it can continue to operate with as little disruption as possible. TrafficVis is a web application built specifically for the efficient analysis of this data. TrafficVis provides the tools to gain a greater understanding of traffic trends and resiliency of the State Highway network.

Acknowledgments

I'd like to thank my supervisors, Dr. Craig Anslow and Chris Vallyon, for their continued support throughout this project. I'd also like to acknowledge the Victoria University Human Computer Interaction research group, for offering continual feedback and providing an enjoyable project atmosphere. Finally, I'd like to acknowledge Daniel Braithwaite and Li Li for their contributions to the Summer Research Scholarship that laid the foundations for this project.

Contents

Figures

Chapter 1

Introduction

The road network is essential infrastructure for any country, facilitating the transport of people and goods on a daily basis. The effectiveness of the State Highway network of New Zealand has a large impact on the economy of the country, as well as the quality of life of general population.

1.1 The Problem

An understanding of normal traffic behaviour is necessary in order to maintain the performance of the State Highway network. Sections of the network which are unable to accommodate their regular levels of traffic without experiencing delays or flow breakdown should be prioritised for future development.

The network may operate without issue when experiencing regular traffic behaviour, but it's also important that the network continues to function under abnormal circumstances. The resiliency of a network refers to it's capability of continuing to operate under such conditions. An increase in traffic volume could be caused by major events such as concerts, sporting events or public holidays. A road may also be closed for any number of reasons, such as an serious accident or extreme weather. Resiliency issues must be identified and resolved as early as possible to minimize the impact on the network when subject to such unexpected conditions.

Throughout the State Highway network are 1496 Traffic Monitoring Service (TMS) sites, as shown in Figure 1.1. Each of these sites count the vehicle throughput for each direction of traffic in 15 minute intervals. Further analysis of this data could provide significant insights into traffic behaviour across the country.

This project builds upon work completed by Li Li, Daniel Braithwaite and myself, in which we completed a Summer Scholarship at Victoria University of Wellington. This project involved the development of a machine learning model for predicting traffic volume and detecting traffic anomalies in New Zealand. This project also produced an early prototype of a web application for visualizing New Zealand traffic data.
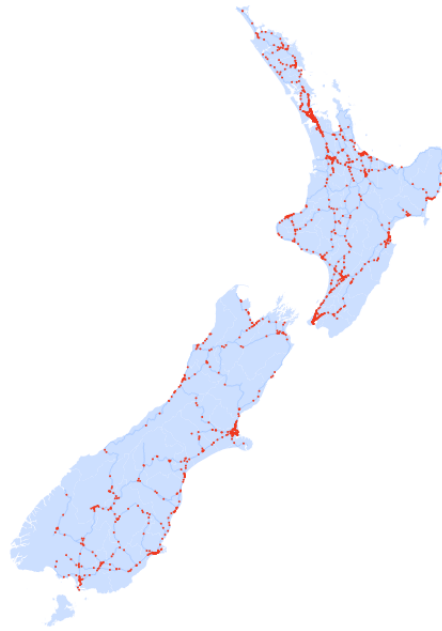
Figure 1.1: A map of New Zealand displaying the position of each TMS site on the State Highway network.

1.2 Solution

To allow for further understanding of traffic behaviour within New Zealand, this project has produced a web application, henceforth referred to as 'TrafficVis', which allows the visualization and analysis of this traffic volume data. TrafficVis offers a highly customizable, widget-based dashboard, that can be configured to suit the needs of each individual user. TrafficVis allows for a number of possible visualizations that can be applied to the data, for viewing and comparing the traffic volume and trends of individual sites or aggregated regions.

The TrafficVis application can be accessed via my homepage:

http://homepages.ecs.vuw.ac.nz/~carrjona

This project has been completed under external supervision of Chris Vallyon of Beca Group Ltd. who has provided access to much of the data required for this solution.

1.3 Research Goals

The design of the TrafficVis web application has been primarily guided by the following goals:

1. Produce a web application which can be utilised to gain insights into the typical traffic behaviour.

2. Produce a web application which can be utilised to gain insights into traffic behaviour when the network is experiencing abnormal conditions.

3. Produce a web application which is usable and intuitive for a range of potential users.

4. Evaluate the effectiveness of various visualization techniques for road traffic data.

Chapter 2

Background

2.1 Types of Traffic Data

There are many different types of data that can be gathered regarding road networks for transport analytics. Each of these data forms are discussed by Gennady Andrienko, et al. in their survey of Visual Analytics of Mobility and Transportation [1]. The three most significant categories of data are spatial, time-series spatial and trajectory data.

2.1.1 Spatial Data

Spatial events are entities that emerge at certain locations and exist for a limited time. [1]. All spatial event data must have a location and a time interval, and can also contain any other information regarding the details of the event.

An example of spatial traffic data could be a vehicular accident, which occurred at a specific location and affected the road for a certain period of time.

2.1.2 Time-Series Spatial Data

Time-series spatial data is spatial information that is chronologically ordered for a fixed location [1].

The core dataset available for this project is the traffic volume counted at each TMS site for each 15 minute interval, which is an example of time-series spatial data.

2.1.3 Trajectory Data

Trajectories are chronologically ordered sequences of records describing how objects move over time, such as the path of a vehicle [1]. This is the most commonly analysed traffic data as it can reveal very valuable information regarding the road network, however no trajectory data is available for analysis during this project.

2.2 Visualization of Transport Data

There are many established methods of visualizing different forms of traffic data. As this project does not include trajectory data; only visualizations of spatial and time-series spatial data will be explored in this section. When visualizations can be animated over time, any spatial visualization can be animated to produce a time-series spatial visualization. Time-series spatial data can also be aggregated to visualize data at a larger scale.

3

Spatial data can be visualized by plotting events on a map according to their geographic location. A circle or other simple shape can be added for each event, and the size or colour of the shape can be varied to show other information possessed by the event. For example, Figure 2.1 shows a visualization by Gennady Andrienko, et al. which shows many sites on a road network as circles, which are coloured according to the vehicle throughput at each point [1].

Figure 2.1: Sites on a map marked by circles which are sized according to the traffic throughput. [1]

A geospatial heatmap is best suited to trajectory data, or data with a very high density of distinct locations, but can be applied to spatial data by interpolating between points. A heatmap such as that in Figure 2.2 by Gennady Andrienko, et al. can be used to visualize the distribution of spatial events over a period of time. While individual events in a dataset may seem insignificant, aggregating data to produce visualizations such as this heatmap can clearly show long-term trends that need to be addressed.
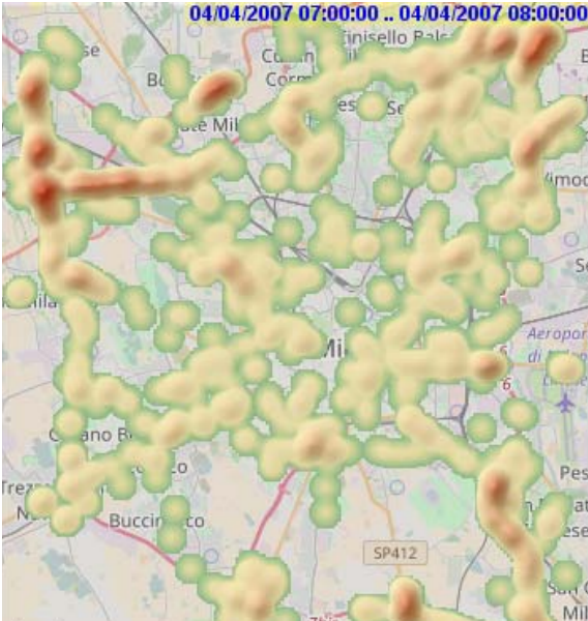
Figure 2.2: The distribution of slow movement events in a time ineterval. Hot spots may correspond to traffic congestion. [1]

In another survey of traffic visualization techniques, Wei Chen et al. display a radial layout, shown in Figure 2.3, which clearly shows daily patterns in the traffic volume of a site [5]. Each section around a ring represents one hour and is coloured according to traffic throughput, with each ring therefore corresponding to 24 hours. Seven rings are displayed such that patterns can be observed over an entire week. This visualisation clearly shows patterns that exist between the different days of the week.
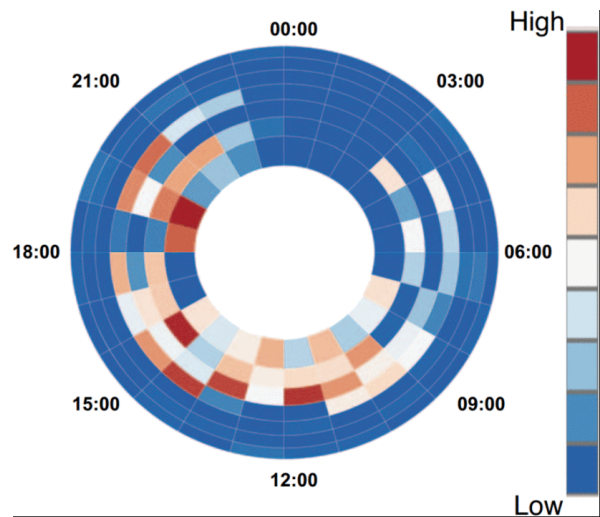
Figure 2.3: Radial layout visualizing periodic time. Colour corresponds to traffic volume, as shown on the colour legend. Each ring shows 24 hours of data, thus the graph as a whole shows the daily patterns in traffic across an entire week. [5]

Afian Anwar et al. pose an interesting approach to highlighting spatial events on a map. This visualization, as shown in Figure 2.4, magnifies a small portion of the map when an event such as an accident has occurred, and shows a border indicating the type of event that has taken place [2]. This approach is very effective at making it obvious to the user when incident has occurred, and makes it easier to witness the effects on the surrounding area of the network.
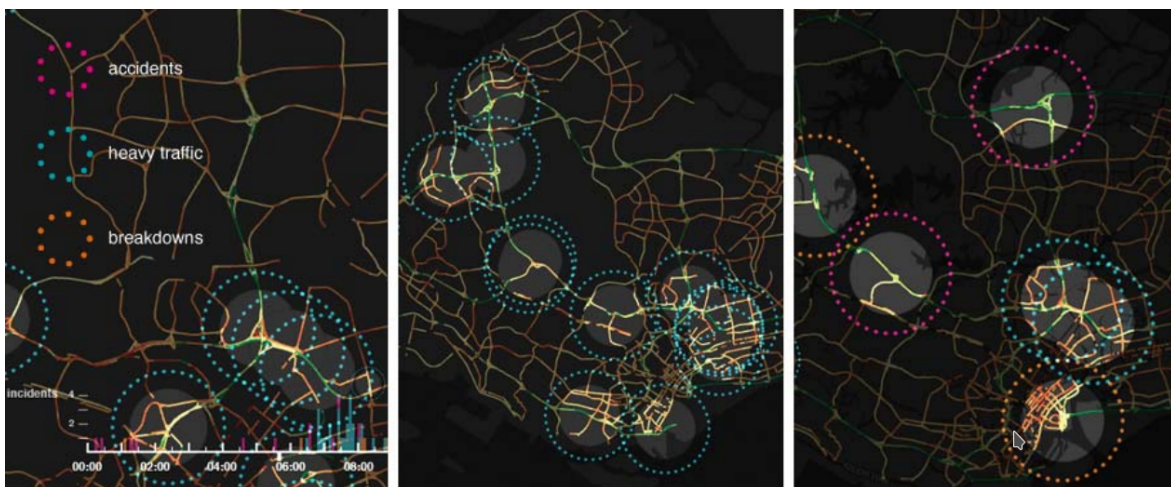
Figure 2.4: This technique of highlighting certain events utilises magnification and highlighting of effected regions when incidents occur [2].

Similarly, Jan-Henrik Haunert and Leon Sering have proposed a different method of showing finer detail of a region of a map. Instead of overlaying a magnified region of the map, this technique, shown in Figure 2.5, distorts the surrounding area to enlarge the [8].

Figure 2.5: The distortion of the map to enlarge the area of interest when necessary. [8]

2.3   Existing Transport Data Visualization Platforms

Many transport analytics tools have already been developed. One such tool was developed by Ardi Imawan and Joonho Kwon, as shown in Figure 2.5 [9]. This system relies on a query entered by the user, consisting of a start date, an end date, and a list of nodes corresponding to areas on the map. The query is processed and a timeline view of congestion events on the selected node in the timeline is displayed alongside a map marking the selected nodes. This is a very limited system showing only one statistic of interest. The data is also not visualized, but simply shown in a text format.
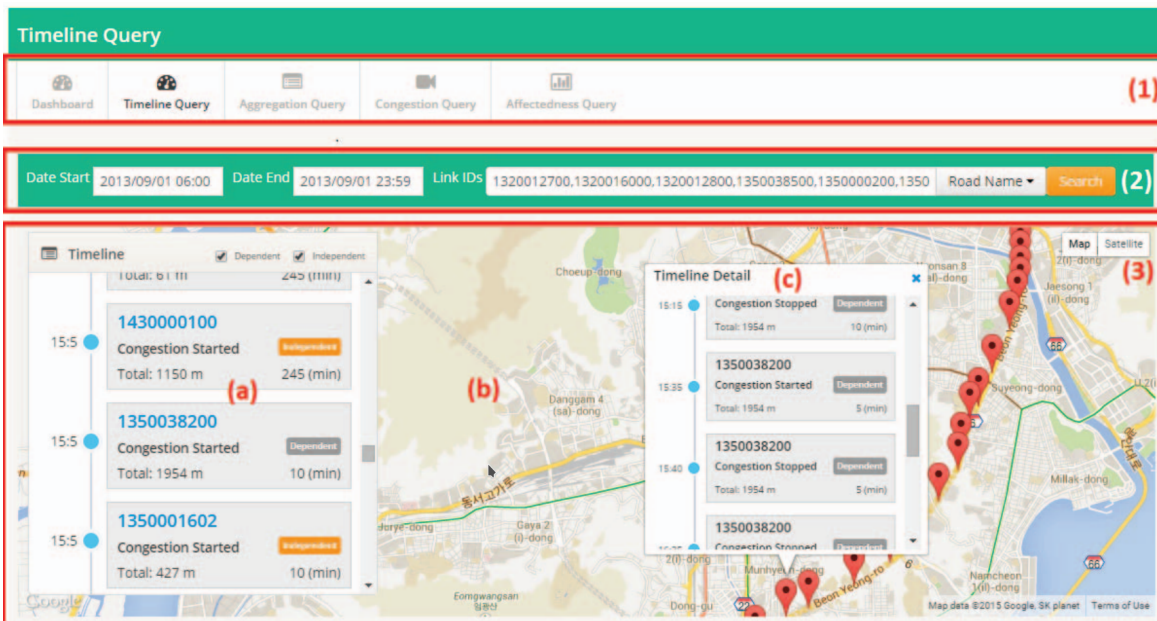
Figure 2.6: A timeline visualization system for raod traffic data displaying details of the selected nodes. [9]

