

VICTORIA UNIVERSITY OF WELLINGTON
Te Whare Wānanga o te Ūpoko o te Ika a Māui



School of Engineering and Computer Science
Te Kura Mātai Pūkaha, Pūrorohiko

PO Box 600
Wellington
New Zealand

Tel: +64 4 463 5341
Fax: +64 4 463 5045
Internet: office@ecs.vuw.ac.nz

**Understanding Environmental
Benefits of Bus Mobility Through
Visualisation**

Chris Todd

Supervisors: Craig Anlsow, Chris Vallyon

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

Abstract

Climate change is a pressing issue in the world, and around the world people are attempting to lower their carbon emissions to reduce the impact of carbon in our atmosphere. The greatest contributors to emissions are transport of all kinds, and in Wellington 35% of all emissions created in the city are due to road transport. This means that organisations that provide transport services, such as the Greater Wellington Regional Council have a desire to investigate their emissions due to operating public transport. Analysts at Greater Wellington current analyse their Public Transport data through spreadsheeting, and their analysis is used by decision makers and policy implementers to action change related to PT. This process is slow, and one of the ways that this can be improved is through visualisation. This report introduces BEVis, a visualisation system for PT analysts to gain insights into PT related emissions, and in doing so, facilitates improved analysis for PT operations considering carbon emissions.

Acknowledgements

I would like to acknowledge the support of my academic supervisor, Dr. Craig Anslow, for his insight and advice throughout the project. His dedication to meetings and discussions in a changing environment contributed significantly to the successful completion of this project. I would also like to acknowledge the work and support of Chris Vallyon of the Greater Wellington Regional Council for his guidance and provision of personnel. Their knowledge has been invaluable to my learning and the projects completion.

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Chapter 1

Introduction

Transportation and its many characteristics have been the subject of many visualisation exercises in the past. With richer data becoming available, there is potential to contribute to current techniques to get a more comprehensive understanding of transport [1]. One way is reducing carbon emissions related to transport. By taking knowledge of the Wellington public bus transport network gained through previous projects with Beca and Greater Wellington Regional Council (GWRC), a tool has been designed and implemented to inform reducing carbon emissions of the bus network by replacing old vehicles with electrics. This report investigates facilitating decision making to reduce carbon emissions by visualising transport data.

In order to meet an ambitious carbon reduction goal [2], GWRC has previously developed a dataset of trips and their emissions for public transport bus operations composed of several smaller datasets. The dataset developed previously uses information from providers, schedules and other sources to form details about individual trips, and can be used to calculate the emissions of historic public transport operations. Using this, GWRC would like to gain an understanding of how their bus operations contribute to emissions overall, and how they offset the emissions of the network. By developing tools to gain insight from this dataset, GWRC hopes to understand the current emissions trend, the factors that affect it and how they can go about reducing them.

This report outlines a potential solution for gaining insights from this dataset and others through visualisation. A web application was designed and implemented using a user centered design approach [3] to help inform decision makers about reducing carbon emissions related to public transport. The web app uses a MongoDB database [4] back-end and a JavaScript front-end with D3 [5] to create visualisations, and is evaluated with qualitative and quantitative surveys. The tool created for this project, called BEVis, is currently hosted on Heroku here: <https://warm-temple-67996.herokuapp.com/>.

1.1 The Problem

With climate change and carbon reduction strategies being introduced by government bodies around the world, there is a need for new analysis to help meet carbon reduction goals [2]. For any reasonably sized city, a major contributor to carbon emissions is the public transport operations. According to a report prepared for the Wellington City Council [6], around 35% of Wellington City's emissions from 2018-2019 was from road transport. With transport such a high contributor, government organisations and companies that run transport services such as GWRC want to develop techniques for improved emissions analysis, to facilitate planning carbon reduction going forward.

Currently to calculate emissions of bus trips, an analyst would have to find relevant CSV's, open them in Excel or some other spreadsheeting software, and begin manually writing formula and functions to find the buses that operated trips on that route, the class of vehicle, the weight, the patronage to add to the weight, and the average speed. In a single month, depending on which route, there could be a few thousand trips, so this process would need to be repeated several times. This project looks to meet those needs of public transport analysts who are looking to expand their analysis of their networks to include emissions considerations, such as GWRC.

Initially, the project proposed investigating emissions, the characteristics of the model that affect them, as well as specifically increasing average speed. The scope of the project has been changed in order to create a more specialist prototype. By removing the investigation of speed, which will best be addressed with a completely new visualisation and dataset, the existing dataset that has been developed can better be tested. Data procurement and cleaning/preprocessing would also have been required as with all new data sets.

The goals for this project, called the Bus Emissions Visualiser, centre on user specific tasks for visualising the public bus transport network data. Visualisations have been planned to assist Public Transport (PT) analysts with tasks related to public transport bus operations and the emissions they create, with the ultimate goal to inform decisions about replacing diesel buses with electrics. Service providers and managers already audit the operations of the public transport network, including utilisation and performance [7], in order to improve their services for the public. As electric vehicles are introduced to the network, these analysts are looking to expand the quality metrics to include environmental factors, in order to get the most value out of replacing existing buses on the network. This is of particular interest to GWRC as it's limited budget means that decisions must be made concerning where to place new electric vehicles as the Wellington fleet of public transport buses slowly progresses to an all electric fleet [8].

1.2 Research Questions

There are two research questions that are being addressed with the design and evaluation of this tool:

RQ1 Can an effective visualisation system be created to gain insights about emissions related to public transport, and be used to inform decision makers?

RQ2 How usable is a tool like this for visualisation and insights gathering?

1.3 Contributions

This section discusses main contributions to transport planning software solutions, which are:

- Describing a tool called BEVis to visualise emissions data from transport networks to gain insights into datasets for further analysis, and building a tool that demonstrates the design.
- Evaluating the implementation of the research tool described in the project.

Chapter 2

Background

This chapter covers the research that was carried out before implementation, and subsequently provided information on how to go about solving this issue.

2.1 Climate Change

Climate change is increased adverse weather caused by global warming [9]. Climate change is already adversely hampering efforts to manage New Zealand's transport networks. The (already observable) increasing frequency and severity of storms, increased coastal erosion, and the increasing frequency and severity of slips and landslides is costing a small fortune in preparing and mitigating transport resilience issues [10]. As such, climate change is a pressing concern for road controlling authorities and the operators of public transport networks.

Carbon and its relation to climate change has been discussed for over 80 years [11]. As more people come to realise the effects that carbon production is having on our climate, there is more interest in finding ways to reduce carbon. As discussed in a report produced for the Wellington City Council [6], the greatest contributor to carbon emissions in Wellington city is transport, at 53%. Of this, 67% is road transport, or 35% of all of Wellington city's carbon production.

2.2 Information Visualisation

Information Visualisation is the process of taking data and transforming it into a visual representation to aid in the rapid digestion of information [12, 13]. Visualisation techniques make use of colours, shapes, sizes, space and other 'visual variables' to convey information about data [14]. Tools for visualisation support Schneidermans information seeking mantra; Overview first, filter and zoom, then details on demand [13]. The intent is for the data to be easily understood by users of both novice and professional domains. Using visual variables and Schniedermans tasks aids in understanding the data and increases the value of the data.

There are several different types of visualisations, all with different advantages and disadvantages. Example visualisations and datasets that are well suited to them are outlined in Heer et al's publication A Tour Through the Visualisation Zoo [15]. Heer et al describe some of the trade offs that occur with visualisation creation, noting often that the short comings of certain visualisations are compensated for through the use of visualisation techniques, such as some of the tasks Schneiderman describes [13].

An interesting issue common for all visualisations is how to effectively communicate more information than would normally be seen. One solution to increase the dimensions



Figure 2.1: The GapMinder Bubble Chart showing life expectancy on the y vs income on the x. Each axis and the radius can be associated with different fields of interest in the dataset. The axis are controlled by the labels, the colour and radius can be set through the menu on the right.

that can be visualised is the GapMinder Bubble Chart, developed by Hans Rosling [16]. This is a chart that draws bubbles on an x and y axis, giving two distinct directional visual variables to represent dimensions in the data, and allows users to choose what characteristic or dimension of the data is associated with which axis. To facilitate 3 dimension characteristic visualisation, the size of the circles can also be changed. Further, the data presented in the GapMinder Bubble Chart is time series data, and an important function to aid users' understanding of trends in data over time is the ability to step through each data point. This allows users to visualise trends in the data presented in a novel way. An example of the GapMinder Bubble Chart is shown in Figure 2.1.

The GapMinder Bubble Chart makes use of several concepts of visual variables and the visualisation tasks. It uses shape, direction, colour and size. It allows users to interact with the data and drill deeper into it after giving an overview by filtering and selection. The concept of changing the characteristics or dimensions associated with the axis and size of circles is an effective idea allowing users greater freedoms to gain insights [17]. The GapMinder Bubble chart has already been proven effective in education and insights discovery [17], so serves as an excellent example.

There are modern tools available for creating visualisations. Two examples are Tableau [18] and D3 [5]. Tableau is a general visualisation tool with an integrated UI that provides functions to create many different types of visualisations from a dataset the user provides. Tableau is designed for people with visualisation experience that have knowledge of their data and how it should be visualised. Due to the wide range of visualisations the tool provides for a single dataset, the visualisations created have less advanced interactive features.

D3 is a library that helps users to create advanced visualisations using JavaScript [5]. The library provides various utilities and functions to interact with the DOM and CSS on a webpage, as well as other functions necessary to implement interactive visualisations. The visualisations are drawn using underlying datasets, and using JavaScript provides flexibility that other visualisation tools such as Tableau lack.

2.3 Emissions Visualisation

New visualisation techniques are being investigated for emissions visualisation in different domains. Hetherington et al [19] look at buildings and their emissions and has guidelines for creating software visualisations for use to reduce carbon emissions in both construction

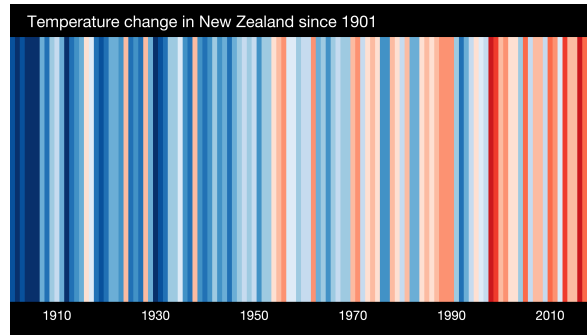


Figure 2.2: A warming stripe of New Zealand Temperatures from 1901-2019. The scale varies from blue (-2.6 std dev from mean) to red (2.6 std dev from mean). The change from mostly blue to mostly red shows an increase of temperature.

and operation. Hetherington et al specifies the need for high quality software, and that the system must be suitable for management, regulatory bodies, communities and users to be useful. This is applicable for the Bus Emissions Visualiser as the users may have to present their findings in some way for the insights to be valuable.

There are many types of emissions visualisations developed making use of visual variables to aid perception of information [20, 21, 22]. One example of these visualisations are the warming stripes from the Climate Lab [20]. These are stripes that are made to convey the change in average temperature, from 1850 - 2017. Each stripe shows the average temperature of a year. The colour scale varies from +/-2.6 standard deviations from the annual averages. It has a very focused goal of visualising just the temperature change of an area. A warming stripe for NZ between 1901-2019 is shown in Figure 2.2.

Although it doesn't implement tools to assist with Schneidermans tasks [13], it does allow overviews with the entire data set. Functions such as filtering would be beneficial as the data could then be used to create custom sets of visualisations, allowing users to make comparisons etc. The set of stripes are more of an infographic, than visualisation because of the lacking interactivity.

Similar to the Warming Stripes, Johansson et al. use colour and geospatial visualisation techniques [14] to communicate change in climate values [21]. They also make use of size, by extruding countries on the world with higher emissions values, to aid users perception and quantitative comparison. Colour seems to be a common indicator for high level overview [20, 21], so was considered for the design of the visualisations in this tool.