6

Another traffic analysis tool was developed by Fi Wang, et al. to analyse traffic trajectory data. This system analyses data on a very granular level, looking at individual roads or small areas within cities.
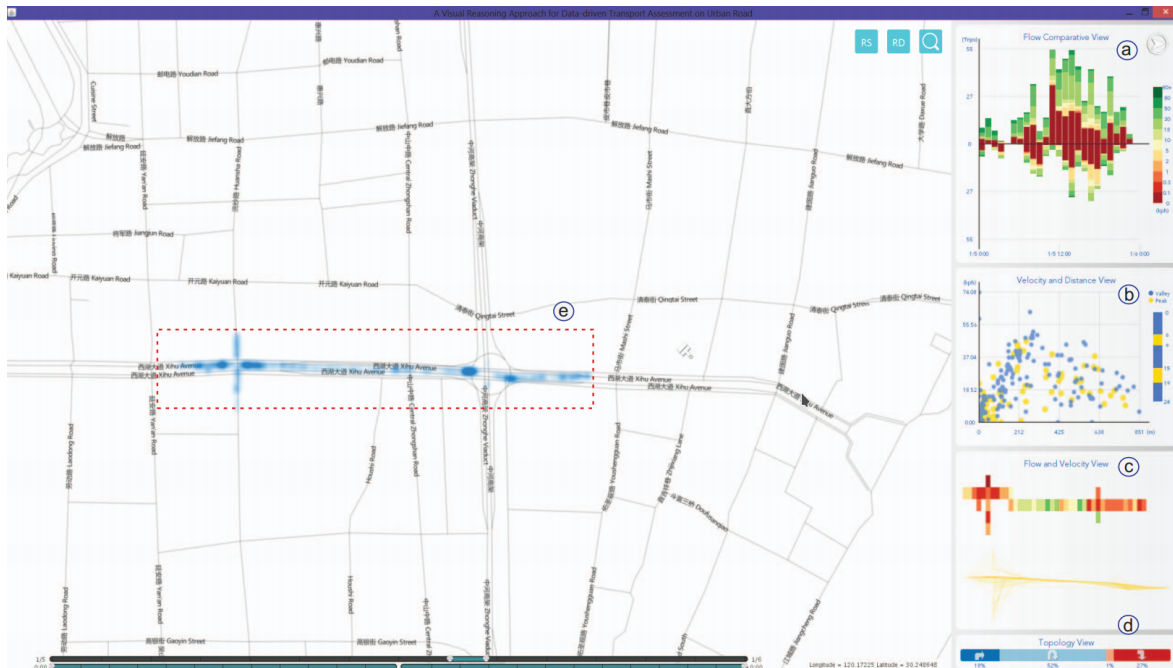
Figure 2.7: The distribution of slow movement events in a time interval. Hot spots may correspond to traffic congestion. [16]

Figure 2.7 shows the many co-ordinated views that compose this traffic visualization system [16]. These views include:

- Visualization A shows a comparison of the flow of each direction of traffic over time using a simple barchart [16].

- Visualization B shows a scatter plot of the velocity of a vehicle and it's travel time across the selected area [16].

- Visualization C shows the status of transportation distributed across the road. [16].

- Visualization D shows the topology of the road [16].

- Visualization E shows the density of flow distributed on the road, similar to that of Figure 2.2 [16].

The design of system is very effective at analysing trends among small areas using very granular data, although this is quite different to the TrafficVis objective which require larger scale analysis over highways with limited numbers of data gathering sites throughout.

Chapter 3

Design

3.1 Requirements

The design of the TrafficVis web application was guided a set of functional and non-functional requirements. These requirements were determined by analysing the available data, and the research goals specified in Section 1.3. The set of functional requirements are as follows:

1. The application must be accessible via a modern web browser.

2. The application must provide a geographical visualization of TMS sites.

3. The application must allow for data from multiple sites to be aggregated.

4. The application must allow for the traffic volume of a site at any time to be viewed.

5. The application must allow for the traffic volumes of multiple sites to be compared.

6. The application must indicate when the network is experiencing abnormal traffic behaviour.

  The set of non-functional requirements are as follows:

1. Usability - The application should be intuitive to use, such that a user with some data analysis experience should be able to use the application as intended with minimal assistance.

2. Performance - Loading times should be kept to a minimum, and visualizations should run smoothly within the browser.

3. Extensibility - The application should be designed that such that the functionality can be easily extended in the future, if more time is dedicated to development, or more data becomes available.

3.2 Data

3.2.1 TMS Site Data

The TrafficVis web application required data of the many TMS sites across the State Highway network of New Zealand. This data was provided in a KML filetype by Beca Group Ltd. KML files store geographic information in an XML format. For this data, the latitude and longitude of each TMS site was stored, as well various information regarding each site, including the ID, region, speed limit, traffic directions, etc.

3.2.2 Traffic Volume Data

Each TMS site records the number of vehicles that pass through in each 15 minute interval, this data is essential for allowing the user to analyse trends in the traffic behaviour. This data was provided by Beca Group Ltd. in the form of a large CSV file, with each row detailing a TMS site, a time interval, a traffic direction, and the count of vehicles.

There are many challenges in utilising this dataset. While the State Highway network contains over 1500 TMS sites, less than 200 have continuous data for the entire time period. This high proportion of missing data needs to be carefully accounted for when visualizing or aggregating data.

Additionally, while the vast majority of TMS sites record at 15 minute intervals, some record hourly, or at different rates. As very few of these sites exist in the dataset, they were simply filtered out during preprocessing.

3.2.3 Traffic Prediction Data

As stated in the Introduction, this previous work by Daniel Braithwaite and Li Li has produced a machine learning model capable of predicting the traffic volume at a TMS site given the previous two weeks of volume data. While not provided with the predictive algorithm itself, this project has been provided with the predicted traffic volume for each site and time interval within the dataset for this project. No predictions exist for the first two weeks during the dataset, as this is taken as the training time. As with the traffic volume data, the traffic volume predictions were supplied in a large CSV file.

3.2.4 Geographic Map Data

Geographic boundary data is made freely available by Stats NZ [14]. This data is necessary for TrafficVis to draw a map of New Zealand, to add geographic context to the TMS sites locations. This data is available as ESRI shapefiles, a common data format for storing geographic data.

3.3 Visualizations

As an information visualization platform, TrafficVis requires a number of visualizations that can provide insights from the various data sources. TrafficVis offers several visualizations, each as their own widgets.

3.3.1 Map Widget

The Map widget displays a map of New Zealand and the State Highway network, as shown as Widget A in Figure 3.12. The user can navigate that map using the mouse to pan and zoom. The map displays each TMS site within the dataset as a circle on the state highways. Each TMS site is coloured on a scale from yellow to red, according to the volume of traffic that has passed through the site in selected previous 15 minute interval. Other dimensions could have been used to visualize traffic volume on the map widget, such as size. If each circle was scaled according to the traffic volume, it would have been very clear which sites were experiencing higher traffic volume than others. However, it was deemed to be very important that the user is able to select each individual site with the mouse, as this is the method of populating other charts. Having larger circles when sites are experiencing higher traffic volumes would have led to issues with larger sites overlapping and preventing smaller sites from being interacted with.

Sites which are detected to be showing abnormal traffic behaviour are highlighted. Traffic behaviour is considered to be abnormal when the measured traffic volume is sufficiently different from what was predicted by the predictive model. If a site is experiencing significantly more traffic than was predicted, it will be highlighted red. If experiencing significantly less traffic than predicted, it will be purple. This highlighting was implemented with the goal of being able to identify at a glance when abnormal traffic is being experienced, such that the cause can potentially be identified and the impact of these traffic abnormalities can be observed.

The TMS sites can be dragged from the map onto another widget in order to add them to the other charts. Sites that are detected to be experiencing anomalies in traffic behaviour are highlighted, as seen in Figure 3.1. The Map widget can be used by analysts to view large-scale trends across the country, but the primary use of this widget is to populate the other widgets with TMS sites.
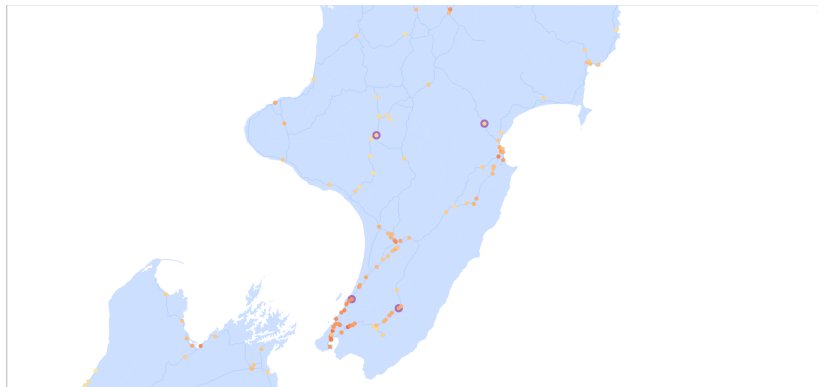
Figure 3.1: The Map widget displaying the TMS sites on the New Zealand state highway network.

The map widget is key to satisfying the functional requirement that the application must provide a geographical visualisation of the TMS sites. The map widget is particularly effective at revealing events that effect multiple TMS sites, whether the impact is on the entire country or localised to a specific area. Figure 3.2 shows the lower south island during Otago Anniversary Day, 2017, at 7am.
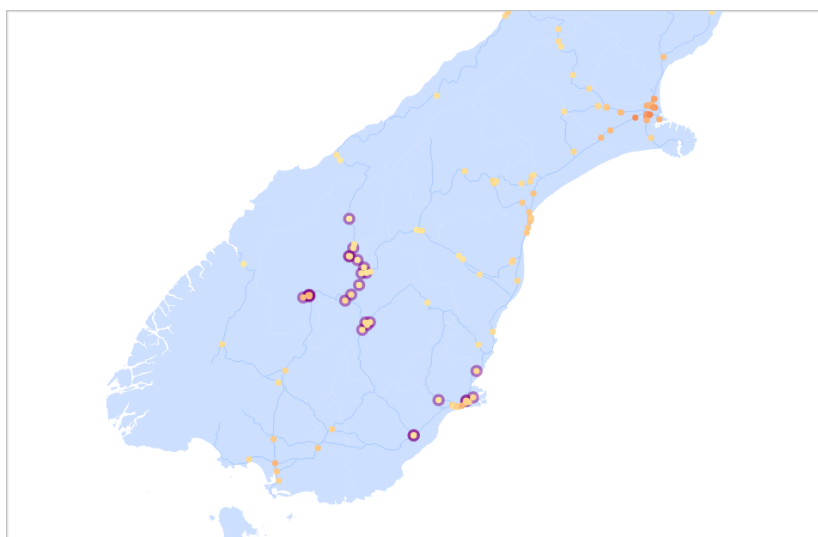
Figure 3.2: The Map widget showing anomalies detected surroudning the Otago region due to a public holiday, Otago Anniversary Day.

It's clearly indicated by the anomaly highlighting that sites across the entire Otago region are experiencing a less traffic volume than is usually expected, given that commuters are not required to travel to work.

3.3.2   Traffic Volume Bar Chart

The Traffic Volume Bar Chart widget displays the traffic volume of selected sites at the current time stamp, as in Widget B of Figure 3.12. This widget allows for the traffic volume of many sites to be compared. Each site shows the volume for both the increasing (southbound) and decreasing (northbound) directions of traffic. The widget allows for the user to toggle between displaying stacked bars, as in Figure , and grouped bars, as in Figure 3.4. Clicking one of the bars highlights it and shows a button for removing the site from the chart.
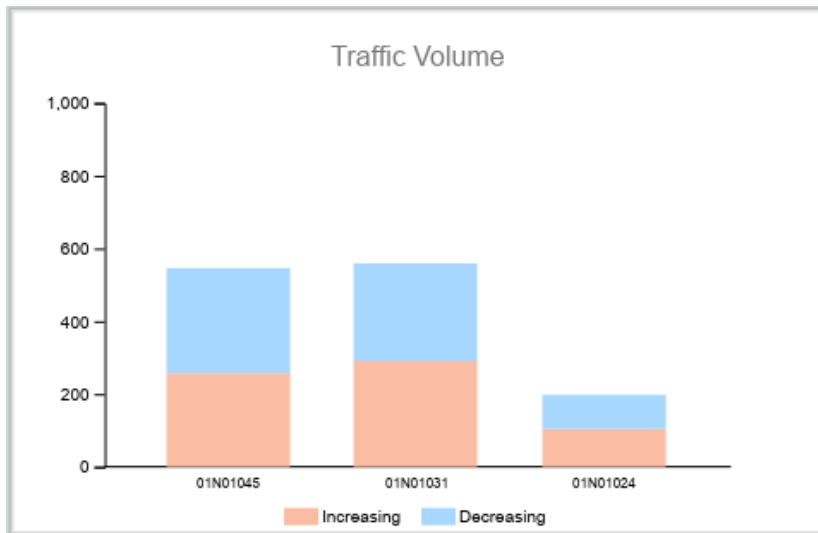
Figure 3.3: The Traffic Volume Bar Chart displaying the increasing and decreasing traffic volumes for the three selected TMS sites with stacked bars.
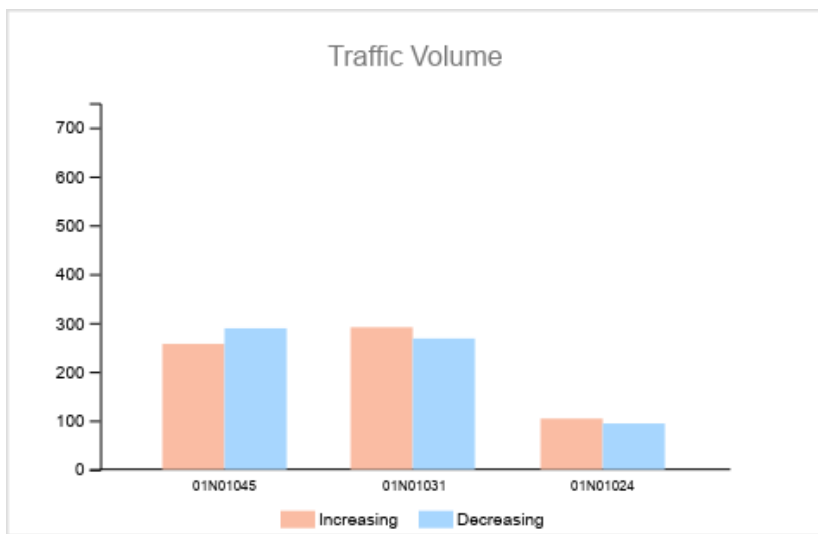
Figure 3.4: The Traffic Volume Bar Chart displaying the increasing and decreasing traffic volumes for the three selected TMS sites with grouped bars.