2.4 Transport Visualisations

Visualisation of transport is a rich area of data visualisation. Various visualisations have been developed for the transport networks [23], including Wellington transport network itself [24, 25]. One of the first transport related visualisations, a map of the London Underground in 1937, proved the effectiveness of utilising visual variables and peoples innate ability to recognise patterns and think in certain ways, however its value was not recognised at the time [23]. The more recent, Wellington based projects investigate the flow and speed of traffic from previous years collection data [25], and visualise the delay/predictability of buses [24]. Transport visualisation is always changing, with growing needs for improved visualisation techniques, as discussed in "Visualisation in Transport: Challenges and Opportunities" [1]. Some work has also gone in to standardising the creation of visualisations by using international PT data standards, such as the GTFS data standard [26, 27].

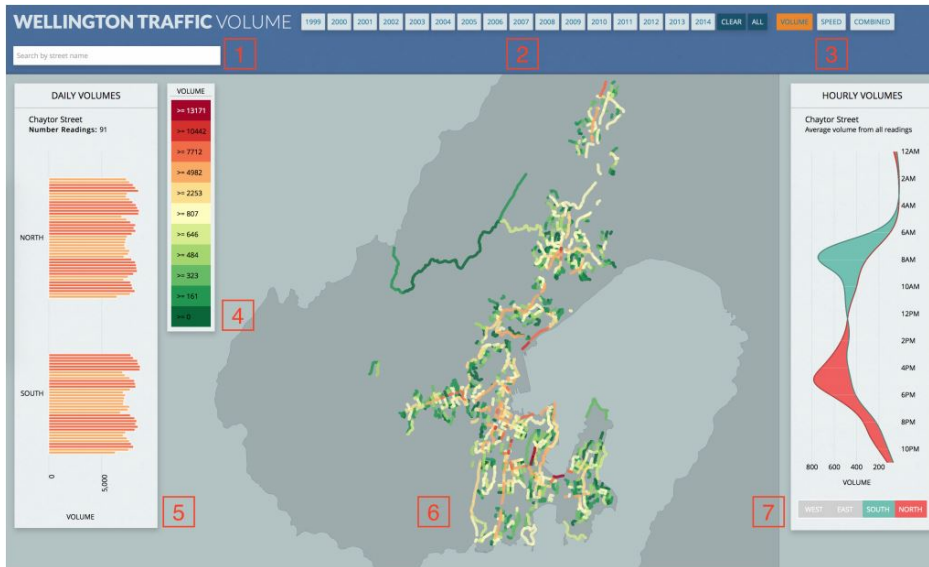


Figure 2.3: The Traffic Flow Analysis tool from [25]. Volumes (amount of vehicles) are shown at different granularities on the left and right visualisations, and the main in the center. 1. Search bar. 2. Year selector. 3. Visualisation selector 4. Legend for main visualisation. 5. Daily volumes of selected street. 6. Map of Wellington roads coloured according to volumes 7. Hourly Volumes of selected street.

The visualisation for flow of traffic [25] uses observations of speed and flow from traffic cameras on the transport network to communicate the utilisation of the road at one time. It uses two different visualisations for flow and capacity, with extra visualisations showing contextual information overlaid. It makes effective use of the information seeking mantra [13] and the visual variables [14], taking advantage of peoples innate understanding of colour scales, size and position, however addresses a different domain of data. The project being developed here largely ignores traffic flow, and requires a different measure of speed to the model in [25], as buses stop and start more often than normal traffic flow.

The delay and predictability of buses visualisation [24] uses real time data to measure the delay of buses on routes. By tracking delay, bus patrons can better predict when to arrive at a bus stop in real time, accounting for things such as traffic or delays earlier in the day. The bus predictability model is still unfortunately not suitable for the speed in this model, nor contains information about the class and patronage of buses. Neither of these solutions consider the emissions as an aspect of the transport network they are modelling.

Another similar project to mine being undertaken by GWRC looks to model the emissions passengers are exposed to as the enter and exit buses [28]. For the data, they use a typical monitoring station at the bus stop. The station collects data on the air quality at various points through the day.

The Bus Emissions Visualiser solution is not likely to achieve such a high level of precision as being able to visualise emissions in an area, however the scope of the system in the two projects is very different. In Mitchells work [28], they aim to quantify air quality at limited traffic hotspots in the center city. Due to the complexities of measuring air quality, this is only possible in a few places around the city. Because this solution looks to quantify the emissions of the entire network, getting such a level of detail with this solution is significantly harder, and requires more data than is currently available. Another large difference is the way in which the projects build their model. The Bus Emissions Visualiser requires a far larger dataset as it is modelling the entire network not just a few stops, and is aiming

to be a data visualisation tool, where as [28] is aiming to create the underlying relationship between buses and emissions, and is focused on reporting.

There are opportunities for new analysis with new data available from the transport industry. As discussed in Pack's article [1], the transport industry has always encouraged high value data collection, but have made little effort to design appropriate visual analytics tools to explore the data, extract knowledge, and represent meaningful results. Referring to the USA, and focused on road congestion, this article still illustrates the need to create visualisations of road networks. It also suggests that the USA is lagging behind other world leaders in terms of road analytics. The Bus Emissions Visualiser tool will help further development in this area in the New Zealand context.

The GTFS-Vis solution as presented by Kunama et al. [27] is a good solution that uses information visualisation techniques to visualise GTFS data. GTFS data is a standard that unifies transportation data in a single standard for the public, transport operators and analysts [26]. This is a solution that presents the data in a geospatial visualisation, and implements simple visualisations such as bar charts from the GTFS data. This is not effective for this project, as the data used is not in GTFS standard, however partially comes from GTFS data. This project also is investigating more advanced visualisations for non-geospatial data, so can take from the system design, and considerations from their evaluation of their tool but not the visualisations.

2.5 Transport Emissions Visualisation

Similar visualisations of emissions and public transport are emerging recently, some include visualisations of emissions on roads in the USA [29], or buses utilisations/ridership in Europe [30]. These visualisations use open source data. Those that investigate pollution all use air quality as a measure, which is different to this solution.

There are few examples of public transport and emissions studies, such as the study that investigates the pollutants a commuter would come into contact with depending on their choice of transport [30]. The study looks at the air quality around subways, buses and trams in Barcelona, and provides some insight to the pollutants different commuting options expose a rider to. An interesting aspect for this study is the different modes used in the test, and how different vehicles have very different pollutant profiles.

While a graphical representation of the relative pollution on the streets were part of the study, the Barcelona commuter visualisation [30] does not have any visualisation techniques discussed. More effort has been put in to produce tabular data instead, which is appropriate for a single street, and a single bus/tram/subway trip. Conversely, the emissions visualisation for this problem will look at emissions from a single mode of transport, with a more detailed model of that mode.

A report by The New York Times created a spatial visualisation of emissions in the form of a map for metro areas (high traffic, central city areas) in the USA [29]. This map highlights sections of the road a particular colour depending on the emissions associated with the road. This report investigates the relationship between the highest growing total CO₂ output of America (the NYC Metro Area) with the output of CO₂ per capita. This is shown in Figure 2.4.

The New York Times Map is a visualisation that makes good use of the Schneidermans tasks [13], and makes use of complementing visualisations well. The map is interactive, and by narrowing the time range, greater details on demand and simpler interactions are able to be used. This means that the users learn more about their data and the discover their own relationships within the data as well.

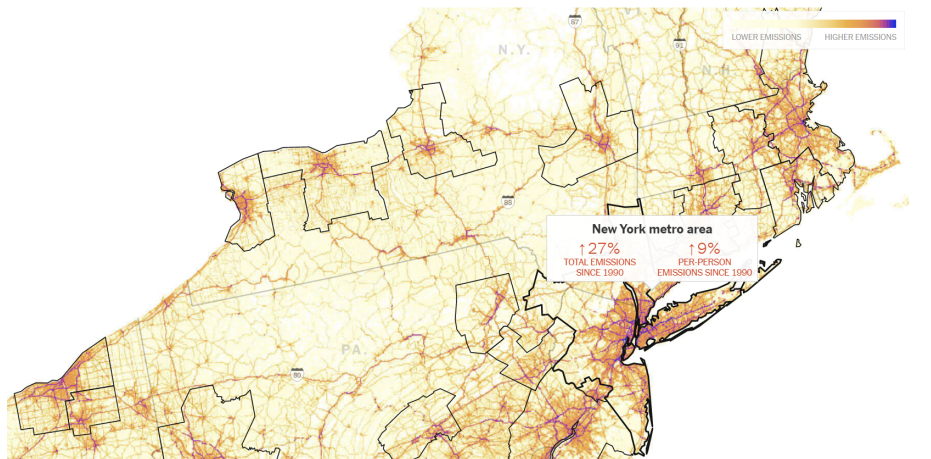


Figure 2.4: This is a geo-spatial visualisation that shows the emissions in different metro areas of cities in America. The legend is in the top right. This map shows the emissions of the areas on the maps through the colours. Highlighted in black is the New York metro area, with a tooltip for extra information about the emissions of the area. The closer to the centre of the New York metro, the darker the colour. Roads and highways can also be seen in purple/red.

2.6 Summary of Previous Work and BEVis

Hetherington et al. and Pack have suggested there is an advantage to domain specific software tools within industries that make use of rich datasets available [1, 19], which provides motivation to investigate different techniques to gain insight from various datasets. Using visualisation techniques [12, 13, 14] to explore data, several visualisations focused on emissions [19, 20], transport [24, 25, 28], and transport emissions [29, 30] have been created. Using these techniques, and tools designed for building visualisations [5], the Bus Emissions Visualiser will create visualisations for public transport analysts to visualise emissions related to their public bus transport operations.

The Bus Emissions Visualisation project is unique in that it visualises the emissions for just a bus fleet in a city. Other visualisations on emissions focus on larger systems, such as road networks or countries that instead have cars and buses as a component of the emissions [28, 30]. Other solutions also often represent this data in a geo-spatial (map) visualisation [24, 25, 29]. This tool will enable users to get finer details on bus operations specifically, and will focus more heavily on time series data visualisations such as timelines and line charts.

Due to the complex functions trying to be implemented, such as dataset manipulation via changing bus class, D3 is a better suited option for this task over Tableau. The intended users also may not have much visualisation experience, so a tool like D3 that allows creating specialised visualisations is a better choice. This way, the visualisations can be designed separate to the user specifically for the dataset they would be using and so they are not required to have knowledge of visualisation techniques.

While good starting points with interesting ideas these projects are still not well suited to this problem. There is no tool for New Zealand contexts, so a tool for the Wellington context would provide a starting point. Though described in high level overviews [1, 19], there are also few implemented and tested domain specific tools for emissions visualisations. This project is aims to address designing and implementing a domain specific tool that uses visualisation of public transport emissions data for PT analysts.

Chapter 3

BEVis

This chapter covers the design and implementation of the BEVis tool, a solution to visualise public transport network data. The final implementation of the UI and BEVis is shown in Figure 3.1. This chapter includes the data preparation and storage, the hosting solution chosen, the widgets such as filters and controls, and the visualisations. In the final subsection of this chapter, there is a case study showing how an analyst may use BEVis for data visualisation and supplement current techniques for insights gathering. The tool is currently hosted on Heroku here: <https://warm-temple-67996.herokuapp.com/>.

The most important features in this tool to GWRC and other users are the visualisation features, where users can delve into the data and get an understanding of the underlying relationships between emissions and details of trips (eg bus class on trip, patronage, speed) with a visual representation of their data. The design of the tool can be broken into 3 sections; the requirement gathering, the visualisation design, and the UI design, with an extra consideration for accessibility due to COVID. This chapter covers these in detail, then discusses alternative designs that were considered and partially implemented, but were dropped in favour of other features.

The system was designed using a user centered design approach [3]. Requirements and features were designed from interviews with 5 analysts from GWRC and domain knowledge gained by myself from working with Beca and GW as part of two summer scholarships. Once requirements gathering had finished, research into existing solutions could begin. Each visualisation was designed using a combination of ideas taken from background research, focused interviews with 5 people from GWRC, and previous experience presenting the existing model and tool to GWRC analysts for feedback.

3.1 Requirements

A significant challenge presented by this project was designing requirements to satisfy the stakeholders, their goals and what was feasible. The final requirements were a mixture of desired features from a primary stakeholder, features requested by potential users, and novel features designed after researching other similar solutions/techniques.

The users of the system are going to be analysts in the transport industry. This is because they would be the most frequent and likely users of such a tool, and to use the tool with the data it contains effectively requires some level of existing domain knowledge about PT operations. That is not to say the tool could be useful for others, but rather these are the most likely users. So the system is designed for PT analysts who understand operational transport and may have some experience with similar tools such as PowerBI [31], a high level visualisation tool by Microsoft, or Excel, a spreadsheeting tool that can be used for data



Figure 3.1: The final layout. 1. Main Visualisation window. 2. Detail Graphs window. 3. Time filter. 4. Replacement filter. 5. Route filter. 6. Legend window. 7. Visualisation selector. 8. Window controls. 9. Extra functions.

analytics.

Initially, the project aimed to address speed and dwell time issues within the network, contributing to a higher average speed, and hence lower emissions. However, this was dropped after a short investigation due to data procurement issues and preprocessing cleaning required to join with the current dataset. Considering time constraints, this was not continued.

While it is not a formal requirement from the client to understand the dataset as is, a user must gain an understanding of a dataset before they can do anything with it, so this was included as a requirement. The main reason the client was not interested is that they already have gained insight from building the model in the first place, however it could be argued that further visualisation is a separate task from producing understanding overall.

A request from several users, the client, and GWRC, was the ability to sensitivity test the existing model dataset, and being able to use it as a base to predict where to get the most value from replacing vehicles in future investment decisions. This led to the requirement to replace existing vehicles with simulated electrics in the existing dataset to visualise the emissions difference between current and potential future emissions. To satisfy this, two major features of the Bus Emissions Visualiser were developed. Both are different ways of visualising a change between the current fleet profile and a new one where some vehicles of different classes becoming electrics. These are implemented in the Emissions by Route and Emissions by Vehicle visualisation, and are discussed in further detail in §3.5.

Bringing together all of the information from interviews with PT analysts, personal experience in the domain, and requests from stakeholders a set of minimum requirements for the tool developed as a solution to this problem was formed by analysing frequency of requests. These requirements are:

- Req1** PT analysts must be able to visualise trips, speed, and emissions between days
- Req2** PT analysts must be able to visualise a group of routes or individual routes contributions to the networks emissions between days
- Req3** PT analysts must be able to select and deselect data based on characteristics that inter-

est them

- Req4** PT analysts must be able to visualise changing bus classes in some way
- Req5** PT analysts must be able to visualise an individual buses contributions to the emissions
- Req6** PT analysts must be able to quantify which buses are “worst” for emissions by measuring different characteristics, in order to get value from replacing them.

3.2 Architecture and Implementation

The project required hosting the existing code base on a platform so it can be accessed anywhere, due to the situation with COVID-19 and different alert levels. This required significant effort as the code base had been developed to be a local project. The app itself and the data for the app also had to be hosted separately, as the implementation required a MongoDB [4] setup. Platform as service providers supported MongoDB but did not implement in house solutions [32, 33]. This means that both MongoAtlas has to be managed, as well as a platform as a service.

The platform for the app that was decided on for this project is Heroku, due to the support that it provides for data loading requests (larger accepted packet size than other services such as Amazon Web Services for example [32, 33]). Heroku also has a vast array of functions, good documentation [34] and online resources discussing its use, such as stack exchange forums. Herokus ability to run Linux programs within applications is crucial [34], as the Flask API requires a wrapper executor called gUnicorn to run on UNIX architecture [35].

The size of the data, and the difficulties of using such data in a web browser meant that there was a need to significantly clean the data, and reduce the size of the sets to allow them to be used on the hosting services [33, 36]. There is an advantage to this work, as it allows the project evaluation to be conducted under future COVID-19 alert levels, as ideally the testing can take place via zoom/some other remote conference tool.

The tool uses a MongoDB [4] database that is hosted on MongoAtlas [36]. This database is queried via a Flask API in Python, then parsed to the front end Javascript to be processed. The high level architecture diagram is shown in Figure 3.2.

3.2.1 Data

The data used for this project comes from work done by GW analysts. The data is a set of public transport bus trips from the start of 2017 to the end of 2019. Preprocessing and cleaning was required to compress the data used to a size to fit on to a MongoAtlas server, maximum 500MB, however the set is 1.5GB large and contains nearly 4 million individual trips. Being so large, the dataset was refined and reduced to contain only trips from 2019, approximately 1.3 million trips (450MB). Not only is this easier to handle and fits on the free MongoDB Atlas, but it is the most representative sample of data for the transport network. The data is stored in JSON form on the MongoDB [4], and so is a format operational PT analysts would have seen. Some sample rows of the data are shown in Figure 3.3.

The data has been loaded into a MongoDB [4] database, which serves as the backend for the project. MongoDB has been chosen as it provides a flexible API similar in functionality to SQL, however does not require the same overhead as an SQL server, such as schema design and strict table management [4, 37]. MongoDB itself offers a large range of functions [37], so any data requested from the database can be calculated on the database itself then

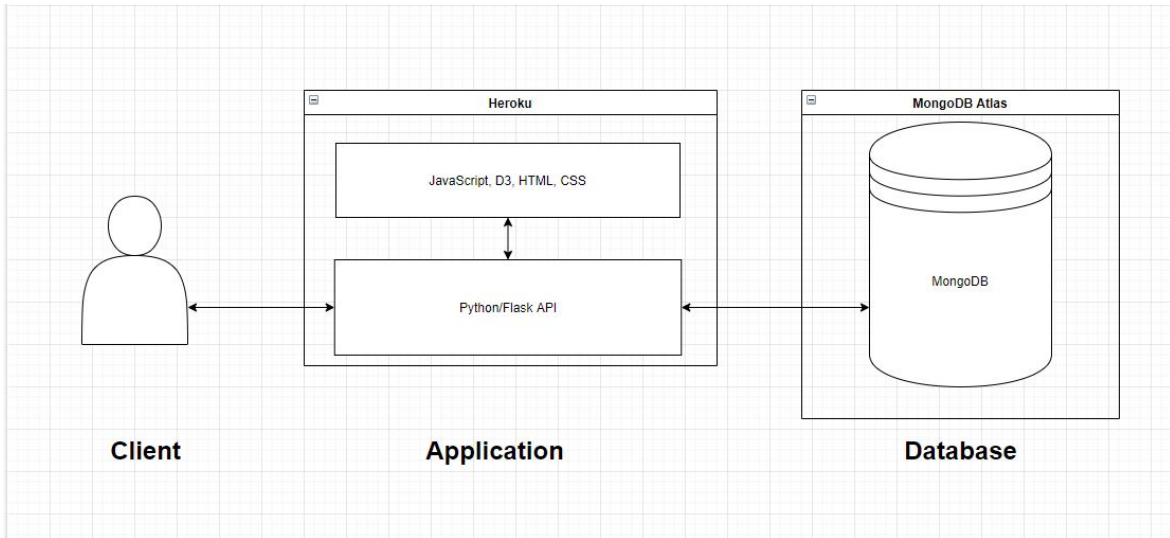


Figure 3.2: The architecture diagram for the system. Everything is handled through Heroku and its API. The data is stored in a MongoDB instance hosted by MongoAtlas, and is served to Heroku via a Flask API, and processed on the front end with JavaScript.

```

date:"2019/01/01"
route:"1"
trip_number:"701"
departure:"07:05:00"
operator:"Wellington"
trip_purpose:"Pub"
vehicle:"3325"
engine_type:"EURO6"
speed:20
distance:20.915
time:"3840"
FC:9.78887169577215
CO:0.03654285223254511
HC:0.0009054863082494312
PM:0.00013871012302307437
NOx:0.019617539766260295
CO2:26.19648214753487
car_co2_equiv:21.469288120799995
pax_km:"101.634"

```

Figure 3.3: The data that represents a single trip in the existing model. Fields vehicle, engine_type, speed, distance, and pax_km are used to calculate the emissions of trips, and by changing the engine_type, the model can be sensitivity tested.

sent back to the frontend, hosted on Heroku. This has two advantages; one that the data can be processed on the MongoDB server, saving computation on a local machine, and the other being that less data is sent from the server each request.

The database is hosted on a free MongoAtlas [36] server. MongoAtlas provides cloud database solutions for MongoDB instances, and is made by MongoDB, so was a natural choice for cloud services over Amazon. The server is located in Australia, which is important as the speed of queries is much faster, particularly in the setup, when the server used is hosted close to the user. Unfortunately speed gained with this is likely lost between MongoAtlas and Heroku, as the Heroku app is hosted in America.

As the database is hosted on a MongoDB using MongoAtlas, it is easy to pay for more storage if needed and then more data can be added to the existing dataset, so new analysis can be performed and adding to the reusability of the system. The advantage of using raw trip data in the database is that little preprocessing is needed before the data can be used in the existing system.

3.2.2 Hosting Solution - Heroku

Heroku is a platform as a service company that offers a hosting service for web apps [33]. Their web apps are easy to set up and free for all the services required here. They provide APIs and the ability to connect to a backend server, such as MongoDB [33, 34]. Heroku gives many advantages including the ability to remote test if required for evaluation, and ease of demonstration to both stakeholders at GW and other third parties with interest in the tool. This is of particular importance as it both provides more exposure for the project and allows people to interact from a distance, working around any restrictions COVID-19 may have imposed on the tools development and evaluation.

An issue with Heroku is the allowed packet size when requesting data through their servers [34]. It means that any data requested from MongoDB has to be below 20MBs, a very restricting limitation when dealing with datasets of this size. The solution to this that is used here is to break requested data into packets of 20MB or less to be returned. This solution results in about one request per day of bus trip data, which means that data is unfortunately slow, an issue for the effectiveness of the study and tool overall. While an inconvenience, this workaround allows data of any size to be requested by the tool.

The convenience and flexibility in testing and development Heroku provides far outweighs the minor disadvantage of packet sizes for requests, so it is used for this tool.

3.3 Alternate Designs

To try to facilitate comparison between routes when filtering and replacing vehicles, a side by side of the Detail Graphs was created. This had two sets of 3 visualisations, with a vehicle trips by class at the top, followed by an emissions by class visualisation, and a mini heat-stripe of the trips all over the same time period. Each set of 3 visualisations could be filtered to a different route, and a user could replace vehicles on either side. This was intended for the user to draw routes compared with each other, and easily allow them to compare which of the routes would be a better candidate for electric vehicles. This was dropped as it was difficult to integrate into the tool, and was a confusing function that interrupted the flow of the page. Instead the overlay which represents the current emissions according to the model was implemented to play a similar role. Another reason this was dropped is that other well designed visualisations already present in the system should help convey this information in a similar way, such as the routes visualisation.