The Bar Chart widget is of use to an analyst using the TrafficVis tool when looking to compare traffic volume levels between sites at the given time. The stacked bar chart is effective at comparing the overall traffic volume at a TMS site, while grouping the bars allows for individual directions of traffic to be easily compared. This widget contributes to the functional requirements of allowing the traffic volume of sites to be viewed and compared.

3.3.3 Line Chart Widget

The Traffic Volume Line Chart widget displays the traffic volume of the selected sites over the previous 24 hour period, as in Widget D of Figure 3.12. This allows for the user to compare the traffic volume and trends between multiple sites or locations. Clicking on the legend legend highlights the line for that site and shows a button allowing for the site to be removed from the chart.

The Line Chart widget is useful for to an analyst using the TrafficVis platform for visualizing and comparing daily trends in the behaviour of traffic at each TMS site.
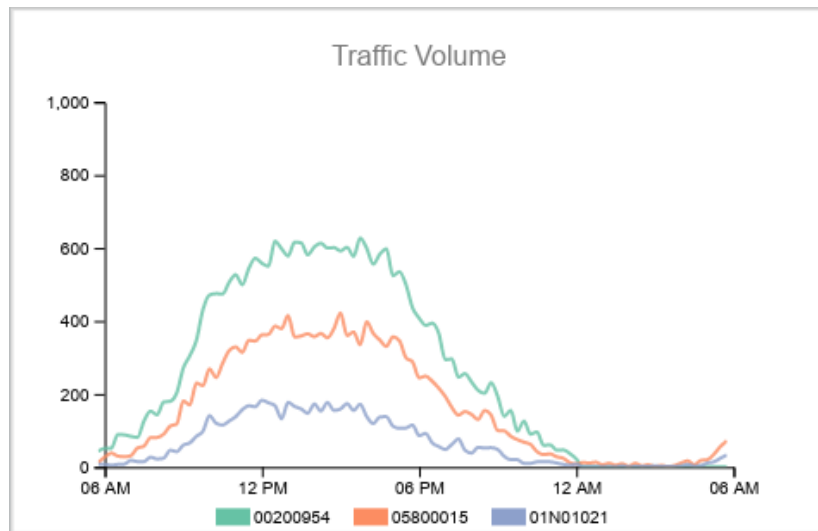
Figure 3.5: The Traffic Volume Line Chart displaying the previous 24 hours of traffic count data for the three selected TMS sites.

This widget contributes to the functional requirements of allowing the traffic volume of sites to be viewed and compared.

3.3.4 Predicted Traffic Widget

The Traffic Prediction Line Chart shows the actual traffic volume of the selected TMS site over the past 24 hours alongside the predicted traffic volume, as in Figure 3.6. This widget allows for the user to split the visualization into two charts, one displaying the traffic volume and prediction for each direction of traffic, as in Figure 3.7.

This widget is of particular value to traffic analysts. The ability to compare the measured traffic behaviour to what was expected for the site allows for significant insights into when abnormal traffic behaviour is occurring, and when the network is exhibiting potential resiliency issues.
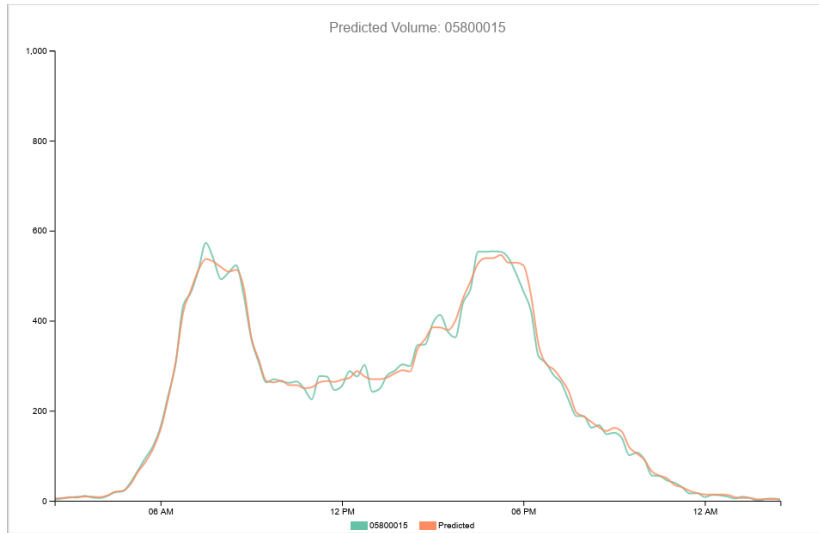
Figure 3.6: The Traffic Prediction Line chart comparing the actual traffic volume of the selected site (green) with the predicted traffic volume (orange).
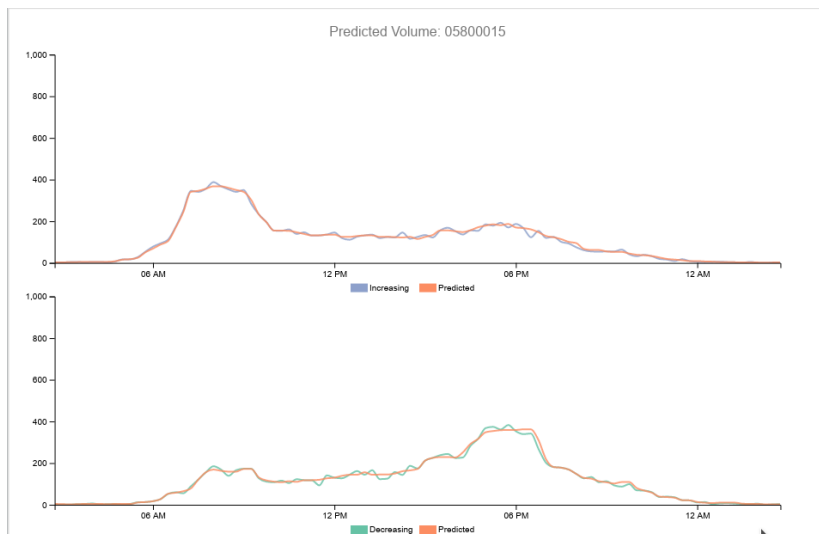
Figure 3.7: The Traffic Prediction Line chart comparing the actual traffic volume of the selected site with the predicted traffic volume for each direction.

This widget is essential in satisfying the functional requirement that abnormal traffic behaviour experienced on the network should be highlighted and able to be observed. For example, Figure 3.8 displays the actual traffic volume recorded from a TMS site south of Auckland compared to the predicted traffic volume on March 23, 2017, the day of an Adele Concert in Auckland.
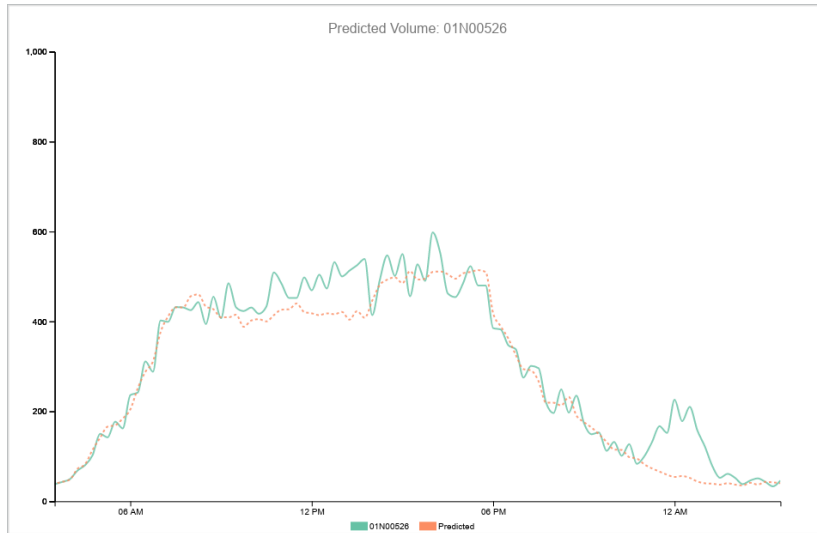
Figure 3.8: The Traffic Prediction Line chart comparing the predicted traffic volume and the actual traffic volume on the day of an Adele concert in Auckland.

The chart clearly shows that throughout the day there were increased levels of traffic, presumably as concert-goers were travelling into Auckland. This was followed by a significant spike in traffic around midnight, likely the result of people leaving Auckland after the concert.

3.3.5   Weekday Flow Profile Widget

The flow profile of a site is the average distribution of traffic volume across the day, as in Figure 3.9. The Weekday Flow Profile widget displays the flow profile of the average weekday for the selected sites. As with the previous charts, clicking on the legend will highlight the line and show a button for removing it from the chart.
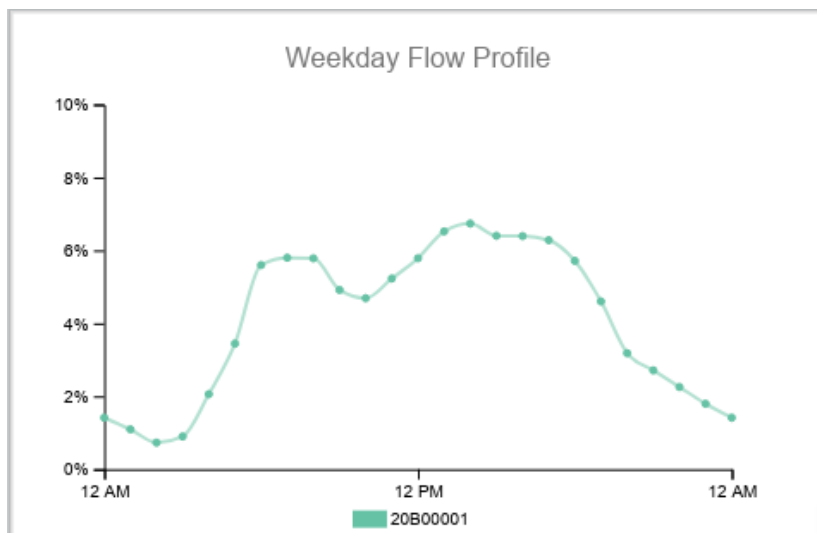
Figure 3.9: The Weekday Flow Profile chart displaying the flow profiles for the two selected TMS sites.

It is useful for a data analyst to view the flow profile of a site in order to understand a glance how traffic is usually distributed and when peak traffic is likely to occur.

15

This visualization is different to the other charts offered by TrafficVis, as it displays an aggregate of the data over the entire dataset, while the other charts only display data surrounding the selected time stamp.

3.4 User Interface Design

3.4.1 Time Controls

The web application displays information for only the selected time. A series of time controls were designed for navigating the dataset. The time controls are implemented as a series of buttons located within the header of the application. The user can pause and resume the passage of time, such that the time of interest can be navigated to, and then paused to allow more time investigating the visualizations at this time stamp. In order to improve the ease at which the user can navigate the dataset, buttons were added to control the speed at which the application will play through the data. This is achieved by moving through a list of predefined playback speeds which each represent a simple rate of time to understand, such as "30 min / sec" or "6 hours / sec". Figure 3.10 displays the buttons for controlling the time in the header of the page, with labels for the current time and the playback speeds.

Figure 3.10: Time controls used to navigate the dataset.

The user can click on the date label in order to select a date in order to quickly navigate the dataset. Figure 3.11 shows the date selection field, alongside buttons for submitting or cancelling the date input, both of which revert the time controls panel to the configuration in Figure 3.10.
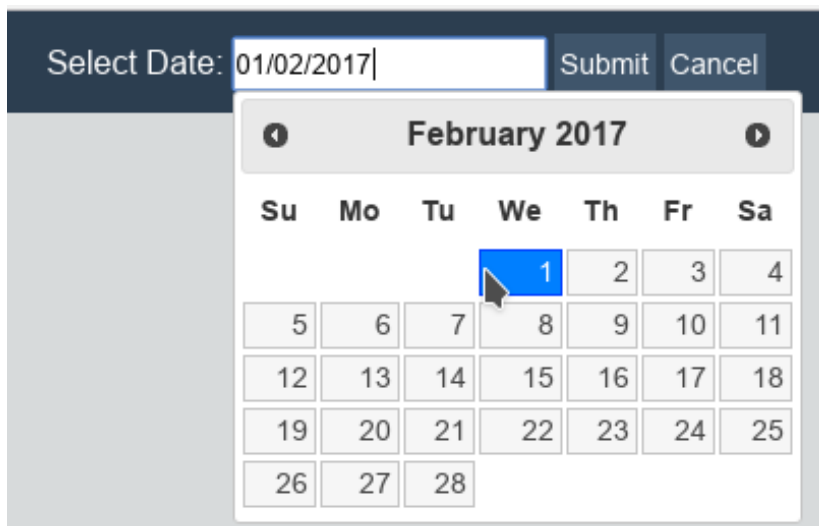
Figure 3.11: Date selection used to quickly navigate the dataset.

This date selection functionality was necessary, as otherwise the user could only reach a certain date by playing through the dataset from the beginning.

16

3.4.2 Widget-based Dashboard

There are a number of possible ways to analyse traffic volume data, and the requirements for a visualization platform may vary depending on the needs of the user. In order to allow for the TrafficVis web application to be flexible, extendible and useful in a number of contexts it has been implemented as a customizable, widget-based dashboard. TrafficVis provides the tools for an analyst to create their own dashboard that fits their current needs. While a wide range of visualizations can be produced with the given data, only a select few are likely to be relevant for any given task. Giving the user the ability to create their own dashboard from a selection of widgets will ensure that the users are giving their attention to only the visualizations necessary for meeting their current goals.

A widget-based dashboard allows for further widgets and functionality to be added to the application as necessary without heavily impacting the existing design. This is in accordance with the non-functional requirement of providing an extensible application.

The user can drag widgets onto the dashboard from the widgets drawer in the header, as is shown in Figure 3.13. Another button in the header toggles "Edit mode". When edit mode is enabled, the user can drag widgets around the dashboard, resize them or remove them. When edit mode is disabled, the user can instead interact with the contents of each widget. The user can add widgets from a selection as necessary to create a customised dashboard to fit their needs. Figure 3.12 shows an example of a dashboard that could be created using TrafficVis.
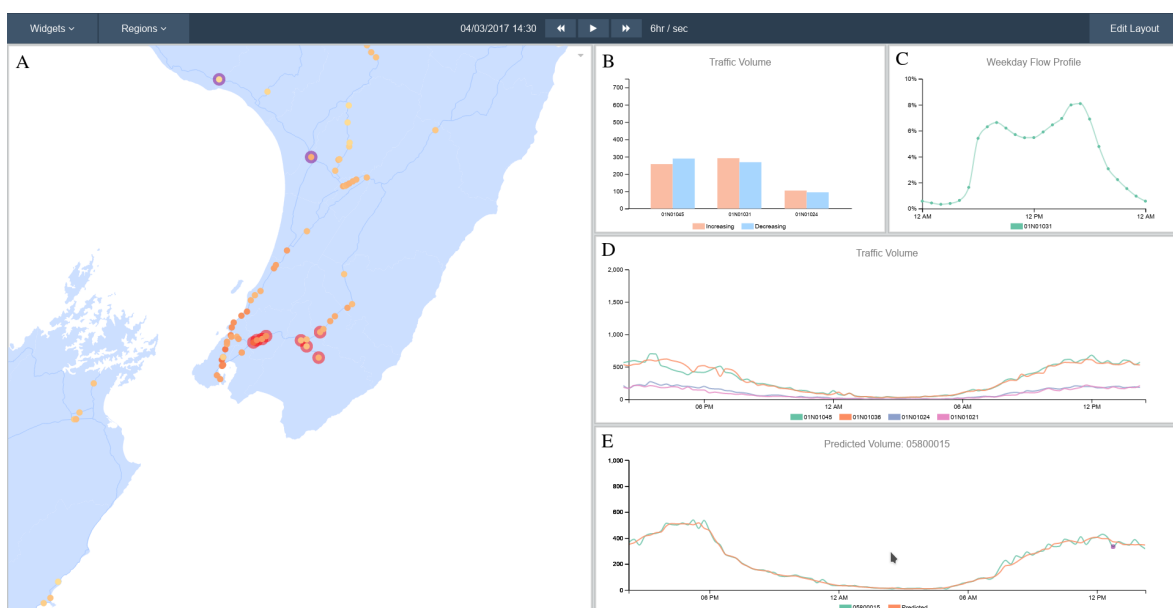
Figure 3.12: An example of a dashboard that could be created using the web application.

17
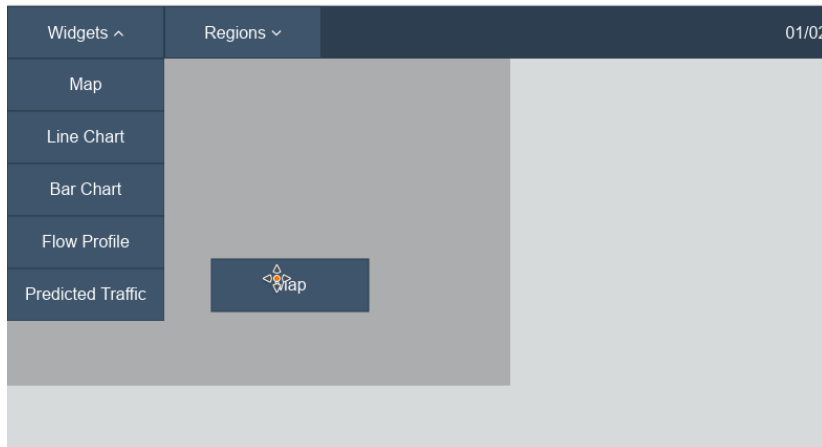
Figure 3.13: A Map widget being dragged from the widget drawer onto the dashboard.

3.4.3 Region Selection and Aggregation

While the visualizations described above give the ability for the user to view and compare details and data of individual TMS sites, this does not meet the functional requirement that the system should allow for the data of many sites to be aggregated. In order to meet this requirement, the ability to define and visualize regions using the various charts was implemented. Regions are defined by a region name, and a list of TMS sites which fall within the region.

A region drawer exists in the header of the application, alongside the widgets drawer. The drawer contains a selection of predefined regions. The TMS site data contained a labelled region that each site belonged it; these region labels were used to construct the default regions for the region drawer.

Regions can be dragged from the region drawer onto one of the existing widgets, and the charts will then display the aggregated data for all TMS sites within the region, for the selected time. This satisfies the functional requirement that data from multiple sites must be able to be aggregated.

At the bottom of the region drawer exists a "Add New Region" button. Clicking this button will present the user with a region selection window, containing a map for selecting sites and a text field for defining the region name, as shown in Figure 3.14.

Figure 3.14: The Weekday Flow Profile chart displaying the flow profiles for the two selected TMS sites.

The region selection window offers 4 different tools to the user for defining their own region:

1. **Selection**. Dragging over the map with this tool will create an ellipse, selecting any sites within. Using this tool will replace any previous selection.

2. **Additive Selection**. Dragging over the map with this tool will create an ellipse, any sites selected by this tool will be added to any existing selection.

3. **Subtractive Selection**. Dragging over the map with this tool will create an ellipse, subtracting sites selected from any existing selection.

4. **Pan and Zoom**. This tool allows the user to pan across the map by dragging with the mouse, or zoom into the map using the scroll wheel.

This selection of tools was selected in order to allow for the user to construct complex regions if necessary. The user can zoom in on any area of interest and can either select a rough group of sites, or carefully select specific if required. After defining a region, it is immediately available within the regions drawer such that data for the region can be aggregated on the various visualizations offered.

Chapter 4

Implementation

4.1 Data Processing

4.1.1 TMS Site Data

In order to be used efficiently with the JavaScript libraries utilised in creating TrafficVis (discussed in Sections 4.2 and 4.3), the data for each TMS site was reformatted as a JavaScript Object Notation (JSON) object. An example of a formatted object for a single TMS site is shown in Listing 4.1

Listing 4.1: An example of a JSON object created to represent a TMS site.

```
{
  "id": "01N00130",
  "coordinates": [
    173.4339175039072,
    -35.1642866787459
  ],
  "properties": {
    "SHAPE": "Point",
    "Region": "01 - Northland",
    "Site_Ref": "01N00130",
    "SH": "1N",
    "Description": "Nth of Ramseys Bridge",
    "Site_Type": "non-continuous",
    "Type": "Dual Loop",
    "Speed_Limit__kph_": "100",
    //Irrelevant information omitted
  }
}
```

4.1.2 Traffic Volume and Prediction Data

The dataset for this project spans a three month period from February to April, 2017. This data was also preprocessed to produce JSON objects which could be more easily used and manipulated by JavaScript scripts. A JSON document was constructed for each day within the dataset that contains the traffic volume and prediction for at each 15 minute interval for each site. An example of such a document for one day is shown in Listing 4.3.

Listing 4.2: An example of a JSON object created to represent a traffic volume and prediction data for a single day.

```json
{
  "00:15": {
    //Data stored for each TMS site
    "00400218": {
      //Data separated by direction of traffic
      "dec": {
        "count": 4,
        "pred": 2
      },
      "inc": {
        "count": 3,
        "pred": 2
      }
    },
    //Additional TMS sites omitted
  }
  //Additional timestamps omitted
}
```

4.1.3   Geographic Map Data

In order to be used by JavaScript visualization libraries, such as D3.js (See Section 4.3.1), these shapefiles were converted to GeoJSON objects. GeoJSON objects are a particular format of JSON objects defined for effectively storing geographic data. A single GeoJSON object stores the bounding box for the entire geographic dataset, and details regarding each feature. Features stores a list of co-ordinates to define the shape, and any other relevant information, such as a label or ID.

The New Zealand gographic boundary data utilised considers each district of New Zealand to be a separate geographic feature. The GeoJSON format utilised is shown in Listing **??**, containing one example feature.

Listing 4.3: An example of a JSON object created to represent a traffic volume and prediction data for a single day.

```json
{
  "type":"FeatureCollection",
  "bbox":[
    166.42628127360476,
    -47.28998472751208,
    178.55037274136544,
    -34.14411700176313
  ],
  "features":[
    {
      "type":"Feature",
      "properties":{
        "TA11":"030",
        "NAME":"Hastings District"},
        "geometry":{
          "type":"Polygon",
          "coordinates":[[
            [176.697713292678,-38.85595561748059],
            [176.71359377641426,-38.9427465676474],
```

```
                //Additional coordinates omitted
            ]]
        }
    }
},
//Additional features omitted
]
}
```

4.2   Server Architecture

The functional requirements require that the application be accessible via the web, therefore
a web server an essential component to this project.
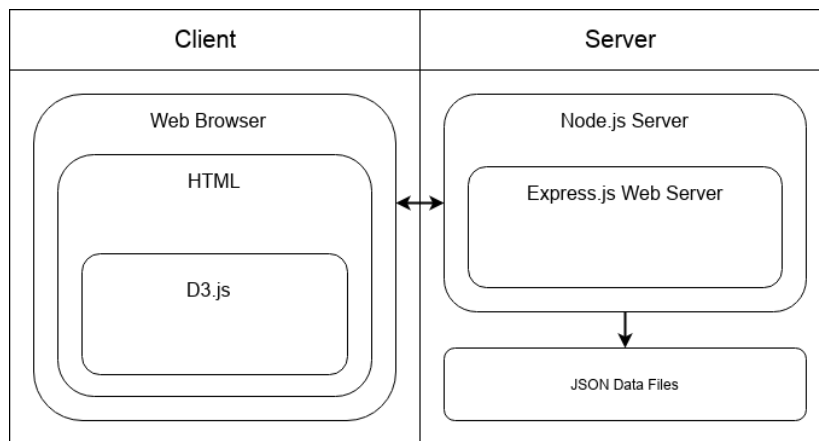
Figure 4.1: Architecture of the TrafficVis Web Application.

4.2.1   Node.js

Node.js is an open-source, cross-platform JavaScript environment that allows JavaScript
code to be executed outside of the browser [7]. Many competing frameworks for web devel-
opment exist and could have been used instead of Node.js, such as Flask, Ruby on Rails or
ASP.NET. However, Node.js offered key advantages over these other frameworks, leading
to its selection for this project. Node.js is particularly simple when compared to many other
frameworks, allowing for a quick server set-up, with more time to be dedicated to the visu-
alization of data, which makes up the majority of the functional requirements. Additionally,
given that the front-end of the application is to be developed using JavaScript libraries, in-
corporating Node.js as a server framework ensures that the primary language is consistent
across code on the client and server. This is beneficial in meeting the non-functional require-
ment of providing an extensible application; future developers need only know JavaScript
in order to develop for both the server and front-end of the application.

4.2.2   Express.js

Express.js is a web application framework for Node.js [6]. While Node.js does offer all the
functionality required to produce a web application without the need for external libraries
or frameworks, it can be quite intensive work. It is much more common to to employ a web

application framework to handle the serving of data and routing of requests. Express.js has become the de facto standard for creating Node.js web applications, due to it's simplicity and high performance.

4.2.3   Data Storage and Transfer

Given the majority of the data is in a JSON format, any document-based NoSQL database system, such as MongoDB, could have stored this data and offered persistent storage and advanced querying options. However, the data storage requirements for this web application are very simple. No complex querying of data is required, and as such it is sufficient to store the data only in flat file, which are served to the web application as required.

A challenge in implementing this application is that the datasets necessary for TrafficVis consist of more than 1GB of data files. In order to avoid significant loadings times, it's important that the only data transferred to the client is data that's actually necessary for the application to perform. In order to control the amount of data transferred, the client only maintains a sliding window of data, consisting of the data of the selected day, and the following three days. As the application navigates to another day, data outside this window is removed from memory, and new data required is requested from the server with simple API calls.

4.3   Front-End Technologies

As an information visualization platform, TrafficVis has utilised external libraries for dynamically visualizing data, and interacting with the server and HTML components.

4.3.1   D3.js

D3.js was selected as a JavaScript visualization library. D3.js allows the binding of data to the Document Object Model (DOM), the application of data-driven transformations to the document, and the creation of visualizations within SVG components [3]. D3.js allows very fine control over the behaviour of visualizations, as while most visualization libraries offer predefined functions for creating specific types of visualizations, D3.js encourages visualizations to be developed from scratch using base SVG element, such as rectangles and lines. This allows D3.js to be utilised for a very wide range of visualizations.

D3.js also allows for interactivity to be added to an application in a very simple way, as each SVG element can listen for one of many common mouse events, including "click", "mousein", "mouseout", "drag", etc. A function can be called when any of these events are triggered, allowing for the developer to design visualizations such that they can react to a wide range of user input.

4.3.2   jQuery

jQuery is a JavaScript library designed to simplify the client-side scripting of web applications [10]. jQuery was utilised in the development of the TrafficVis application to simplify the interactions with buttons and similar HTML elements, and the process of retrieving data from the server via simple API calls.

While all of this functionality could have been completed using only JavaScript without the need for external libraries, jQuery offers much simpler and more concise function calls and interfaces, greatly improving the readability of the code.

4.4 Dashboard Implementation

4.4.1 Grid Layout

As discussed in Section 3.4.2, a customizable widget-based dashboard was implemented in order to allow the user to customize their experience to meet their needs. In order to allow for this customizability while ensuring it was easy to arrange widgets as required, and the resulting dashboard would remain aesthetically pleasing, the dashboard was implemented such that widgets are aligned to a grid. The position and size of each widget is represented by grid units. Figure 4.2 shows how widgets are aligned to an underlying grid of four columns by three rows; the dimensions of each widget are multiple of the dimensions of a single grid square.
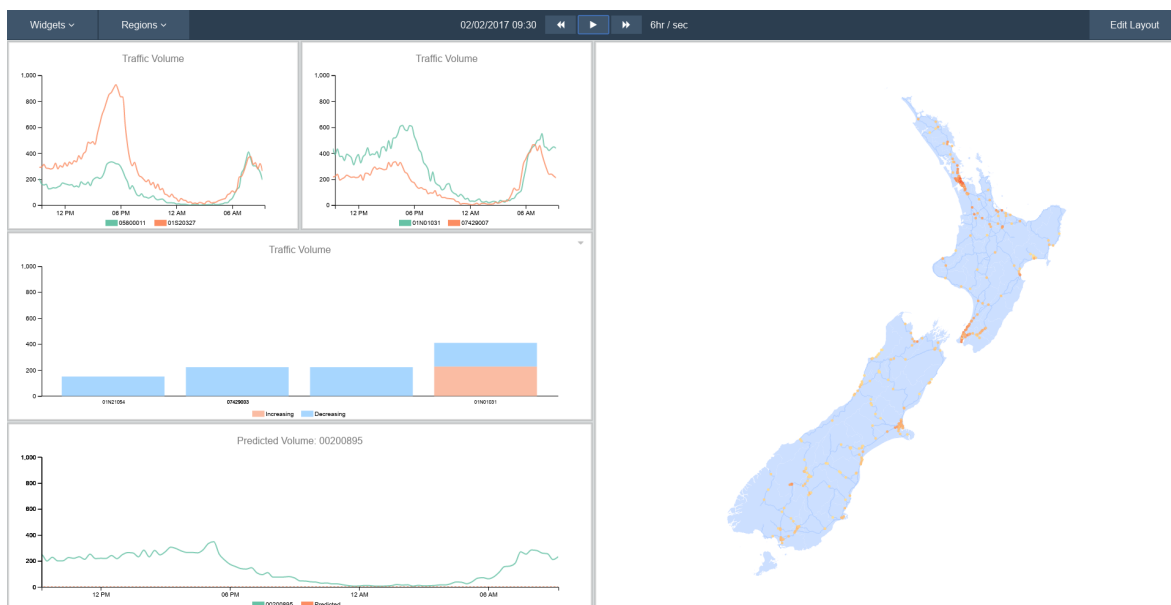
Figure 4.2: The dashboard of the TrafficVis application

The entire dashboard below the header consists of layers of SVG elements, such that they can be efficiently manipulated by D3.js.