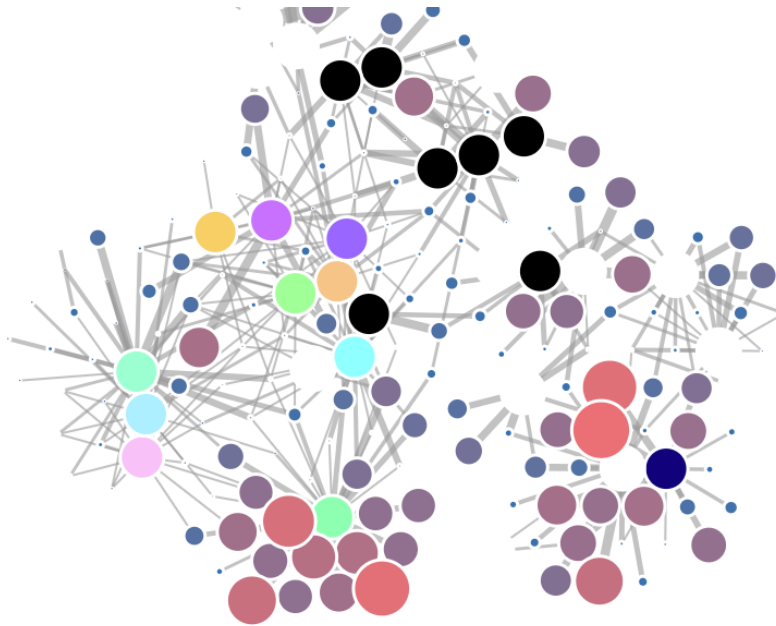


Figure 3.4: A force diagram of vehicles associated to routes. Buses are either dark blue or red, and routes are any other colour. The connections between routes and vehicles are different thicknesses depending on the frequency of use. The size of the circle corresponds to the emissions produced. This visualisation is not used in the final implementation.

Another design that was considered was the force diagram to represent similar information to the Emissions by Vehicle visualisation, which makes use of visual variables shape colour and size [14]. The size would be the emissions value and the colour either the route or bus class. Each vehicle circle was associated to another circle that represented the route it operated on, and the line connecting the vehicle circle with the routes would vary in thickness depending on the frequency of trips that vehicle ran on that route. An example of this visualisation is shown in Figure 3.4.

This would give a graph that shows vehicles associated to routes, and which route a vehicle is used the most on. Using this visualisation, an analyst could potentially understand the value of replacing vehicles by seeing a reduction in the vehicles size, and a subsequent reduction in all of the routes that a vehicle circle is joined to. While interesting, this idea is exploring an area of the data that is not necessary, as vehicles actually belong to units, not routes. Units are sets of routes that a bus provider owns, and so provides buses for. This means that replacing buses and visualising the effect it has this way is redundant, as it is a side effect of replacing individual vehicles. This led to the development of the third visualisation for vehicle emissions, the GapMinder Bubblechart.

3.4 Design

The Bus Emissions Visualiser (BEV), has 3 visualisations available through the selector on the main page. Harmful pollutants and greenhouse gases are distinguished in real-world analysis of emissions and climate change. Harmful pollutants include things like Nitrous Oxide, Hydro and Fluoro Carbons, and particulate matter to name a few. This is a detail that is not considered here, as it is considered out of scope. Instead the model in the tool focuses on carbon dioxide, which is often used in intermodal transport emissions comparison (light vehicles/cars in this case) [38, 39].

Features of this tool include novel insights derivation, and model data manipulation. Both of these are important as the intended users will be using the tool to try to gain insight faster than initially possible with current techniques. After discovering a trend or relationship of interest in the data with the tool, slight model changes can be affected before the heavy lifting of real analysis begins. This saves time and a step in the current process transport analysts and planners use to carry out changes to the operations. These features are listed in this section in detail.

The main tasks the Bus Emissions Visualiser aims to help an analyst achieve are:

- Understand the volume of bus trips on a daily basis, and other factors that affect the emissions associated to bus trips. For example, the emissions are directly tied to the quantity of bus trips per day, and these operations have potential to change in the future. Understanding how they change is important to understanding the trends of emissions.
- Understand how different bus routes, classes and vehicles contribute to emissions, and facilitate comparison between them. This should include the ability to investigate the impact of operational changes. This will allow users to see the impacts of changing bus engine classes on emissions, and gain insight on deployment strategies to best use buses with less polluting engine classes.
- Test the characteristics of the model with output of the emissions. Allowing users to change the quantity of operations and the class of engine, and facilitate decisions on where to get value from bus replacement based on operational characteristics e.g. vehicle 3303 contributes the most emissions over this month, therefore it should be removed and replaced.

3.5 Visualisations

The visualisations are designed to address the main user tasks defined in §3.4, hence there are 3 main visualisations developed as part of this tool. They aim to address different tasks or questions analysts may have, and assist them in gaining initial insights concerning public transport operations. The three visualisations are:

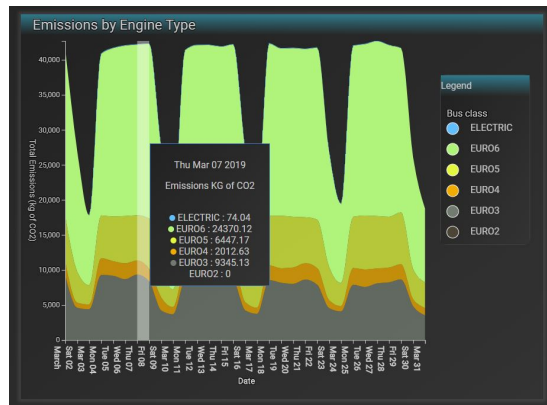
Emissions - Class Visualises emissions of classes of vehicles, and other factors relating to the emissions such as speed of a class. Satisfies Req1 & Req3.

Emissions - Route Visualises emissions of a route, and how those emissions change. This allows the user to dive deep into the data and replace different vehicle classes with other vehicles to visualise the effect this has on emissions. Satisfies Req2-Req4.

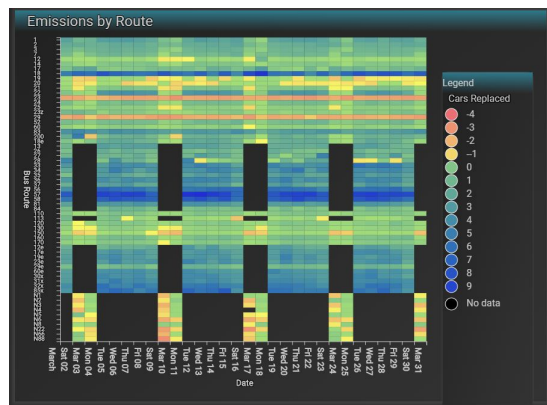
Emissions - Vehicles Visualises emissions of individual vehicles, and allows users to change individual vehicles to Electrics to see the effect various factors have on emissions of a single vehicle. Satisfies Req5 & Req6.

The final implementation of each visualisation is shown in Figure 3.5.

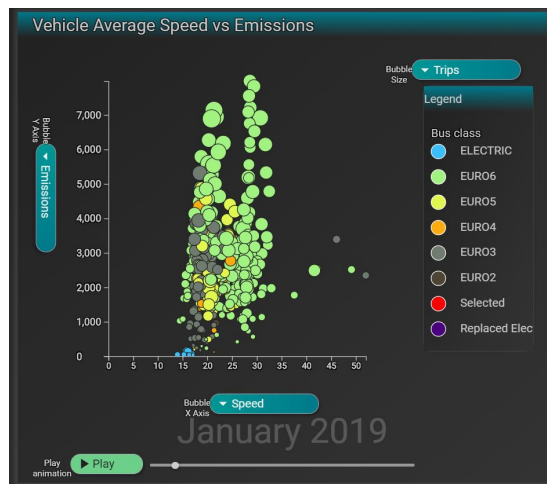
Each visualisation has a tooltip when a user hovers on a point of interest that displays more information as needed. The tooltip is a details on demand feature that helps the visualisation implement Schneiderman's Mantra [13], and is common for complex visualisations [15]. Other widgets also help with some of the tasks Schneiderman describes, such as the filters being well suited to the zoom and filter task. Overview is aided by the "Detail Graphs"



(a) Stacked graph called Emissions by Class visualisation.



(b) Heatchart called Emissions by Route visualisation.



(c) Bubblechart called Emissions by Vehicle visualisation.

Figure 3.5: The set of visualisations available in BEVis.

window, where extra complimenting visualisations that give more contextual information are drawn if applicable.

The data in the dataset is time series data, and there are several different novel ways to visualise time series data [15]. One of these is a stacked graph (Figure 3.7), where data is aggregated to create a visualisation with stacked areas. A bus has many defining characteristics that affect the emissions that it produces as it provides a service (completes a trip). One of these characteristics is the engine class of the bus, which is one of 7 potential cases: EURO1-EURO6, and Electric; EURO1 being the worst for pollutants of both kinds (greenhouse gases and harmful pollutants). By using the class of a bus as the stack separator, a stacked visualisation can be created with emissions data. The stacked graph can be made using the tool and helps to satisfy requirements Req1 & Req2.

The heat chart display (Figure 3.8) is for an overview of comparing bus routes and their emissions to each other, and visualising the effect on the networks overall emissions output. It is similar to the Warming Stripes concept [20], using a colour gradient on a plane to communicate differences between observations. The comparison display, which is a combination of the heatmap and the streamgraph, is useful for visualising the effect on emissions of changing characteristics about routes, such as the type of vehicle that is used on the route. Users can change sets of vehicles to electric as well, giving the emissions and other contextual information after changing a bus class. This satisfies requirements Req2 and Req4.

The final visualisation that has been designed and implemented (Figure 3.9) is a version of the GapMinder bubble chart [16]. This chart offers 3 dimensions to visualise numerical data, the x and y axis, and the area of each circle. Each circle represents a single vehicle, and the graph can be drawn for each month. Selecting a circle will draw a new circle that represents the value of the x, y and area if that selected circle became an electric bus. This allows a user to visualise the effect on emissions individual buses have, and how it may change with future investment, satisfying requirements Req4-Req6.

Where suitable, each visualisation has a further set of accompanying visualisations that display other relevant data for the user. These are contained in a separate "window" beside the main visualisation. Because of the complexity of the data and public transport planning in general [1], these graphs were one of the simplest ways of communicating as much information from the data as possible. Using all of these visualisations a user will be able to identify buses by class, the routes they operate on and individual vehicles that would maximise the decrease in emissions by utilising new vehicles being brought in to serve the routes.

3.5.1 Emissions by Class Visualisation

The main visualisation is a stream graph of bus emissions, shown on the left of Figure 3.7, with areas coloured according to the class of vehicle that it relates to. The emissions by class visualisation is designed as an overview and introduction to the tool and data. A vehicle class has greater emissions the older the class of vehicle; the lower the number the worse it is for producing emissions, i.e. a EURO3 bus is a greater polluter than a EURO6 bus.

This visualisation introduces the colour scheme for the bus classes, which is repeated throughout the tool where ever the bus class is relevant. This aids the users visual perception, where colour is bound to one dimension of the data and communicates this consistently through the tool. This in turn helps the user understand the visualisations faster and easier than looking for a class name in a spreadsheet. The colour scheme takes advantage peoples natural understanding of colour by using a black to green to blue gradient, communicating differences with black being negative and blue being positive [12]. Colour is a good visual variable to use for this as it is an effective associative variable [14]. The colour scheme is



Figure 3.6: This is the legend for the Emissions by Class visualisation. It shows the nominal colour scheme used for the bus classes throughout the tool.

shown in the legend in Figure 3.6.

The other two visualisations on this page, on the right of Figure 3.7, show the average speed by bus class, and the trips per day of a bus class. These two pieces of information are important as they are the factors that affect the emissions of a bus trip the most, aside from the class of the bus. Understanding these, alongside the visualisation of emissions by bus class, analysts can gain insights about the data that is within the model.

Each of the visualisations have tooltips, and hovering on sections of one graph in the Emissions by Class visualisation will highlight the same sections of the other graphs in the Detail Graphs window. For example, if an analyst is interested in a particular days emissions, they can hover on the graph at the point of interest, get a tooltip, and in doing so highlight the same class of vehicle on the other two graphs. This gives an analyst a better understanding of the factors that contribute to a trips emissions. Say, for example, emissions look high for a class of vehicle on a particular day. By hovering on the day of interest, users will see that day and vehicle class highlighted on the other two visualisations, showing the total trips performed on that day by that class of vehicle and the average speed of that day of a vehicle.

3.5.2 Emissions by Route Visualisation

The Emissions by Route visualisation allows a user to get an overview of emissions associated to a bus route within a time period. The heatmap shows an average of the emissions saved by each trip per day. This value is calculated by taking the total emissions that would be generated if each person on the bus trip were to drive the distance of their trip, and dividing the actual emissions by this. The actual emissions are calculated the same way as in the rest of the model, based on bus class, speed of the trip, weight of the vehicles/patrons, and patronage. The lower the emissions for each trip compared to the potential emissions if the bus was not present (the total emissions that would be generated), the higher the value (the more dark blue the colour) and therefore the more valuable the service is to reducing emissions. A heatmap was chosen as it is a visualisation well suited to large dimensionality data, as well as being regarded as low for mental load [40]. The disadvantages of heatmaps and similar displays [15, 40], such as difficulty in accurate readings, can also be mitigated by visualisation tasks [13].

This visualisation is accompanied by two complementing graphs in the Detail Graphs



Figure 3.7: The Emissions by Class visualisation displaying data from March 2019. Left: The Emissions by Class main visualisation in the main window. Right: The Average Speed by Class and the Daily Trips by Class secondary visualisations contained in the Detail Graphs window.

window. One is a streamgraph that displays the emissions by bus class of the time period selected with the time range selector. This is below a donut chart that displays the total count of trips by bus class of the trips that correspond to the trips in the viewed data. Together these visualisations aid understanding of the data by giving extra details not available on the heatmap. The bus classes have their own unique qualitative colour scheme for visualisations that convey information about the class of a bus. This is the same colour scheme that is used throughout the tool to represent bus class. An example of this visualisation is shown in Figure 3.8.

Each square of the heatmap can be selected. Once selected, a more detailed breakdown for that day will appear on the mini heat stripe beside the main heatmap, in the Detail Graphs window. Selecting a heat square will also change the complimenting visualisations in the Details Graph window, which will then display the emissions for that route and day specifically, and the total trips by bus class for that route on the donut chart. This is shown in the second heat chart in Figure 3.8 labelled 2), where only the route one is selected. The selected route is displayed as a title for the Detail Graphs window, and above the legend in 2). This second heatchart was designed similarly to the Warming Stripes [20], where the goal is to communicate one aspect (emissions in this case) well.

Using these visualisations a user is able to understand the impact a route makes on the overall carbon footprint of the Wellington transport network, such as quantifying the CO2 equivalent used by the route, or if the bus reduces potential emissions. Further, this visualisation can be used to test changes in the fleet by using the Replace Vehicles by Class widget. This can be done across all the data or a single route. An analyst can choose the quantity of new buses and select a class of vehicle that they want to replace, and add this change to the model. Doing so will cause the visualisations to change, where the donut chart now displays the trips of bus classes with the new vehicles, the emissions graph will display the emissions with the changes implemented and the heatstripe at the bottom will do the same. The emissions graph will display a line representing the old emissions of the selection, and the new emissions in coloured areas as before. Using this feature, an analyst can test as many fleet changes as they desire and see the change in the emissions themselves.

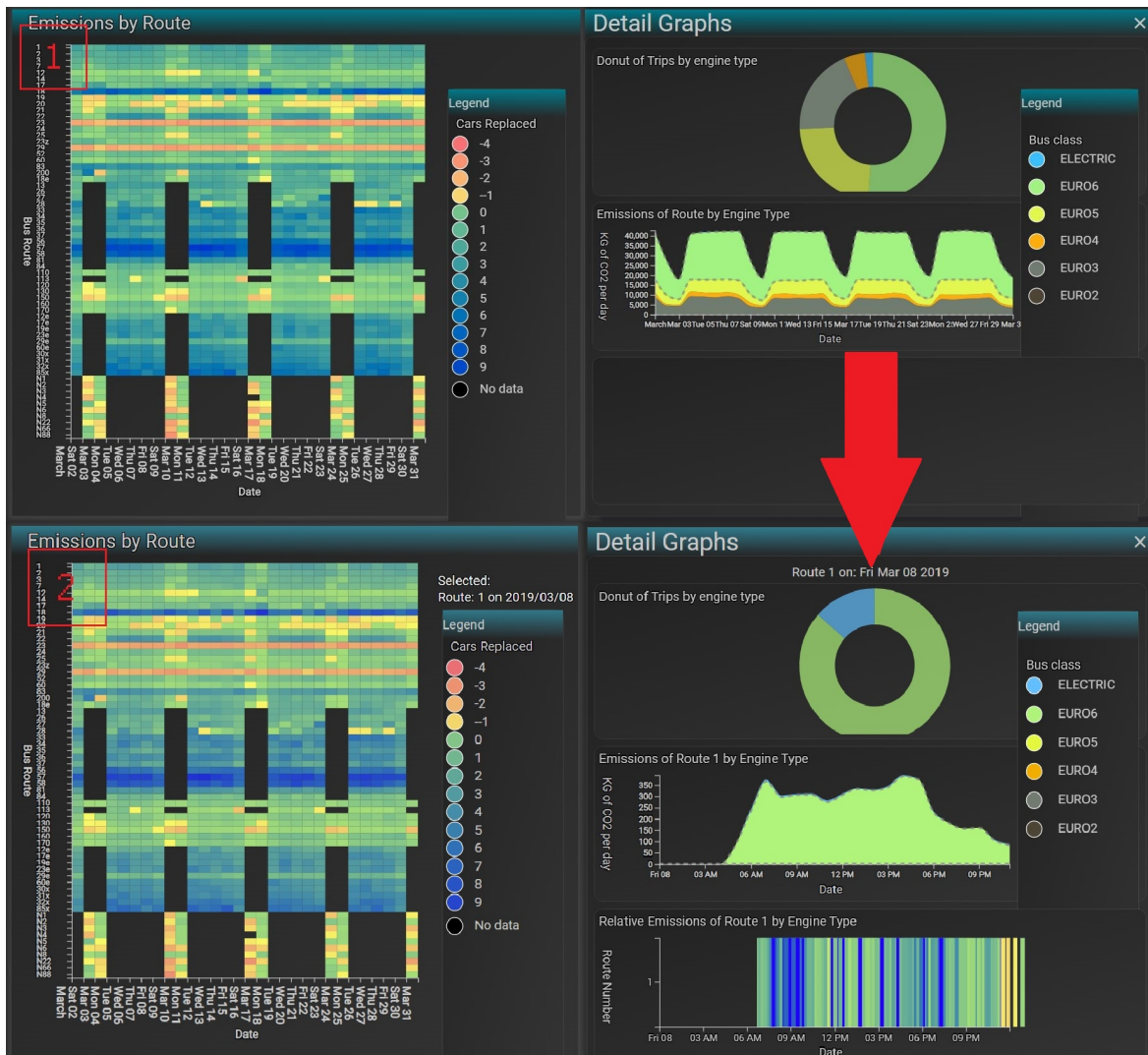


Figure 3.8: The Emissions by Route visualisation displaying data from March 2019. When a square is selected (clicked) the graphs change from 1) to 2), where the Detail Graphs now show the data for that particular square (trips for that particular day, on that route).

Left: The Emissions by Route main visualisation in the main window. It uses a different colour scheme to the other visualisations as it is representing different data. High performing routes can be seen in blue, such as route 18, whereas poor performing routes are red/orange, such as route 23 or 29. Right: The secondary visualisations: Donut Chart of Trips and Emissions by Class.

3.5.3 Emissions by Vehicle Visualisation

The third visualisation developed was the Emissions by Vehicle Number. It creates a bubble chart of vehicles over a month, with a bubble representing a single vehicle. Each vehicle dot is coloured using the same colour scheme for bus classes as the other visualisations to aid the users visual perception. An analyst can select what value is plotted on the x and y axis, and can use a value to control its size, as in Roslings GapMinder Bubble Chart [16]. This gives an analyst the opportunity to plot the most interesting aspects available in the data for themselves to visualise in different ways, and so discover trends in the data. Some of the fields that can be visualised from the data on these axes are average speed, quantity of trips, emissions and passenger kilometers.

In addition to the month by month visualisations that this chart can produce, the function to animate these through time has been implemented. By using the "Play" button in the bottom left, or dragging the slider at the bottom, an animation can be played that shows the vehicle circles slowly move as they change from month to month, similar to the bubble chart in Rosling's work [16]. This animation is another way to visualise trends present in the data, that may not have been obvious with a static chart [15, 16], and uses visual variables of size, colour, position and direction [14].

The widgets add extra depth to this visualisation, particularly the replace vehicles menu [13]. Using the filters an analyst can visualise aspects of each vehicle's overall performance on individual or a group of routes, the quantity of each item measured between a time range, and compare individual buses with their theoretical electric replacement. Replacing individual buses also works if the circle is clicked on. When replacing vehicles, the current vehicle circle will be highlighted. A new circle coloured purple will also appear that represents the same vehicle with the same properties except the vehicle class (which is now electric).

This visualisation is intended to give analysts insight to potential candidates for electric replacement by presenting total emissions of each vehicle, one of the best measures to use to compare between candidate vehicles for replacement. This helps to satisfy requirements Req3, Req4 and Req5.

3.6 User Interface

The interface that contains the visualisations is designed with two main considerations: The project is looking to identify visualisation techniques that are useful for insights gathering in public transport data, so the UI should not hinder the user in completing their goal therefore is not the main focus of the design. The app should provide all the tools a user needs, and those it provides must be well designed. This is because while the filters are important to a visualisation system, they should not take away from the visualisation of the data itself. Using a user centered design approach [3], designs were sketched and discussed with PhD and Masters software and computer science majors in the University, and refined with pilot studies. The UI layout saw many iterations of design, where tools and filters were constantly moved around until the least intrusive and most intuitive design was found according to feedback from pilot study participants.

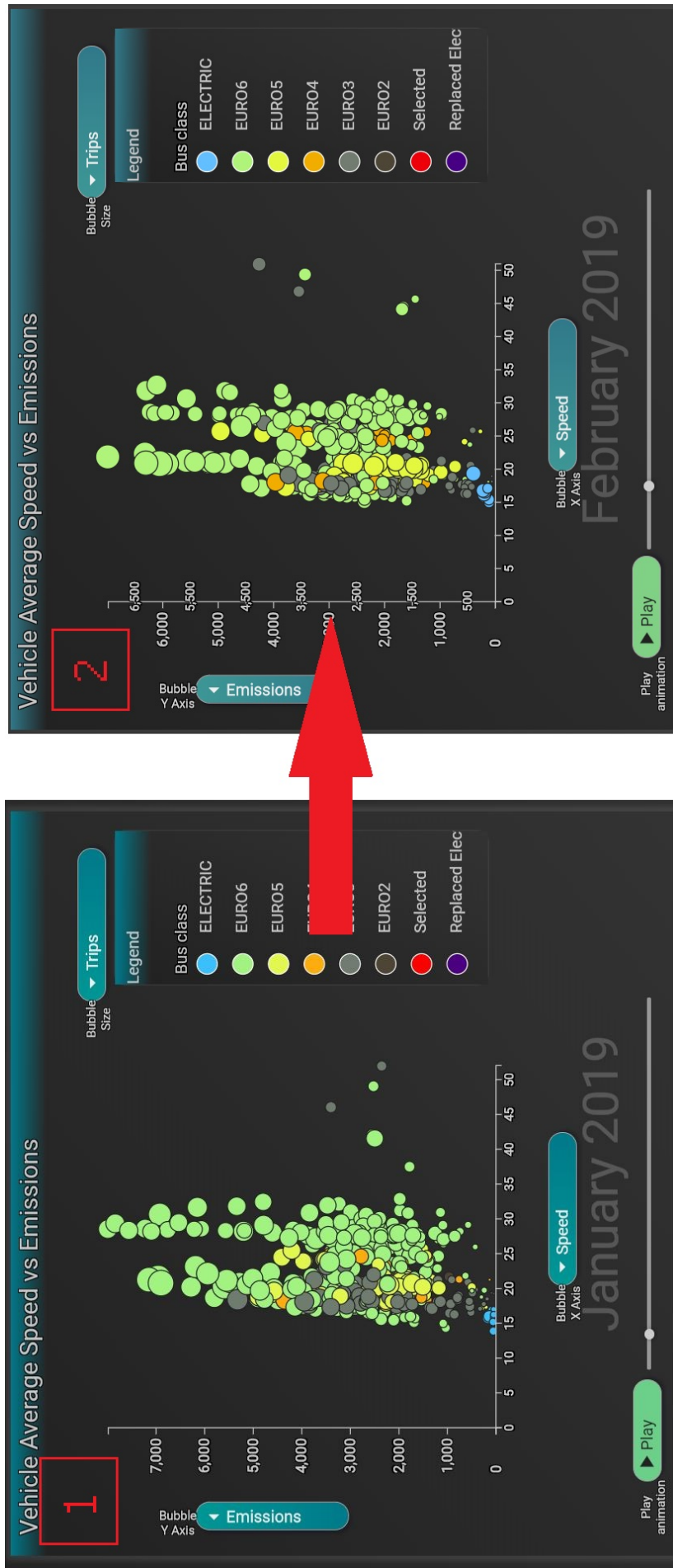


Figure 3.9: The Emissions by Vehicles visualisation displaying data from January & February 2019.