4.4.2 Adding and Manipulating Widgets

Widgets are added to the dashboard by dragging them from the widgets drawer onto an unoccupied grid square of the dashboard. Initially, all widgets are the size of a single grid square. In order to clearly convey to the user where a widget will be placed, a space indicator is shown on the dashboard displaying the location the widget would occupy if placed. This space indicator is also utilised moving or resizing widgets, as shown in Figure 4.3.
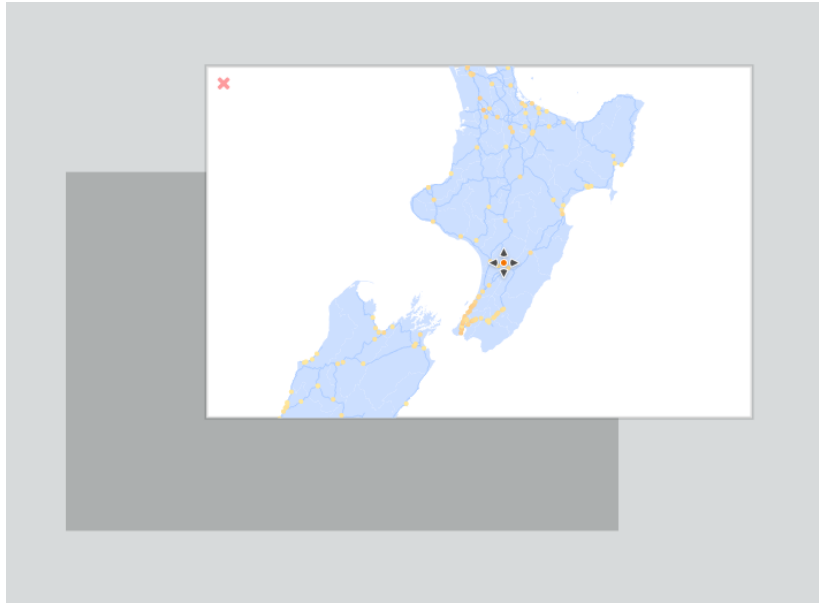
Figure 4.3: The space indicator shown upon moving a widget on the dashboard. Upon releasing the widget, it would snap to the location shown by the space indicator.

The space indicator is also used to convey to the user when they are attempting to manipulate the dashboard into an impossible state, such as when trying to place a widget in an occupied space, as shown in Figure 4.4.
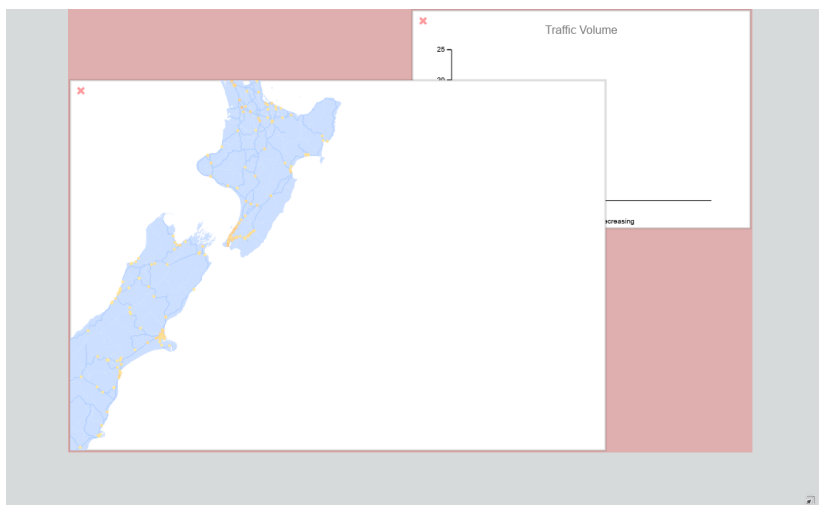
Figure 4.4: An example of how the space indicator is used to notify to the user that action can't be completed.

4.4.3 Responsiveness

The dashboard is implemented such that the grid layout is always four columns by three rows, with the size of each grid square is determined by the dimensions of the browser window. Upon resizing the window, the size of each widget and grid square will readjust such that the dashboard is always proportioned correctly to be displayed on any size monitor.

Chapter 5

User Study

5.1 Study Choice

User studies can be used to evaluate the strengths and weaknesses of different visualization techniques, and other design decisions within an application [11]. Well designed studies can show whether new visualization techniques are effective for a specific task, and aim to seek insight into why a particular technique is effective. It can be difficult to evaluate the effectiveness of a design without utilising external observers, given that the designers and developers of an interface will always be very comfortable and familiar with it. Gaining feedback from user study participants who have not had experience with a system before can provide valuable insights into how usable and effective an application can be [13].

5.2 Ethics Approval

This study was approved by the Human Ethics Committee on 31st August, 2018. The completed ethics application can be found in Appendix A. The user study information sheet, consent form, tasks and questionnaire can be found in Appendix B.

5.3 Participants

The target users of the TrafficVis application are data analysts, particularly those with a focus on analysing traffic data. The ideal user study participants would therefore have been analysts with experience using data analysis tools and an interest in transport data. However, I was unable to have any professional transport analysts take part an the study. Instead, many students, academics, or other individuals with experience in data analysis were approached.

The study was completed by 19 participants. 14 of these participants were third and fourth year students of the School of Engineering and Computer Science at Victoria University of Wellington. These students completed the study under observation. The remaining 5 participants were students and academics based at other universities, who participated in the study online.

While all participants are of groups which are generally technologically literate, it's important to note that the majority had significantly less transport domain knowledge and experience in data analysis tools than the target users of the TrafficVis application.

5.4 Procedure

The user study was completed as per the following procedure:

1. Participants would have the opportunity to complete a brief tutorial covering the core functionality of the TrafficVis application.

2. Participants would read the study information sheet, and complete the study consent form if they wish to continue.

3. Participants would complete a brief initial questionnaire describing their level of experience with data analysis tools.

4. Participants complete a series of 5 tasks that explore most of the functionality offered by the application. Each task is described in Section **??**.

5. Participants complete a questionnaire evaluating the effectiveness and the usability of the TrafficVis web application. The questionnaire is described in Section **??**.

5.5 Tasks

A series of tasks were constructed for the participants to complete. The aim of the series of task was to have the user explore the core functionality of the application. Each task involves answering a question using the application, then rating the difficulty of the task.

A Likert scale was used to ask the user to rate the difficulty of each task, as shown in Figure 5.1.

I found this task difficult to complete.

| | 1 | 2 | 3 | 4 | 5 | |
| Strongly disagree | ○ | ○ | ○ | ○ | ○ | Strongly agree |
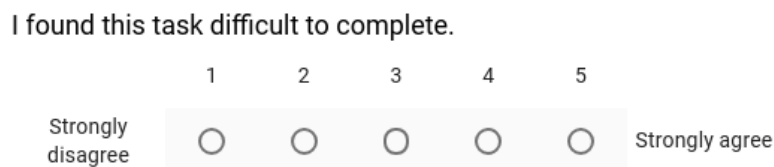
Figure 5.1: A 5 point Likert scale in which the participants can evaluate the difficulty of a task.

Likert scales are a widely-used rating question format in which a five-point or seven-point scale is presented to the user to select an answer from a spectrum [12]. Most commonly, the Likert scale will range from 'Strongly Disagree' to 'Strongly Agree', with a neutral option in the middle of the scale. Likert scales are effective tools as they are often very familiar to the participants, and can be analysed very effectively by viewing the distribution of responses on the scale.

5.5.1 Task 1: Using the Flow Profile Widget

The first task asks the user to use the Weekday Flow Profile widget to view the flow profile of a certain site from the Kapiti Coast, north of Wellington. The user is asked which hour of the average weekday shows the highest traffic volume for the site.

This task required the participant to complete the following actions:

- Use the widgets drawer to add a map widget and a flow profile widget.

- Interact with the map to navigate to the desired site.

- Use the map to populate the flow profile widget.

- Understand and interpret the output of the flow profile widget.

5.5.2 Task 2: Using the Bar Chart Widget

The second task asks the user to compare the traffic volume of the Northland and Taranaki regions over a single day using the bar chart widget, and state which region generally showed a higher traffic volume.

In addition to skills observed by previous task, this task required the participant to complete the following actions:

- Add and populate the bar chart widget.

- Use the regions drawer to add regions to a widget.

- Use the time controls to play through a portion of the dataset.

- Understand and interpret the output of the bar chart widget.

5.5.3 Task 3: Using the Line Chart Widget

The third task involves using the line chart widget to compare the traffic volume of a site from north of Auckland with that of a site south of Auckland on 1st March, 2017.

In addition to skills observed by previous tasks, this task required the participant to complete the following actions:

- Add and populate the line chart widget.

- Use the time controls to navigate to a specific day within the dataset.

- Understand and interpret the output of the line chart widget.

5.5.4 Task 4: Using the Traffic Prediction Widget

The fourth task asks the user to utilise predicted traffic widget to observe the effect of Taranaki Anniversary Day on the traffic volume of Taranaki. The user is then asked how traffic differed from what was predicted.

In addition to skills observed by previous tasks, this task required the participant to complete the following actions:

- Add and populate the predicted traffic widget.

- Understand and interpret the output of the predicted traffic widget.

5.5.5 Task 5: Defining a Region

The fifth task asked the user to define a new region for Wellington, and then use the predicted traffic widget to observe the effects of the Homegrown Music Festival on traffic behaviour within the Wellington region.

In addition to skills observed by previous tasks, this task required the participant to complete the following actions:

- Use the region selection tool to create a region for a specific set of sites.

- Use a user-created region to populate a widget.

5.6 Questionnaire

After completing the five tasks, participants are asked to complete a brief questionnaire evaluating the application. In an attempt to ensure that the questionnaire is not a burden to complete, the majority of the questions simply involve rating the effectiveness, enjoyability or usability of a tool on a five point scale.

The post study questionnaire involved the following three sections of questions.

5.6.1 Evaluation of the Dashboard

This section asks the participant to evaluate the dashboard design without yet commenting on the effectiveness of the visualizations themselves. The users are asked to evaluate their experiences in:

- Adding and manipulating widgets within the dashboard.

- Navigating through the dataset using the time controls.

- Creating a region using the region selection tools.

- Having control over their own dashboard, as opposed to using a predefined dashboards to complete tasks.

5.6.2 Evaluation of the Visualizations

This section asks the participant to evaluate the effectiveness of each of the five widgets offered by the TrafficVis web application. The following widgets are rated by how effectively the user feels than can convey traffic data:

- The flow profile widget.

- The bar chart widget.

- The line chart widget.

- The predicted traffic widget.

- The flow profile widget.

Users are also offered the opportunity to give more detailed feedback on any of these widgets if they wish to do so.

5.6.3 General Usability Questions

In order to evaluate the general usability of the system, the System Usability Scale (SUS) is used [4]. The SUS is a simple, ten-item scale that provides a rating of how usable the system is. Each of the ten questions asked as per the SUS are in the form of five-point Likert scale questions. The questions required for the SUS are shown in Figure 5.2.

Figure 5.2: The ten questions that make up the System Usability Scale [4].

The SUS questions have been designed to consider a wide range of usability requirements that can be applied to almost any system. A series of transformations can then be applied to the results in order to produce a SUS score, in the range of 0 to 100, representing a composite measure of the overall usability of the system [4].

5.7 Pilot Study

A pilot study is a trial run done in preparation of a larger-scale study, in which a small sample of participants complete the study, with the intent being on evaluating the study itself, not the application. Pilot studies can be very valuable for assessing the feasibility of the full-scale study, identifying potential issues in the research method and developing a research question and plan [15].

A pilot study was completed with two participants from the Human Computer Interaction research group of Victoria University of Wellington. The pilot study proved to be very beneficial to the study, particularly in identifying many potential areas of confusion within the tasks and questionnaire. Additionally, the pilot study also provided some prelimary data showing how much time each study is likely to require, which helped guide the recruitment strategy for the full-scale study.

Chapter 6

Results

6.1 Tasks Results

After each task, user study participants were asked to rate the difficulty of completing the task. The results of the task difficulty evaluation can be viewed in Figure 6.1.

Difficulty Rating of Tasks 1 - 5
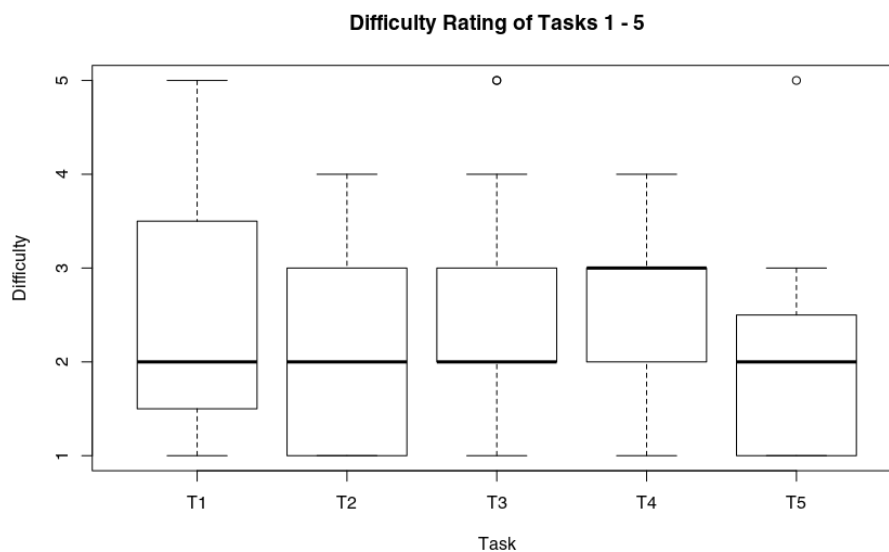
Figure 6.1: The results of the participants' evaluation of the difficulty of each task.
Of particular interest are the questions with a wide spread of results:

The user study was designed such that the tasks would increase in difficulty as the participant progressed through the study. I expected the results to reflect this, with difficulty ratings increasing for later tasks. However, the results have actually revealed that users found later tasks to be easier than earlier tasks. This is likely due to the nature of each task building upon what was learnt in previous tasks. Therefore, learning the core functionality of the application in earlier tasks significantly helped in completing more advanced tasks. This suggests that the web application consistent design and functionality, such that skills learnt during one task are directly transferable to other areas of the application.

6.2 Evaluation of the Dashboard

The first section of the questionnaire involved the evaluation of different components of the dashboard implementation, disregarding the effectiveness of the visualizations themselves. Users were asked to evaluate the difficulty in the following aspects of the application:

- **Q1**: Adding and manipulating widgets to produce a dashboard for a specific purpose.