The Emissions by Vehicles main visualisation in the top right. The axis controls are on the left and bottom for the y and x respectively. The radius control is in the top right, near the legend. This visualisation animates between months, and so a user can watch the animation and gain insights by recognising patterns in the data.

The visualisations are contained within "windows", as are all of the filters on the page. There are two visualisation windows, one for the main visualisation, one for extra visualisations to give contextual information called the Detail Graphs window. Having two windows with different visualisations is a similar design choice to the traffic flow for Wellington project [25], and have been implemented to give more information about the main visualisation, minimising issues that arise with advanced visualisations [15]. These extra visualisations were used because during presentations and discussions at GWRC with analysts, there was interest in a lot of different aspects of the bus operations, speed for example, that could not be shown at the same time.

The windows can be moved around and closed at the users desire, allowing a clearer view of the tool, useful for new users [41]. Once a user has some confidence with the system, these windows containing tools can be reopened using a dropdown style menu at the top. This is intended to be similar to other programs users may have encountered, facilitating better performance with the tool faster.

The legend of each visualisation is one of these windowed tools. The legend is different depending on the visualisation, and can be removed if the user desires to create a physically larger visualisation on the screen.

Other tools that are windowed items are the filters, which include the bus class filter, the bus route filter, and the time filter. These three filters are always at the bottom of the screen (unless a user moves them during their time using the tool) and facilitate filtering of data displayed on the current visualisation. These three aspects of the data were chosen as filters because of the frequency of requests from analysts at GW, and they are considered to be the most important aspects when performing analysis on such data. A common exercise for public transport planners is to analyse data from AM and PM peak traffic (6:00am-9:00am, and 3:00pm-6:00pm), for example, so these features are a must have for the visualisation tool. These features help satisfy Req3.

The final window item on the page is an item referred to as the replacement filter. This menu displays options to change vehicles to different classes of vehicles, depending on the visualisation. One of these operates on the Emissions by Class and Emissions by Route, where an analyst can change any number of vehicles within the data they are visualising to a new class. This works on both upgrades and downgrades. For example an analyst can filter to a particular route, then use this menu to change all EURO3 vehicles to electric. The visualisations will change and now show the analyst what the emissions, trips by class, and efficiency of that route will be with the new electrics. Or they can do the opposite, and see what the profile would look like if all of the EURO6's were EURO3's. For the Emissions by Vehicle visualisation, the analyst can select a single vehicle to replace with electric, and thus see what the emissions of that vehicle will be if it were an electric. These filters satisfy Req4, giving users two different ways to visualise changing classes of vehicles.

The final implementation of the layout and widgets is shown in Figure 3.1.

Each widget or visualisation is contained within a single "window" that can be moved, with a header describing its purpose, information bubbles with more information on hovering, and a close button. Each window is either a filter or a visualisation, both of which are clearly distinct.

The page that the visualisations are contained in provide basic filtering functions. The legend is interactive, to aid fast digestion of overview information. Depending on the visualisation, the legend highlights sections of the graph and can be used as a kind of filter. Hovering on the diverging legend for the heatmap/heat stripe highlights all bus trips that are under the value that is being hovered on. This can be used for quick comparison, taking advantage of visual variables of colour and shade for quick recognition [14], and if that does not give enough information, there is also the tooltip and Detail Graphs view. These

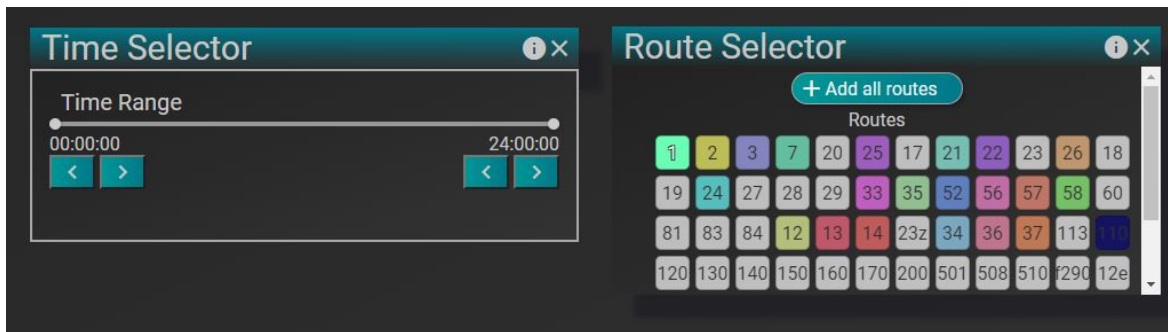


Figure 3.10: Left: Time selection filter: By changing the range slider a user can select a time range of interest to them.

Right: Route Filter: Dark routes are filtered out, bright routes are selected and will be included in visualisation.

all implement Schneidermans visualisation task of allowing details on demand [13].

There are filters the time of trips, the bus class and the bus routes. These filters provide a level of interactivity so that a user can change some variables in the system, such as select a time bracket of interest and see the relative emissions on the heatmap, the actual emissions and trips between that time period on a day. This is useful for comparing the morning peak emissions to the afternoon peak, etc, a common exercise for PT analysts. These filters also apply to all of the visualisations on the page so as to not confuse users, and contribute to the page flow/ease of use. Two of the filters available in BEVis are shown in Figure 3.10.

The other filters are the replacement filters, one for the vehicle emissions visualisation and one for the other two visualisations. These filters appear and disappear with their associated graph, and share the same slot in the dropdown menus at the top. This means that the user goes to the same place for both replacement filter types, and so to the user, they look like the same function. The Emissions by Vehicle replacement filter is a sorted list of all the vehicles that are present in the dataset, ordered from worst for emissions output to best. There are three columns, an identifier (the vehicle number), and the two emissions values; one for the current emissions one for projected emissions if the bus were electric. The two emissions values have the bus colour next to the number, aiding quick recognition.

The replacement filter for the Emissions by Class and Emissions by Route is a slightly more complex filter, which allows a user to select a class of vehicle to replace, what class of vehicle to replace it with, and the amount of vehicles to replace. These changes can then be added to the model, so a user can build a custom fleet for a route/the dataset, and see the emissions that would be produced if the network operated with those select types of vehicle in that quantity. This filter also changes the Details Graphs, which shows things like the trips that are associated to each bus class, with the replacement change in the data.

The replacement filters work in a similar way, the replacement by class is almost just a repeated version of the replacement by vehicle. When a user selects a vehicle to replace, the system uses a pre-programmed function that takes features of a trip such as speed, vehicle weight and class, and calculates emissions from that. By selecting a vehicle, the system takes the information about that vehicle, such as the weight of the bus and the average speed, and calculates the emissions for the vehicle based on the electric vehicles emissions function. This way, the process can be repeated several times over and applied to individual trips, and then these trips are summed to give the expected emissions of a vehicle if it were electric.

Similarly, replacing by class takes the set of data that is currently being viewed by the user and replaces vehicles of a certain class with another. Depending on the quantity of

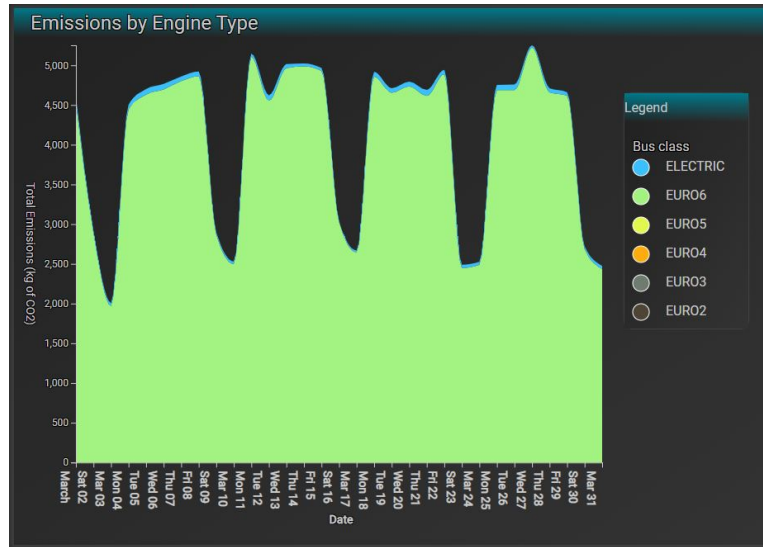


Figure 3.11: The emissions for Route 1. In order to compare with the previous year, all that needs to be done is to load the relevant data then these visualisations can be compared.

new vehicles available, new vehicles can be added in place of old classes whenever there is a vehicle with a suitable engine type. Once a vehicle has been "replaced", it cannot be used again to replace another trip until it completes its current trip. After completing a trip, there is a repositioning time allowed based on the average 30% of a trip's duration for repositioning, and only after the repositioning time can the vehicle replace another trip. This repeated for all trips in the view at the time gives the new emissions for a route/set of routes over time.

All of the filters mentioned above implement Schneidermans visualisation technique of zoom and filter, allowing completing common visualisation tasks such as insights gathering [13], and therefore help to fulfil Req3. These features and others such as tooltips are recommended by Heer et al., Gherson et al. and Schneiderman [12, 13, 15] to overcome some of the limitations of static infographics or visualisations.

3.7 BEVis Case Study

To demonstrate how the Bus Emissions Visualiser is a suitable solution to meet the requirements in §3.1, consider the problem presented in §1.1. That is, a scenario where an analyst is tasked with finding the emissions for a particular route in March 2019 as GW want to know if their emissions have decreased compared with the previous year. Initially, an analyst would have to find relevant CSV's, open them in Excel or some other spreadsheeting software, and begin manually writing formula and functions to find the buses that operated trips on that route, the class of vehicle, the weight, the patronage to add to the weight, and the average speed. In a single month, depending on which route, there could be a few thousand trips, so this process would need to be repeated several times.

However, using BEVis, an analyst can open either the Emissions by Class or the Emissions by Route visualisation to answer this question. By using the filters for the routes on the Emissions by Class visualisation, analysts can select routes whose emissions they want to visualise. Once selected, the BEVis tool produces a visualisation that shows the emissions of the route, along with the average speed by vehicle class and the trips by vehicle class. These can then be compared with the output from 2018 and compared, and answer-

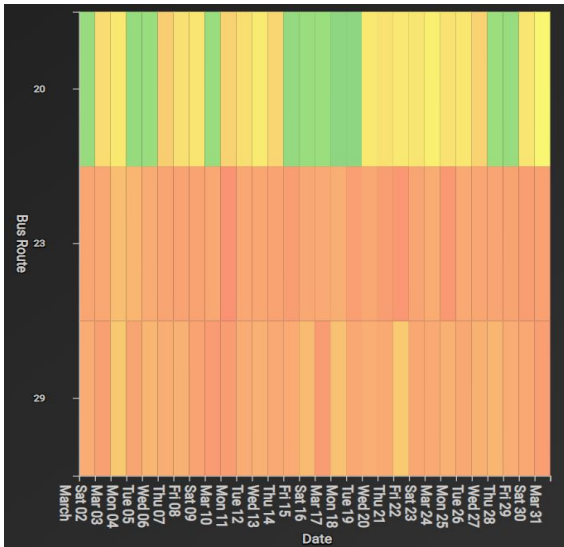


Figure 3.12: Candidates for the worst performing route in March 2019. The darker colour of the route 23 shows that it is the worst performing route. 29 is also bad, however the yellow indicates a lower emissions value. This visualisation makes use of the route filter for a more clear view for comparison.

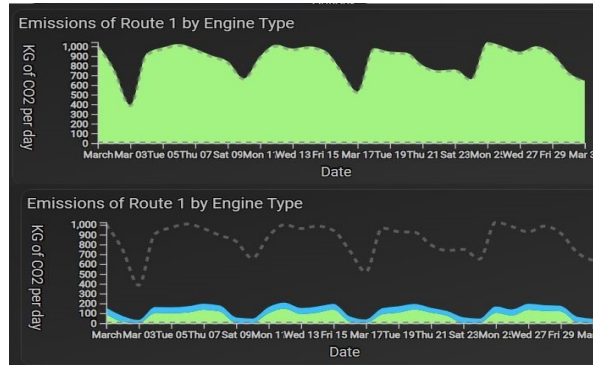


Figure 3.13: This shows the change in emissions predicted by the model by introducing 3 new electric vehicles to replace existing vehicles. The gray line on the bottom visualisation represents the old emissions without replacements. This shows the drastic reduction in emissions by replacing just 3 vehicles on a route.

ing the question in a matter of minutes, not requiring days of effort. The Emissions by Class visualisation that shows the emissions for just route 1 in March 2019 is shown in Figure 3.11.

In another case, consider GW analysts wanting to reconsider and reprioritise buses to reduce the network emissions as greatly as possible. This kind of analysis was unlikely to ever be carried out previously, as the manual process was a huge amount of effort and the benefit was not seen as worthwhile. The requirement to consider emissions output in the capacity that GW is currently moving towards is also a new business consideration.

By using BEVis, analysts can visualise a heatmap of how effective each route is at moving people compared with regular single occupancy vehicles (cars). The Emissions by Route visualisation shows each route compared to each other, or can show a group of routes by using route filters. By selecting a route, the Detail Graphs will show just that routes emissions and trips. To visualise the data at a finer granularity, a user can click on a square on the heatmap and see this information displayed on the Detail Graphs.

As shown in Figure 3.12, there are a few different candidates for the worst performing route in March 2019. By hovering on squares, the user gets a more detailed explanation of the colours, a feature recommended by Heer et al. to allow finer grained analysis than colour can communicate [14, 15]. They would consider the 23 to be the worst performing vehicle, as the colour is darker, and the tooltip gives more detail for comparing colours that are close together.

Now, the analysts want to see the potential decrease in emissions if this route were to get some electric buses. Again, something not previously possible, BEVis now makes possible. The user can use the replace vehicles by class filter to choose how many vehicles they want to replace. By using the drop downs and entering a number of vehicles, the Detail Graphs will change to display the emissions of the route if those changes were made. Say they want at least a 70% decrease in emissions. This is why the Detail Graphs are effective, by slowly

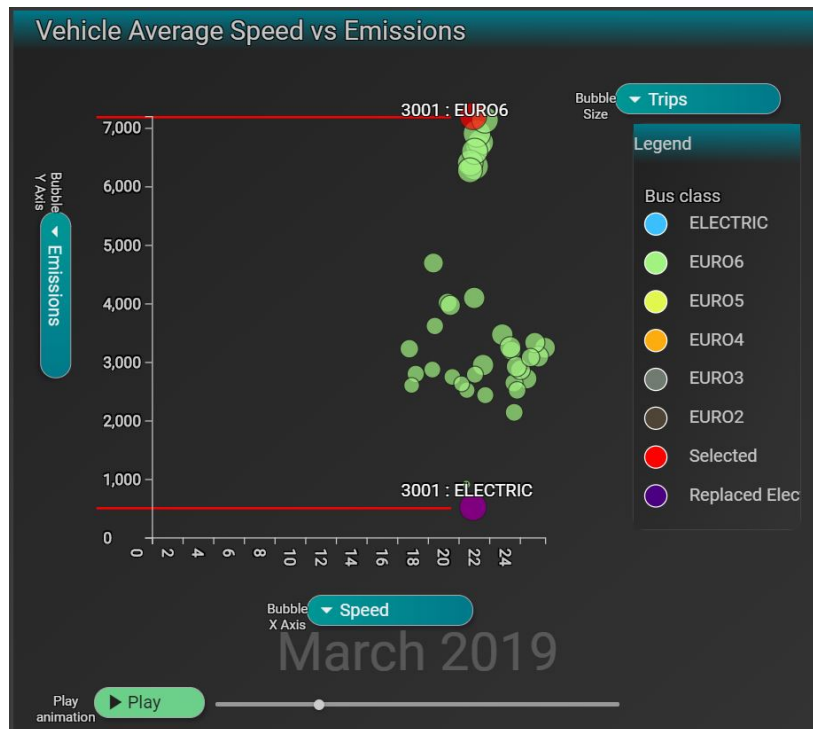


Figure 3.14: This shows the emissions prediction for the worst polluting bus on Route 23 in March 2019. The red dot is the current vehicle and the emissions it creates. The purple dot is the electric equivalent. This demonstrates the drastic improvement on emissions possible through using electric vehicles, and helps to satisfy Req4-Req6.

ramping up vehicles to be replaced, an analyst can gain an understanding of savings to vehicles utilised, and make more informed decisions about changes to the fleet. As shown in Figure 3.13, the Detail Graphs show emissions drop drastically by introducing 3 vehicles.

Now that they have an idea of potential savings in emissions and have decided it is worth rolling out 3 buses to save 80% of emissions for this route, now they need to know which vehicles specifically are the best candidates to save emissions. This is also possible using BEVis, with the Emissions by Vehicle visualisation. By selecting the time of interest, March 2019, and the route using the route filter, a bubblechart of the characteristics of vehicles on that route will be drawn.

By selecting emissions in the dropdown to the left of the y axis, the analyst can visualise the emissions associated to each bus used on the route in March 2019. The 3 bubbles drawn the highest will tell them the best buses to replace based on pure emissions, the buses that when replaced will give an emissions profile of approximately the same as the Emissions by Route with replacements showed. Clicking one of these buses, or finding it number in the replace menu, will add a purple dot to the visualisation, showing the emissions that the bus would have produced for the same trips if it were electric. This takes advantage of the visual variable of position and its quantitative properties to facilitate understanding of emissions differences [14]. The replacement for the worst polluting bus in March 2019 is shown in Figure 3.14.

Chapter 4

Evaluation

This section outlines the evaluation for the BEVis tool. It covers the initial pilot studies used to refine the study protocol and usability of the tool, the evaluation method and design of the study. The evaluation indicates whether the design meets the requirements, and if the system is usable. By evaluating the tool with real users, the performance of the tool can be assessed and therefore an understanding can be gained about the suitability for this type of solution for insights gathering informing decision making in PT, and if BEVis is an improvement over current techniques. The tool was tested with a total of 24 participants; 8 pilot studies and 16 user studies.

4.1 Pilot Studies

8 pilot studies were conducted in the lead up to the actual user study, which are a usability testing practice that helps refine studies before they are conducted [41]. This in turn produces better results in the final studies, and allows users to focus on the aspects of the system of interest, such as the visualisations effectiveness. These were conducted with computer science and software engineering students, with Masters and PhD students. The pilot studies provided feedback on the UI and usability of the tool, and helped to refine the study protocol [41]. Each participant sat in lab with myself and worked through the tool in a semi-cognitive walkthrough [42, 43].

Doing these pilot studies allowed the tool to be further refined than it otherwise would have been when testing, and supports a user centered design process [3]. This meant that the user studies would be more likely to get feedback about the features for data insights and model sensitivity testing over usability issues, which is the goal of the tool and study.

The usability pilot studies provided a large amount of feedback. The participants worked through the tool with some guidance and their feedback noted. This feedback was then added to the development backlog and worked into the last sprints before user testing began. Some of the suggestions that were implemented included:

1. Adding a line to the emissions detail visualisation, which represents the profile of emissions before changing any vehicle that is present within the data.
2. Adding cross graph highlights, so when a user hovers on a bus class section on the main visualisation or detail visualisation, the other graph highlights the same section. This aids visual perception.
3. Adding units to tooltips, not just the axis'. Also adding colours next to the relevant classes on the Emissions - Class visualisation.

4. Increase size of axis labels.
5. Starting to use the tool was ambiguous with so many things on the screen initially, so the design was changed to allow everything to be a window that you can activate or close, allowing the screen to be less cluttered.

These studies also gave the opportunity to fix issues with the study protocol. Running these tests also gave confidence that the amount of tasks was suitable for the time given, and the tasks were understandable to users. The feedback received concerning the study protocol and survey was:

1. Rewrite the questions to give more clarity
2. Allow users to enter answers either in numbers or combination eg 1400, or 1400KG/CO2 should be accepted when 1400 is the answer
3. Split a task into two tasks instead of asking for two values

4.2 User Studies

BEVis was evaluated with an in lab study and a total of 16 study participants. Users sat with a tester and talked aloud as they attempted to complete a short list of tasks that guided them to use the most important aspects of the design. After completing the tasks, or after one hour, they answered survey questions that asked about their perception of the tool and how effective they found it, which is presented and analysed in the Results Section. The goal of the user studies is to evaluate the tools success at meeting requirements as set out in §3.1, and if BEVis addresses the research questions from §1.2. The success (errors) of the participants in the study tasks, the perceptions of the visualisations and BEVis are all used to evaluate the tool, and address RQ1. The usability of BEVis and if it is successful at reducing the load on the analysts as they try to discover new insights is also evaluated, to address RQ2. The approved Human Ethics Committee application is in Appendix A.

4.2.1 Participants

The participants and their relevant information are shown in Table 4.1.

The participants were industry transport planners from a range of organisations in Wellington. There were 14 male, and 2 female, from organisations Greater Wellington Regional Council, Metlink, Beca, Wellington City Council, and VUW researchers. Five were 20-30 years, three were 30-40 years, two were 40-50, and 6 were 50+ years old.

A range of experienced users were tested on, from beginners to career public transport planners, business analysts and data analysts. Their experience in public transport was measured in years, and is shown in Table 4.1. This allowed a greater range of feedback from users and hopefully contributed a greater range of suggestions for improvement. Using a range of skilled users also gives an understanding of features that are useful for different skill levels. Public transport professionals were used as they are the intended end user. Participants that were technical operations analysts had experience with Microsoft PowerBI [31], and all users had experience with Excel.