- **Q2**: Navigating through the data set using the time controls provided.

- **Q3**: Defining a new region using the region selection tools provided.

The results of these difficulty evaluations are shown in Figure 6.2
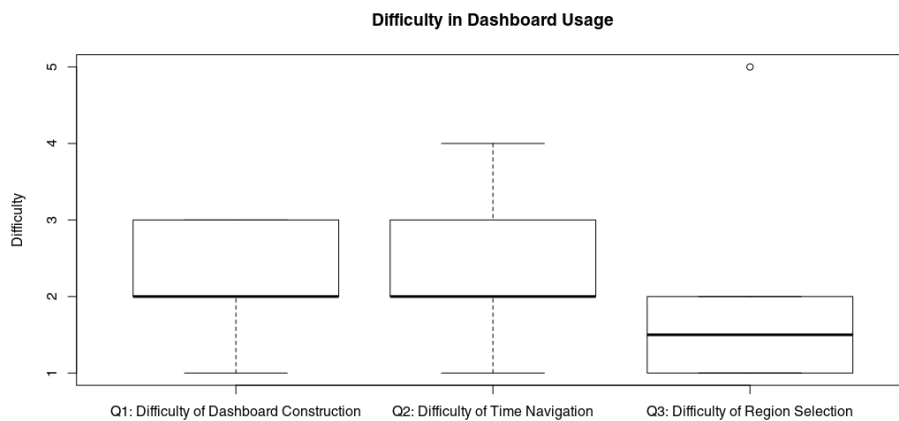
Figure 6.2: The results of participant's evaluation of the difficulty in using different aspects of the dashboard implementation.

These results show that most participants did not find it particularly difficult to create dashboards by adding and manipulating widgets. Over half of the participants rated the difficulty a one or two on a five point scale, with no responses being greater than three out of five. The most commonly criticism of the dashboard construction process by those who provided further comments is that it was cumbersome to continuously toggle in and out of "edit mode" in order to manipulate the widgets. This is a difficult design issues to resolve, as different modes of interaction are required to differentiate between the user wanting to move and manipulate the widgets, and interact with the visualizations themselves. Perhaps more significant visual queues could be implemented in order to make it clearer which interaction mode is currently engaged.

Users also found it fairly easy to navigate through the dataset using the provided time controls, although there were still some users who rated them as quite difficult to use, with a maximum rating of four on a five point scale. There were two commonly stated difficulties in using the time controls:

1. There is currently no implemented method of "rewinding" the dataset. The only way to move to a previous time interval is to use the date selection to move to a prior date.

2. There is no visual indication that clicking on the date label will provide a form for inputting a specific date. Users have stated that they would never have found this core functionality if not for the tutorial provided.

34

Users found it very easy to define their own regions with the region selection tools provided. All participants but one provided a rating of one or two on the five point scale. A single user did give a rating of five, but did not give further explanation as to why they found this to be difficult.

The questionnaire also asked users to discuss explain whether they believed that it was beneficial to be able to create their own purpose-built dashboard, as opposed to having predefined dashboards that could be utilised for specific tasks. Of the 19 responses, 8 participants were in favour of having the ability to make their own customizable dashboard, 8 would have preferred a selection of predefined dashboards, and 3 did not specify a preference, as shown in Figure 6.3.
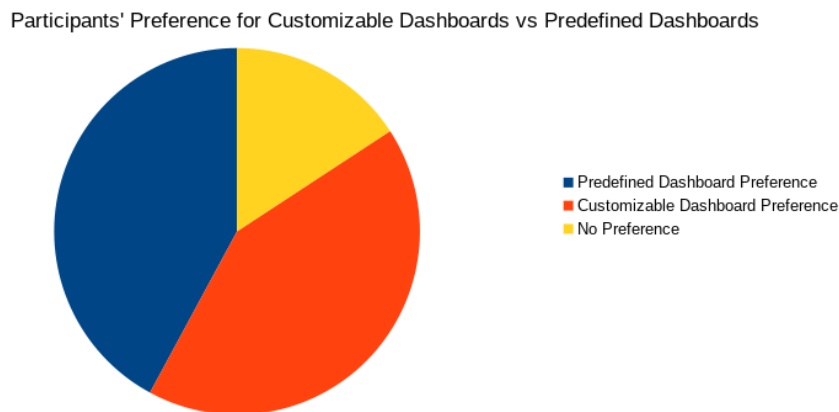
Figure 6.3: Participants preference for customizable dashboards or predefined dashboards.

The most common reasons provided for preferring a fully customizable dashboard experience were as follows:

- It's beneficial to have a dashboard showing only the information that's of interest without any other extraneous data.

- For a given task, only a small subset of the functionality offered by application will be required. The ability to select which features are relevant to the task can provide a much more focused dashboard.

- It's a more enjoyable experience to build a purpose-built dashboard.

On the contrary, all arguments using predefined dashboards were due to a single argument; being able to select an existing dashboard instead of creating one from scratch would significantly speed up the process of visualizing data using the application.

This has revealed that while users tend to appreciate the ability to customize their experience, it does significantly improve the amount of effort required to use the application, particularly for small tasks. Both groups of users may be satisfied by maintaining the possible customizability of the dashboards, but also offering a number of predefined dashboards that could be utilised if desired. Additionally, the ability to save and load previously created dashboard configurations could improve the efficiency in which the user could use the application, without sacrificing the customizability of the experience.

6.3 Evaluation of the Visualizations

Participants were asked to rate the effectiveness of each widget offered by the TrafficVis application by how well they feel the visualization convey transport data. ach visualization

was rated on a five-point Likert-like ranging from "very ineffective" to "very effective". scale The results are summarised in Figure 6.4.
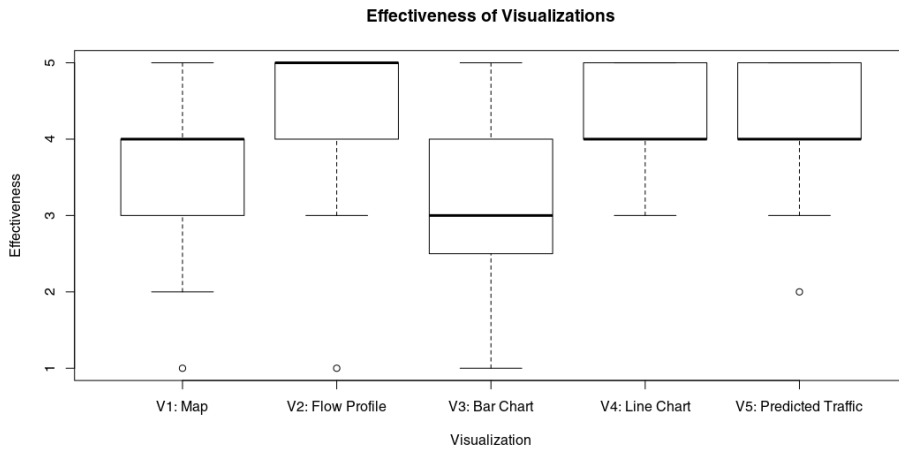
Figure 6.4: The distribution of responses when participants were asked to rate the effectiveness of each visualization technique.

The results show that the bar chart was the lowest rated of all visualizations by a significant margin. While being the only widget to allow the comparison of different directions of traffic for multiple sites, the bar chart is significantly limited compared to many other widgets as it can only display the traffic volume for a single time stamp within the dataset.

In retrospect, the poor opinion of the bar chart may have been partly a result of the design of the user study. Given no user study tasks involved the analysis of traffic by direction, participants have not had experienced the one aspect of the bar chart that offers functionality not offered by other widgets.

The line chart and predicted traffic widgets were rated very similarly, with a median effectiveness rating of four on the five-point scale, and an upper quartile of a perfect five. Study participants appreciated how effectively the line chart is able to show daily trends in the traffic volume of a site, or compare such trends between multiple sites. Many users commented that the bar chart widget felt unnecessary given the line chart showed the current traffic volume just as well, while also providing more temporal context. Some improvements suggested for the line chart widget include having a more descriptive x axis, displaying the date or day as well as the time, and adding the ability to set which period of time the x axis should cover.

The traffic prediction widget received very similar comments to the line chart widget. Participants found it effective at displaying traffic volumes, and provided unique insights by comparing this volume to the predicted traffic volume. One user suggested that the widget should highlight when the traffic volume is deviating significantly from that which is predicted. This would further improve the ability of the system to clearly show when anomalous traffic behaviour is being experienced.

The flow profile widget was rated the most effective visualization for conveying traffic data. This widget has a median effectiveness rating of five on the five-point scale, showing that participants preferred it significantly more than the other widgets of the system. This widget offers the only visualization of the platform which aggregates from the entire dataset. This clearly provides a clearer representation of the data from which to gain insights as the aggregation reduces the impact of noise on the visualization. This widget is also not effected by the time controls, which some participants struggled to utilise.

6.4　System Usability Scale

The results of the ten questions used to construct the system usability scale are shown in Figure 6.6.
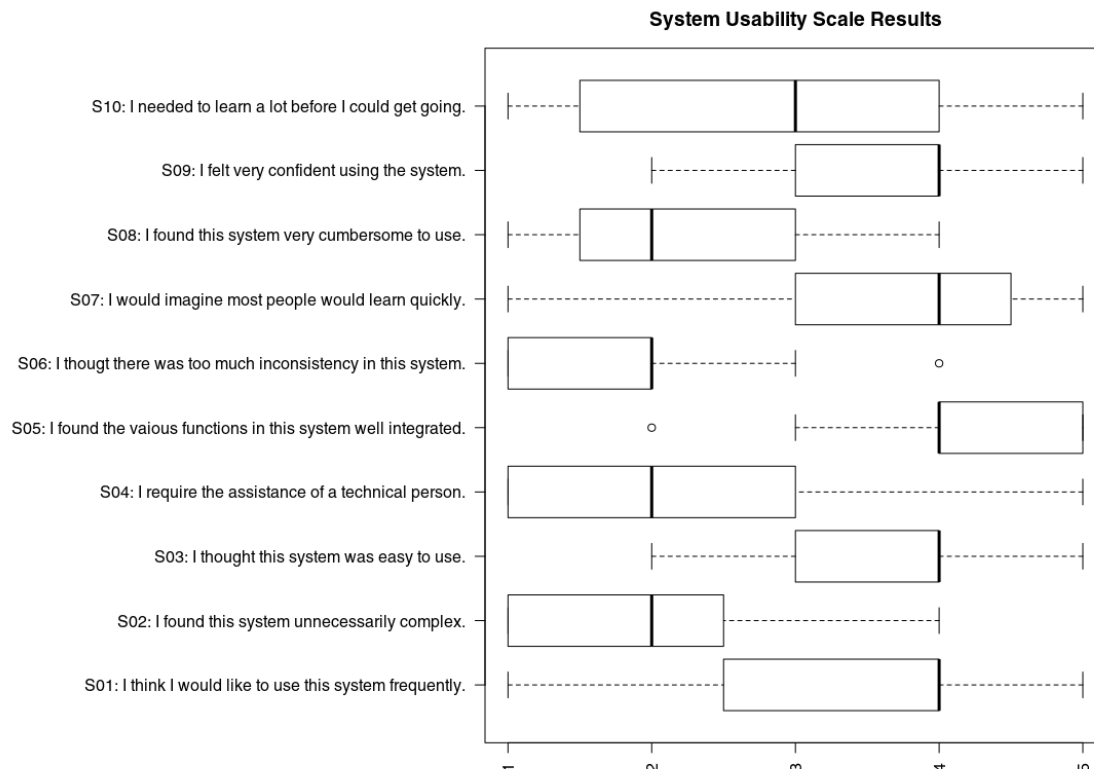
Figure 6.5: The distribution of responses when participants were asked to rate the effectiveness of each visualization technique.

The results shown for these general usability questions are generally positive. The only question above that shows particularly negative results is S10: "I needed to learn a lot of things before I could get going with this system".

While users generally found the system to be effective, enjoyable, consistent, and well-executed, it is clear from the results of these two questions that the system is not intuitive to use when first presented.

The distribution composite scores computed from the System Usability Scale questions is shown in Figure 6.6.This score represents the overall usability of the system on a scale from 0 to 100. With a mean score of 74, it is clear that the system is generally usable, but there is still significant room for improvement.
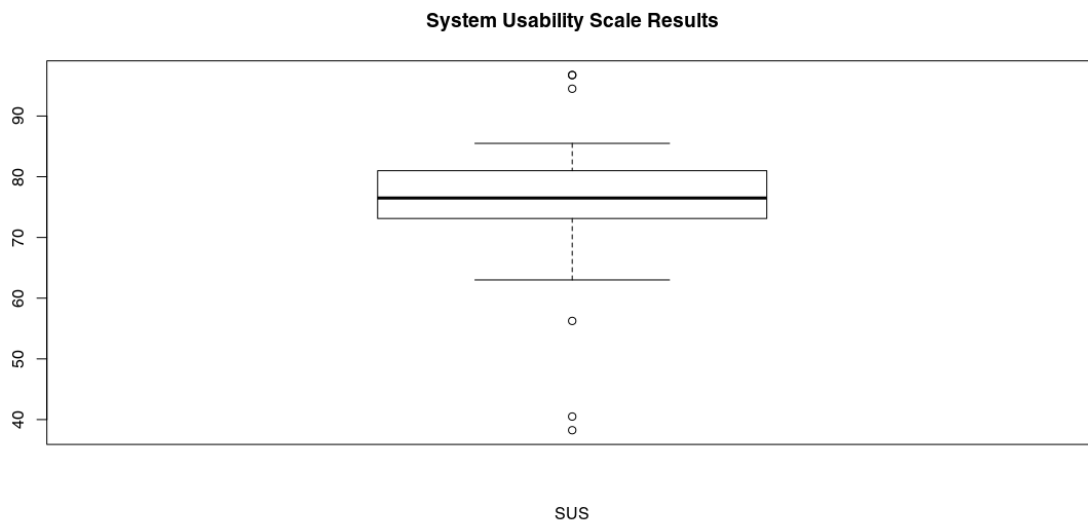
Figure 6.6: The distribution of composite scores for the System Usability Scale.

Chapter 7

Summary

7.1 Future Work

The evaluation of the TrafficVis web application has revealed a number of improvements which could be made in order to improve the usability and effectiveness of the application.

The following changes could be implemented in order to produce a more usable system:

- Provide a more visual indicator when in edit mode, such that users do not mistakenly try to interact with their widgets prior to saving the layout.

- Add rewind functionality to the time controls, to allow the user to have more fine control as they navigate through the data set.

- Provide a more intuitive interface for selecting a new date.

- Provide a series of default dashboard which can be selected instead of building a dashboard from scratch.

- Allow for dashboards to be saved and opened again at a later time.

In order to improve the effectiveness of TrafficVis as a visualization system, further visualizations which provide aggregations over the data, such as the low profile widget, should be implemented. The majority of the visualizations implemented only allow for the data to be viewed for a brief window of time, which removes much of the context from the each visualization. It's difficult to know if the data being viewed is being heavily affected by noise, or if there are long term trends in the data which cannot be observed.

7.2 Contributions

The aim of this project was to design and implement an information visualization system that would allow the user to explore traffic data gathered from the State Highway network of New Zealand.

The TrafficVis web application has been produced, providing a customizable widget-based dashbaord with a number of visualizations which can be added:

- A map widget, showing the locations and traffic volume of each TMS site on the State Highway network.

- A bar chart widget, displaying the traffic volume for each direction of traffic for each selected site.

- A line chart widget, allowing for daily trends in traffic volume to be observed and compared between sites.

- A predicted traffic widget, allowing the the observed traffic volume for a site to be compared to what was predicted by a machine learning model.

- A flow profile widget, showing the distribution of traffic for the average week day for selected sites.

The application offers time controls allowing the user to navigate through the dataset, and allows for sites to be aggregated into regions for less granular analysis of data.

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Appendix A

Ethics Application

ResearchMaster

Human Ethics Application

Application ID :	0000026264
Application Title :	TrafficVis: Visualizing data of the New Zealand State Highway Network
Date of Submission :	N/A
Primary Investigator :	Jonathan Carr; Principal Investigator
Other Personnel :	Dr Stuart Marshall; Head of School (or delegate)
	Dr Craig Anslow; Supervisor

44

Research Form

Application Type

1.

> **IMPORTANT: Please select type of research below and click on 'Save' to access the rest of the form.**

*

Research

Application Details

Category

B

3. Application ID

0000026264

5. Title of project
(Click the ? icon for more info)*

TrafficVis: Visualizing data of the New Zealand State Highway Network

6. School or research centre*

Engineering and Computer Science

7. Personnel*

1	Given Name	Jonathan
	Surname	Carr
	Full Name	Jonathan Carr
	AOU	
	Position	Principal Investigator
	Primary?	Yes

8. Are any of the researchers from outside Victoria?*

◯ Yes
⦿ No

9. Is the principal investigator a student?*

⦿ Yes
◯ No

Student Research

9a. What is your course code (e.g. ANTH 690)?*

ENGR 489

9b. Supervisor*

1	Given Name	Craig
	Surname	Anslow
	Full Name	Dr Craig Anslow
	AOU	Engineering and Computer Science
	Position	Supervisor

9c. What is your email address? (this is needed in case the committee needs to contact you about this application)*

carrjona@ecs.vuw.ac.nz

Project Details

10. The following question is meant to help applicants consider their research application and any protocols that should be uploaded and to help committee members review the application. Please check the box if if your research:

- ☐ Is an anonymous questionnaire
- ☑ Uses tertiary students as participants
- ☐ Is a health or disability research project
- ☐ Includes Māori participants, or otherwise has an impact on Māori
- ☐ Includes participants from another significant cultural group, or has an impact on that group
- ☐ Uses highly sensitive information (see Policy for definition)
- ☐ Collects or uses human tissue, including blood, saliva and genetic material
- ☐ Uses noninvasive physiological procedures (e.g., EEG, heart rate monitor)
- ☐ Uses equipment (e.g., TMS) that may temporarily alter mental function
- ☐ Administers substances (e.g., food, alcohol, placebo pill) to be ingested by participants

11. Does this application relate to any previous applications submitted to an ethics committee?*
- ◯ Yes
- ◉ No

12. Describe the aims and objectives of the project
Provide a brief summary in plain language of the purpose, research questions/hypothesis, and objectives of your project. *

The purpose of this research is to investigate how a web app can be produced that can intuitively visualise data from the New Zealand State Highway network, with a focus on the capability of identifying network resiliency issues. a resiliency issue is when the road network would be unable to perform under unexpected circumstances (such as an increase in traffic or a road closure).

This research involves the development of a web application, which is to be evaluated via participation in a trial app, followed by a questionnaire.

The two main research questions are:
- How can traffic volume data be visualized to identify and compare traffic behaviour and trends?
- How can data visualization techniques be used to identify network resiliency issues?

This research is being completed under external supervision of Beca Group Ltd. Beca Group Ltd will not have access to any of the data collected during user studies; they will receive only the Honours report and software produced.

An early prototype of the web application is accessible from homepages.ecs.vuw.ac.nz/~carrjona

13. Describe the benefits and scholarly value of the project
*Briefly place the project in perspective, explaining its significance and worthwhile outcomes. Include how this project will build on relevant literature, including references if appropriate.**

This research project will produce a web application that is capable of analysing large amounts of data from the New Zealand State Highway network. There is currently no application designed for this purpose, so the TrafficVis web application may be of significant value to data and traffic analysts looking to identify and understand New Zealand traffic trends.

In particular, the ability to investigate the effects of abnormal traffic behaviour in order to identify resiliency issues could help guide future spending on New Zealand infrastructure by identifying which areas of the network require further analysis or developement.

14. Explain any ethical issues your research raises for participants, yourself as the researcher, or wider communities and institutions, and how you will address these. This is an opportunity to present what you think the key risks are in your project and show how you have taken them into account.*

I do not think there are any significant ethical issues involved in the research itself, other than the ethical considerations for completing an observational study outlined in the remainder of this application.

Key Dates

If approved, this application will cover this research project from the date of approval

15. Proposed start date for data collection*

01/09/2018

16. Proposed end date for data collection*

30/09/2018

17. Proposed end date for research project*

17/11/2018

Proposed source of funding and other ethical considerations

18. Indicate any sources of funding, including self-funding (tick all that apply)

Internally: by a University grant, such as the University Research Fund
Externally: funding from an external organisation for this project, or a scholarship awarded by an external organisation
Self-funded: paying for research costs such as travel, postage etc. from your own funds

☐ Internally funded
☐ Externally funded
☐ Self-funded
This question is not answered.

19. Is any professional code of ethics to be followed?*****
○ Yes
◉ No

20. Do you require ethical approval from any other organisation, such as another tertiary institution in New Zealand or overseas, or a District Health Board?*****
○ Yes
◉ No

Data Collection and Recruitment

21. Please select all forms of data collection you will use in your project*****
☐ Interviews
☐ Focus groups
☑ Questionnaires
☑ Observation
☐ Other

22. Provide an explanation of the sampling rationale for your study.
E.g. representative sampling of a particular population, purposive sampling, convenience sampling. Include here your eligibility criteria for potential participants -- will there be particular criteria for participants to be included in your study, or criteria that will exclude them? *****

> Ideally, the study will involve participants that have experience as data analysts or traffic analysts. This is a limited population of possible participants so anyone that is willing to participate and meets this criteria is likely to be selected. This is an example of convenience sampling.
>
> If I am unable to complete user studies with participants with data analysis experience, studies will be completed using third-year and fourth-year tertiary students from the School of Engineering and Computer Science. Students that are willing to participate in the study are likely to be selected, unless the a mutually agreed time cannot be arranged, or if the student has prior experience using my web prototype.

23. How many participants will be involved in your research?
If there will be several different groups of participants, please specify how many groups and how many participants in each group. *****

> It is likely to be difficult to gain participants with the required background for this project; up to 5 participants will be involved.
>
> If students are used as study participants, greater numbers of participants will be possible. 10 - 15 students may be involved.

24. What are the characteristics of the people you will be recruiting?*****

> The study will involve participants that have experience as data analysts or traffic analysts. This is the target demographic of the TrafficVis Web Application so will provide the most value as user study participants.
>
> If students are to be used as study participants, as students from the School of Engineering and Computer Science they are likely to have some experience using data analysis tools.

25. Outline in detail the method(s) of recruitment you will use for participants in your study. *Include here how potential participants will be identified, who will contact them and how. Please include copies of all advertisements, online posts or recruitment emails in the 'Documents' section.* *****

> This project is being completed in part with an external supervisor, Chris Vallyon of Beca Group Ltd. Chris may be able to help me get in contact with data/traffic analysts so that I can explain the project and ask if any are interested in participating in a user study. At this point in time it is looking to be extremely unlikely that I will have the opportunity to recruit any experiences data/traffic analysts.
>
> If students are to be used as test participants, students will be recruited primarily via asking for participants at relevant research group meetings (i.e., the Human-Computer Interaction research group meetings).
>
> My recruitment speech (for both groups) will be similar to the following:
>
> "I am completing an Honours project which involves the development of a web application for analysing traffic data from the New Zealand State Highway network. The application provides a customizable dashboard which incorporates machine learning techniques, and a number of visualizations and tools that can be used to explore the data.
>
> I am looking for participants to take place in an observational study in which you will use the application to complete a number of tasks, and then complete a short survey on your experience. The both the screen and your voice will be recorded for the duration of the study.
>
> [If I am able to offer supermarket vouchers, I will state so here]
>
> This project is being completed under external supervision of Beca Group Ltd. However, Beca will not be involved in the user study or analysis of resulting data."

26. Explain the details of the method of data collection. For example, describe the location of your research procedures, if appropriate (e.g. where your interviews will take place). If necessary, upload a research protocol in the 'Documents' section.*****

> User Studies will take place in Cotton 241. The participants monitor will and voice will be recorded. The participant will complete a number of tasks using the web application prototype and then complete a questionnaire.

27. Will your research project take place overseas?*****

47

○ Yes
◉ No

28. Does the research involve any other situation which may put the researcher at risk of harm (e.g. gathering data in private homes)?*
○ Yes
◉ No

Participants and Informed Consent

29. Does your research target members of a vulnerable population?
This includes, but is not limited to, children under the age of 16, people with significant mental illness, people with serious intellectual disability, prisoners, employees and students of a researcher, and people whose health, employment, citizenship or housing status is compromised. Vulnerability is a broad category and encompasses people who may lack the ability to consent freely or may be particularly susceptible to harm.*
○ Yes
◉ No

30. Have you undertaken any consultation with the groups from which you will be recruiting, regarding your method of recruitment, data collection, or your project more widely?*
○ Yes
◉ No

31. Will your participants receive any gifts/koha in return for participating?*
○ Yes
◉ No

32. Will your participants receive any compensation for participation (for instance, meals, transport, or reimbursement of expenses)?*
◉ Yes
○ No

32a. Give details of the compensation participants will receive.*

Students will receive supermarket vouchers in return for their participation.

33. How will informed consent be obtained? (tick all that apply to the research you are describing in this application)*
☐ Informed consent will be implied through voluntary participation (anonymous research only)
☑ Informed consent will be obtained through a signed consent form
☐ Informed consent will be obtained by some other method

Treaty of Waitangi

How does your research conform to the University's Treaty of Waitangi Statute? (you can access the statute from Victoria's Treaty of Waitangi page)*

Victoria's Treaty of Waitangi Statute has been read and understood. This research project does not need to take into account the Principle of Government, Principle of Self-Management, the Rangatiratanga Principle, Principle of Reasonable Cooperation or the Principle of Equality.

4.1
No actors in this research are acting under the delegated authority of the council.

4.2
No actors in this research commit to Māori research excellence, building Māori staff capability, or the contribution of Matauranga Māori or Te Reo Māori and Tikanga Māori to the
culture of Victoria.

4.3
No actors in this research are acting under delegated authority of the council.

4.4
The protection of Taonga is not relevant to this research.

Minimisation of Harm

34. Is it possible that participants may experience any physical discomfort as a result of the research?*
○ Yes
◉ No

35. Is it possible that participants may experience any emotional or psychological discomfort as a result of the research? (E.g. asking participants to recall upsetting events, viewing disturbing imagery.)*
○ Yes
◉ No

36. Will your participants experience any deception as a result of the research?*

○ Yes
◉ No

37. Is any third party likely to experience any special hazard/risk including breach of privacy or release of commercially sensitive information? This may occur in the instance participants are asked to discuss identifiable third parties in the research.*

○ Yes
◉ No

38. Do you have any professional, personal, or financial relationship with prospective research participants? *

○ Yes
◉ No

39. What opportunity will participants have to review the information they provide? (tick all that apply)*

☐ Will be given a full transcript of their interview and given an opportunity to provide comments
☐ Will be given a full transcript of their interview and NOT given an opportunity to provide comments
☑ Will be given a summary of their interview
☐ Other opportunity
☐ Will not have an opportunity to review the information they provide

Confidentiality and Anonymity

40. Will participation in the research be anonymous?
'Anonymous' means that the identity of the research participant is not known to anyone involved in the research, including researchers themselves. It is not possible for the researchers to identify whether the person took part in the research, or to subsequently identify people who took part (e.g., by recognising them in different settings by their appearance, or being able to identify them retrospectively by their appearance, or because of the distinctiveness of the information they were asked to provide).

○ Yes
◉ No

41. Will participation in the research be confidential?
Confidential means that those involved in the research are able to identify the participants but will not reveal their identity to anyone outside the research team. Researchers will also take reasonable precautions to ensure that participants' identities cannot be linked to their responses in the future.

◉ Yes
○ No

41a. How will confidentiality be maintained in terms of access to the identifiable research data? (tick all that apply)*

☐ Access to the research will be restricted to the investigator
☑ Access to the research will be restricted to the investigator and their supervisor
☐ Focus groups will have confidentiality ground rules
☐ Transcribers will sign confidentiality forms
☐ Other

41b. How will confidentiality be maintained in terms of reporting of the data? (tick all that apply)*

☑ Pseudonyms will be used
☐ Data will be aggregated
☐ Participants will be referred to by role rather than by name
☐ Other

42. Will participation in the research be neither confidential nor anonymous, and participants will be identifiable in any outputs or publications relating to the research? *

○ Yes
◉ No

Access, storage, use, and disposal of data

43. Which of the following best describes the form in which data generated in your study will be stored during the study?
See help text for guidance on these terms. Further info available on human ethics website

○ Identifiable
○ Potentially identifiable
○ Partially de-identified
◉ De-identified
○ Anonymous
○ Other

44. Which of the following best describes the form in which data generated in your study will be stored after the study is completed?
*See help text for guidance on these terms. Further info available on human ethics website**

○ Identifiable
○ Potentially identifiable
○ Partially de-identified
◉ De-identified
○ Anonymous
○ Other

45a. Proposed date for destruction of identifiable research data (i.e. the date when data will be de-identified and personal information on participants destroyed)

*
| 31/08/2018 |

45b. Proposed date for destruction of de-identified research data, including anonymous data

*
| 17/11/2018 |

46. Will any research data will be kept for longer than 5 years after the conclusion of the research?*

○ Yes
◉ No

47. Who will have access to identifiable, de-identified or anonymous data, both during and at the conclusion of the research?*

○ Access restricted to the researcher only (whoever is named as PI)
◉ Access restricted to researcher and their supervisor
○ Access restricted to researcher and immediate research team, e.g. co-investigators, assistants
○ Other

48. Are there any plans to re-use either identifiable, de-identified or anonymous data?*

○ Yes
◉ No

49. What procedures will be in place for the storage of, access to and disposal of data, both during and at the conclusion of the research? (Check all that apply)
*Information regarding appropriate data storage is available on the human ethics website. Note that storing research data on USB drives is strongly discouraged for security reasons. **

☑ All hard copy material will be stored securely e.g. in a locked filing cabinet
☑ All electronic material will be held securely, e.g. only on University servers, password protected
☑ All hard copy material will be appropriately destroyed (e.g. shredded) on the dates given above
☑ All electronic data will be deleted on the dates given (ITS should be consulted on proper method)

Dissemination

50. How will you provide feedback to participants?*

| The user studies will be conducted in person so immediate feedback will be possible when necessary.
Participants will have the option of receiving a transcript of their user study.
Participants will have the option of receiving a summary of their user study.
Participants will have the option of receiving a copy of the Honours report when it is completed. |

51. How will results be reported and published? Indicate which of the following are appropriate. The proposed form of publications should be indicated to participants on the information sheet and/or consent form*

☐ Publication in academic or professional journals
☐ Dissemination at academic or professional conferences
☐ Availability of the research paper or thesis in the University Library and Institutional Repository
☑ Other

51a. Describe how the results will be disseminated*

| Results will not be published in any journals or available via the University Library. |

52. Is it likely that this research will generate commercialisable intellectual property?
*(Click the ? icon for more info)**

○ Yes
◉ No

50

Documents

53. Please upload any documents relating to this application. Sample documents are available on the Human Ethics web page.

Please ensure that your files are small enough to upload easily, and in formats which reviewers can easily download and review. To replace a document, click the tick in the column to the right of the document title. A green arrow will appear - click this arrow to upload a new document. To add a new document click on 'Add New Document', at top right of the documents window. Then enter the document name in the box that appears and click the green tick. A green arrow will appear to the right of the file name which allows you to upload the new file.

Please also collate all your documents into one PDF or Word file, and upload as a new document. This should be labelled as 'Combined Documents'.*

Description	Reference	Soft copy	Hard copy
Participant information sheet(s)	information-sheet.pdf	✓	
Participant consent form(s)	consent-form.pdf	✓	
Combined Documents	consent-form.pdf	✓	

Amendment or extension request (available only for approved applications)

43. Are you applying for an extension, an amendment, or both?*

○ Extension
● Amendment
○ Both an extension and an amendment

43a. What changes would you like to make for this application?*

This question is not answered.

43b. Please enter the date you are submitting this request*

This question is not answered.

Please check that you have answered all mandatory questions and have saved the application before submitting your form. Any new or amended documents (e.g. Participant Information Sheet) to be added to your application should be emailed to ethicsadmin@vuw.ac.nz before submission. To submit your form, click on the Action tab and then click on Submit for review

44. Do you have a second amendment/extension request to make?

○ Yes
○ No
This question is not answered.

45. Do you have a third amendment/extension request to make?

○ Yes
○ No
This question is not answered.

46. Do you have a fourth amendment/extension request to make?

○ Yes
○ No
This question is not answered.

Incident Reporting

Research teams must immediately advise the Human Ethics Committee if an adverse incident occurs in the course of their research project.

Adverse incidents are instances of potential or actual physical harm to participants or researchers; emotional harm or distress to participants or researchers; and any other unforeseen events that raise ethical issues.

A full incident report must be completed and emailed to ethicsadmin@vuw.ac.nz. You can download this form here (link to be added). After you have emailed the form, please complete the questions below, then click on the **Action** tab and click **Report Incident**

Do you have an incident to report?

☐ Yes
This question is not answered.

52

Please go to the **Action** tab and click on **Report Incident** to complete the process.

52

Appendix B

User Study Forms

TrafficVis Evaluation

Hi!

The purpose of this study to evaluate the TrafficVis prototype. TrafficVis is a web application for the visualisation and analysis of road traffic data gathered from the New Zealand State Highway network.

TrafficVis is being developed as an Honours project by myself, Jonathan Carr, at Victoria University of Wellington. This project is being completed under supervision of Dr. Craig Anslow of Victoria University, and Chris Vallyon of Beca Group Ltd.

If you agree to take part in this study, you will complete the following for sections of this study:

1. Consent Form
2. Pre-Study Questionnaire (~2 minutes)
3. 5 Tasks to Attempt (~15 minutes)
4. Post-Study Questionnaire (~5 minutes)

But first, we have some formalities to cover:

This research has been approved by the Victoria University of Wellington Human Ethics Committee, Application Number: 0000026264.

This research is confidential. This means that the researchers named above will be aware of your identity but the research data will be combined and your identity will not be revealed in any reports, presentations, or public documentation.

The information produced by this study will be used in my Honours report, and will contribute to the development of the TrafficVis web application.

You do not have to accept this invitation if you don't want to. If you do decide to participate, you have the right to:
• choose not to answer any question;
• withdraw from the study before 30 September, 2018;
• receive a copy of your study transcript;
• receive a copy of the completed Honours report.

If you have any questions, either now or in the future, please feel free to contact either Jonathan Carr at Jonathan.Carr@ecs.vuw.ac.nz, or Dr. Craig Anslow at Craig.Anslow@vuw.ac.nz.

If you have any concerns about the ethical conduct of the research you may contact the Victoria University HEC Convenor: Dr Judith Loveridge. Email hec@vuw.ac.nz or telephone +64-4-463 6028.

You can access the TrafficVis prototype at the following link. Please use Google Chrome if possible.

http://barretts.ecs.vuw.ac.nz:56656

You can find a brief tutorial on the application here:

http://homepages.ecs.vuw.ac.nz/~carrjona/tutorial

Thanks for your participation if you choose to continue!

*Required

Consent Form

I understand that:

• I may withdraw from this study at any point before 10 September, 2018, and any information that I have provided will be returned to me or destroyed.

- The identifiable information I have provided will be destroyed on 30 September, 2018.

- Any information I provide will be kept confidential to the researcher and the supervisor.

- I understand that the results will be used for an Honours Report

- My name will not be used in reports, nor will any information that would identify me.

1. **Consent to Study** *
   Tick all that apply.

   ☐ I agree to the above terms.

2. **Further Communication**
   Tick all that apply.

   ☐ I would like to receive a copy of my survey responses and have added my email address below.

   ☐ I would like to receive a copy of the final report and have added my email address below.

3. **Email Address: (Optional)**

   _____

Pre-Study Questionnaire

Please complete this short questionnaire prior to moving on to attempt the tasks.

4. **Which of the following groups best describes you?**
   Mark only one oval.

   ◯ Student

   ◯ Academic

   ◯ Data or Traffic Analyst

   ◯ Other/I'd rather not say

5. **Do you have much experience using Data Analysis tools or platforms? (i.e., Power BI, Tableau, Excel, etc.)**
   Mark only one oval.

	1	2	3	4	5	
None	◯	◯	◯	◯	◯	I am very experienced

Tasks

Please complete the following tasks.

Task 1 - Viewing a Weekday Flow Profile

Use the Flow Profile widget to view the weekday flow profile of a single site from somewhere along the Kapiti Coast.
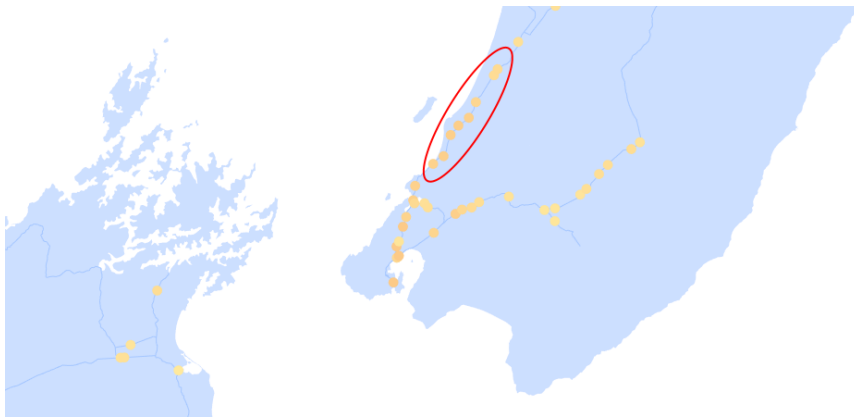
6. **Which hour of the day shows the highest traffic volume for your site?**

_____

7. **I found this task difficult to complete.**
   Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

Task 2 - Comparing Regions with the Bar Chart Widget

Add the Northland and Taranaki regions to the Bar Chart widget.

Use the time controls to 'play' the data for the day of 1st February, 2017.

8. **Which region generally showed a higher traffic volume?**
   Mark only one oval.

   ◯ Northland

   ◯ Taranaki

   ◯ No significant difference

9. **How difficult did you find this task?**
   Mark only one oval.

	1	2	3	4	5	
I found this task easy.	◯	◯	◯	◯	◯	I was unable to complete this task.

Task 3 - Comparing Sites with the Line Chart Widget

Use the time controls to navigate to the 1st March, 2017.

Add a site from North of Auckland and a site from South of Auckland (as shown in the image below) to the Line Chart widget.

Use the time controls to 'play' the data through at least 24 hours.
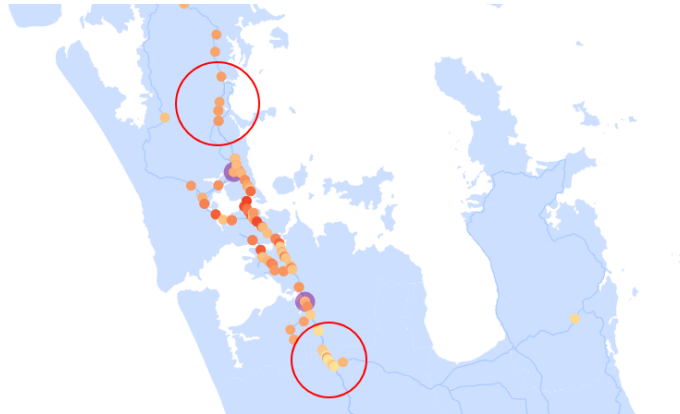
10. **Which site generally showed a higher traffic volume?**
    Mark only one oval.

    ◯ Site from north of Auckland

    ◯ Site from south of Auckland

    ◯ No significant difference

11. **How difficult did you find this task?**
    Mark only one oval.

	1	2	3	4	5	
I found this task easy.	◯	◯	◯	◯	◯	I was unable to complete this task.

Task 4 - Using the Predicted Traffic widget

13th March, 2017 was Taranaki Anniversary Day.

Add the Taranaki region to the Predicted Traffic widget, and view how the actual traffic volume varied from what was predicted on Taranaki Anniversary Day.

12. **Which of the following statements best describes the impact of Taranaki Anniversary Day on traffic volume?**
Mark only one oval.

○ There was no significant impact on traffic volume.

○ There was less traffic than usual throughout the entire day.

○ There was more traffic than usual throughout the entire day.

○ There was less traffic than usual in the morning, but more in the afternoon.

○ There was more traffic than usual in the morning, but less in the afternoon.

13. **How difficult did you find this task?**
Mark only one oval.

	1	2	3	4	5	
I found this task easy.	○	○	○	○	○	I was unable to complete this task.

Task 5 - Defining new regions

There's currently no region defined for Wellington.

Use the "Add New Region" tool in the Regions drawer to select and save a region for Wellington.

On 4th March, 2017 Wellington hosted the Homegrown Music Festival. Use your new Wellington region and the Predicted Traffic widget to view the impact Homegrown had on traffic volume in the region.

14. **How did Homegrown 2017 impact traffic in the Wellington region?**
Mark only one oval.

○ There was no significant impact on traffic volume.

○ There was less traffic than usual.

○ There was more traffic than usual.

15. **How difficult did you find this task?**
Mark only one oval.

	1	2	3	4	5	
I found this task easy.	○	○	○	○	○	I was unable to complete this task.

Post-Study Questionnaire

Thanks for completing the tasks! Please fill out this brief questionnaire on your experience using TrafficVis.

You are welcome to further explore the TrafficVis prototype before answering these questions if you'd like.

If you wish to expand more on any of your ratings, there is room for extra comments at the bottom of this page.

Evaluation of Dashboard

16. **1. Did you find it difficult to create your own dashboards by adding and manipulating widgets?**
Mark only one oval.

	1	2	3	4	5	
I didn't find it difficult at all	◯	◯	◯	◯	◯	I found it very difficult

17. **2. Do you think the ability to create your own dashboards is more effective than it would be to have a series of predefined dashboards for purposes? Why?**

_____

_____

_____

_____

_____

18. **3. Did you find it difficult to navigate through the dataset using the time controls?**
Mark only one oval.

	1	2	3	4	5	
I didn't find it difficult at all	◯	◯	◯	◯	◯	I found it very difficult

19. **4. Did you find it difficult to create your own region with the region selection tools provided?**
Mark only one oval.

	1	2	3	4	5	
I didn't find it difficult at all	◯	◯	◯	◯	◯	I found it very difficult

Evaluation of Widgets

20. **5. Please rate the effectiveness of the Map widget at conveying traffic volume data**
Mark only one oval.

	1	2	3	4	5	
Not very effective	◯	◯	◯	◯	◯	Very effective

21. **6. Please rate the effectiveness of the Flow Profile widget at conveying traffic volume data**
Mark only one oval.

	1	2	3	4	5	
Not very effective	◯	◯	◯	◯	◯	Very effective

22. **7. Please rate the effectiveness of the Bar Chart widget at conveying traffic volume data**
Mark only one oval.

	1	2	3	4	5	
Not very effective	◯	◯	◯	◯	◯	Very effective

23. **8. Please rate the effectiveness of the Line Chart widget at conveying traffic volume data**
Mark only one oval.

	1	2	3	4	5	
Not very effective	◯	◯	◯	◯	◯	Very effective

24. **9. Please rate the effectiveness of the Predicted Traffic widget at conveying traffic volume data**
Mark only one oval.

	1	2	3	4	5	
Not very effective	◯	◯	◯	◯	◯	Very effective

25. **10. If you'd like to expand on any of your widget ratings, please do so here. Any criticism, suggestions or other feedback are appreciated.**

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General Usability Questions

Please state how strongly you agree or disagree with the following statements.

26. **11. I think I that I would like to use this system frequently**
Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

27. **12. I found this system unnecessarily complex**
Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

28. **13. I thought this system was easy to use**
Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

29. **14. I think that I would need the support of a technical person to be able to use this system**
Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

30. **15. I found the various functions in this system were well integrated**
Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

31. **16. I thought there was too much inconsistency in this system**
Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

32. **17. I would imagine that most people would learn to use this system very quickly**
Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

33. **18. I found the system very cumbersome to use**
Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

34. **19. I felt very confident using the system**
Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

61

35. **20. I needed to learn a lot of things before I could get going with this system**
Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

Other Feedback

36. **21. Do you have any additional comments or feedback about TrafficVis?**

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