4.2.2 Procedure

The study had 3 sections, pre-evaluation survey, the user tasks survey, and the post evaluation survey. The goal is to gather qualitative data about the performance of the tool, which

Table 4.1: Participants Information

PID	Organisation	Age	Gender	Role	Experience (PT) <i>years</i>
1	GWRC	30-40	Male	Customer Journey Advisor	1-3
2	Metlink	50+	Male	Principal Advisor Policy	0
3	GWRC	50+	Male	Senior Policy Advisor, Metlink PT	5+
4	GWRC	20-30	Male	Public transport planner	1-3
5	Metlink, GWRC	20-30	Male	Transport Data Analyst	0-1
6	GWRC	50+	Male	Business Analyst	1-3
7	GWRC	40-50	Male	Service Delivery Advisor (PT Op)	5+
8	GWRC	20-30	Male	Transport Planner	1-3
9	Metlink, GWRC	40-50	Male	Data and Tech Lead	0-1
10	GWRC	50+	Male	Senior Planner (PT Policy)	5+
11	WCC	20-30	Female	Wellington City Councillor	0
12	WCC	30-40	Male	City Innovation Lead	5+
13	Beca Ltd	30-40	Male	Software Engineer	0-1
14	Beca Ltd	20-30	Male	Transport Engineer	1-3
15	VUW	20-30	Female	Student	0
16	Connect WLG	50+	Male	Committee Member	1-3

will be a combination of users' commentary that has been analysed, survey feedback, and observations during testing. Participants were allowed up to an hour to do the entire study. The form of the study is a semi-cognitive walkthrough [42, 43]. A screen and voice recording of each study was taken for detailed analysis. This data will then be used to understand the effectiveness of the visualisations at communicating their intended information, and the overall effectiveness of the tool as a system to complement existing data insight discovery techniques in transport analytics.

Section 1, the pre-evaluation survey, was intended to only take 5 minutes maximum, and involved the users reading and agreeing to the study formalities (study date, consent to use their information, understand what will happen to their information etc). The forms given to the participants are at the end of this document.

Section 2, the user tasks, consisted of 10 small tasks for the user to complete. It was expected to take a participant between 15-20 minutes to complete. The user tasks are broken into 3 categories, one for each visualisation. The tasks are intended to lead on from one another for each visualisation, then the user moves to a different visualisation. The performance of individuals in these tasks will help determine the effectiveness, simplicity and other factors of the software tool.

The final section concerns the users perceptions about the tool, how they thought it performed and how if at all they thought it was effective/useful/an improvement on current techniques.

4.2.3 Study Tasks

There were a total of 10 unique tasks within the study. Each participant completed each task in order and was given the opportunity to comment on unique visualisations in the post evaluation survey. These tasks were broken into 3 sections, one for each visualisation and therefore one section for each main requirement of the system, as defined in §3.1. The tasks were designed to be followed sequentially, and to allow the user to slowly gain an

understanding of how to use the system to gain insights. The study tasks are shown in Appendix C. The tasks in the study relating to the **Emissions - Class visualisation** were:

1. Identify the class of vehicle used the most on a day, which relates to Req1
2. Identify the speed of a class of vehicle, which relates to Req1
3. Identify the emissions associated to a class of vehicle between a time range, which relates to Req1 and Req3

The filters for the visualisations were tested previously therefore they are not used after the previous section of the study. The study tasks related to the **Emissions - Route visualisation** were:

4. Identify bus routes that are the most polluting compared to single occupancy vehicles, which relates to Req2
5. Identify and quantify emissions from routes on particular days, which relates to Req2 and Req3
6. Quantify the emissions of a route after replacing some vehicles with electrics, which relates to Req4
7. Quantify the trips done by class of vehicle after replacing some vehicles with electrics, which relates to Req4

The Emissions - Vehicle visualisation uses a different technique to display changes in emissions than that of the visualisation above, therefore it retests the replace vehicles function, in the hopes users can identify issues with either technique separately. The study tasks related to the **Emissions - Vehicle visualisation** were:

8. Identify vehicles which contribute the most emissions for a month, which relates to Req5
9. Quantify passenger kilometers per KG/CO2 in a month, which relates to Req5 and Req6
10. Quantify passenger kilometers per KG/CO2 in a month if a certain bus becomes electric, which relates to Req5 and Req6

4.2.4 Data Collection/Analysis

Data was collected from the surveys as well as a recording of the screen and their voice as they work through the tasks and answer questions. The study uses the think aloud technique where users comment on what they are doing and thinking at each step [41]. There is also a post interview stage, where I asked each participant questions after completing tasks. All of the significant comments captured in these voice recordings will be noted before destroying the recordings. Participants will have the opportunity to request their personal recording if they so wish.

The data collected will be analysed through qualitative measures. The survey focuses on users perceptions, and uses two formal user surveys to gauge success. These are the Task Loading Index (TLX) [44], and the System Usability Scale (SUS) [45]. The Task Loading Index is a tool for measuring and conducting subjective mental workload assessment, whereas the System Usability Scale is a quick way to assess the usability of a system.

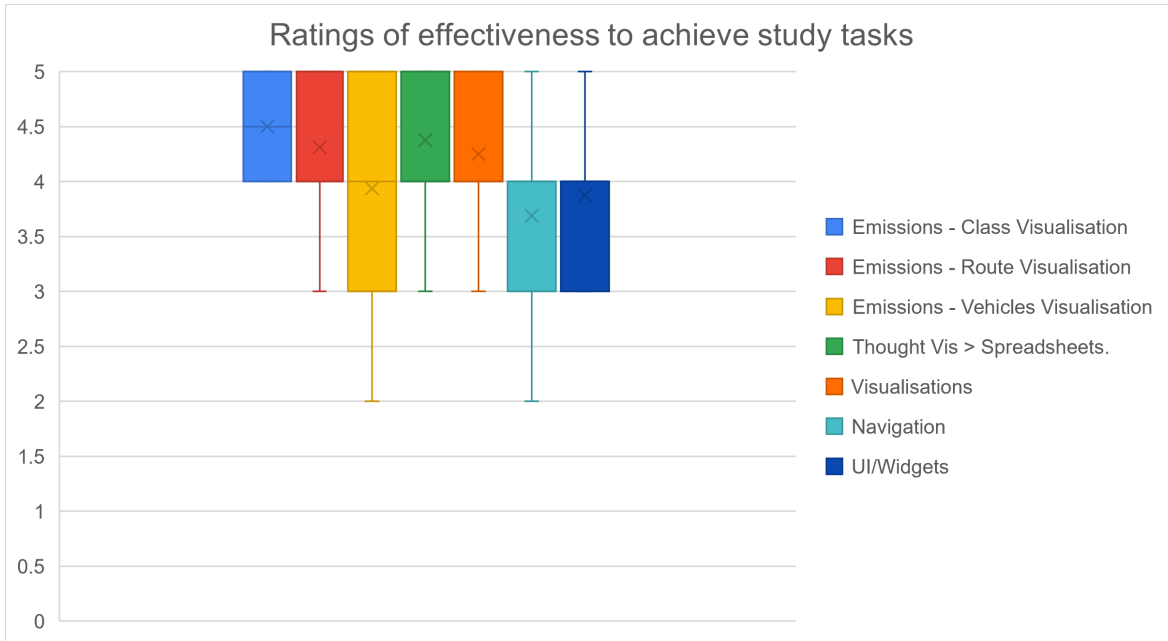


Figure 4.1: The visualisations and UI rated on a Likert scale by study participants. The median is shown as a grey x. From left to right, the first 3 are the visualisations.

By using the TLX and SUS the system can be rated on how usable it is, and how much cognitive load each task uses. These give an indication of whether the tool is usable, and whether the tool is easy to use to solve the user tasks. The results are drawn on box and whisker plots to understand the validity of the outcomes, and to draw accurate conclusions by reducing the impact of outliers.

The visualisations, UI and navigation are measured by participant ratings on Likert scales [46, 47]. The scale is out of 5, 5 being extremely effective and 1 being extremely ineffective. These scales are able to produce accurate results from small samples [47], crucial for valid results here with a small study.

4.3 Quantitative Results

This section considers the effectiveness of the tool by the perception of the users, their scores using two formal techniques to measure cognitive load and usability, and the feedback of the tool from both the survey and observations during the study.

The main measures used to evaluate the success of the tool are the errors made when answering questions, the NASA Task Loading Index, and the System Usability Scale. Each of these measure a different aspect of the tool and its effectiveness as a visualisation system.

4.3.1 Visualisation Effectiveness

To measure the effectiveness of the visualisations and UI, participants were asked to rate various aspects of the tool on a Likert [46] scale between 1-5, 1 being very ineffective, 5 being very effective. There were two groups of questions; were the visualisations effective, and was the UI effective. The boxplot of scores of the users for each of these is displayed in Figure 4.1.

Overall the effectiveness of each visualisation was above average according to users. The Emissions by Class and Emissions by Route visualisation were more favoured than

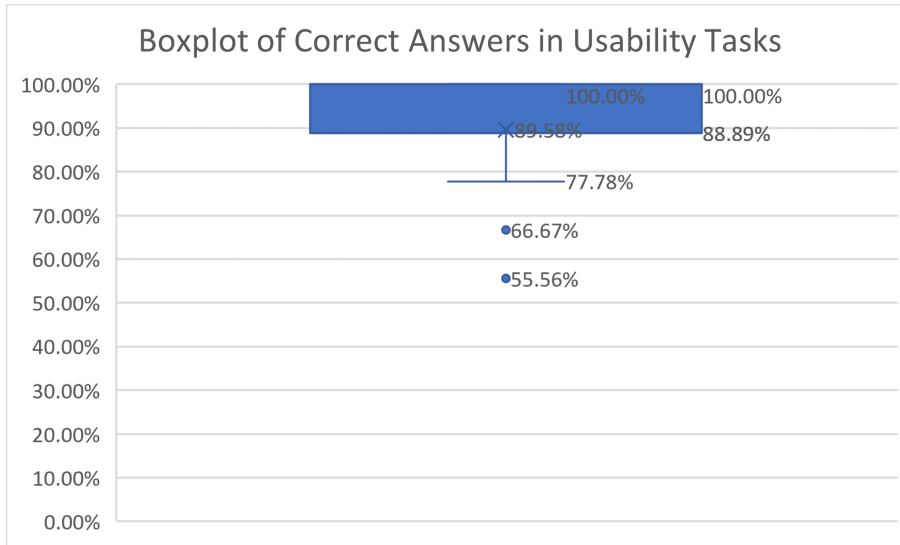


Figure 4.2: Percentage of participants correct answers in the User Tasks section of Usability Evaluation.

the Emissions by Vehicle. The average effectiveness of each visualisation was 4.5 for the Emissions by Class, 4.3 for the Emissions by Route, and 3.9 for the Emissions by Vehicle visualisations. 75% of participants rated the Emissions by Route/Class 4 or above, where as 75% rated the Emissions by Vehicle as 3 or above. This indicates the effectiveness of each visualisation, showing the Emissions by Route as the most effective. 75% of participants agreed that the tool was better than using spreadsheets for insights. Again, 75% of participants thought that the visualisations were effective, while 50% of participants believed that the navigation and UI was between average and well suited for the study tasks.

The final Likert scale participants provided was their perception of whether BEVis is better than using spreadsheets for similar analysis (green in Figure 4.1). This address whether BEVis is effective compared to spreadsheets. 75% of participants agreed, where the average score across all participants was 4.4. This indicates that BEVis is preferred by analysts over spreadsheets.

By using the Likert scales of visualisation effectiveness, the research questions from §1.2 can be answered partially. RQ1 is addressed by the effectiveness of each visualisation, where each visualisation was considered effective for the study tasks. RQ2 is addressed by their perception of the better tool, visualisations or spreadsheets, where participants agreed that visualisations were more effective.

4.3.2 Time and Errors

The tasks that the users completed without errors is displayed in Figure 4.2. It shows that 75% of users got 90% or greater, suggesting that the tool is very well suited to the study tasks. Every participant completed the tasks in the time given as well, suggesting that the visualisations were suited to the tasks, and hence the requirements in §3.1. This, in conjunction with the other measures used, shows that the tool is suited to the requirements. Outliers come from users that have been in public transport planning for a short amount of time, or have no experience at all, according to their information in Table 4.1.

The success of participants in the study tasks, or errors made, shows that the visualisation system is effective for meeting requirements as in §3.1. This helps to address RQ1, where BEVis has been shown to be effective at creating visualisations for insights gather-

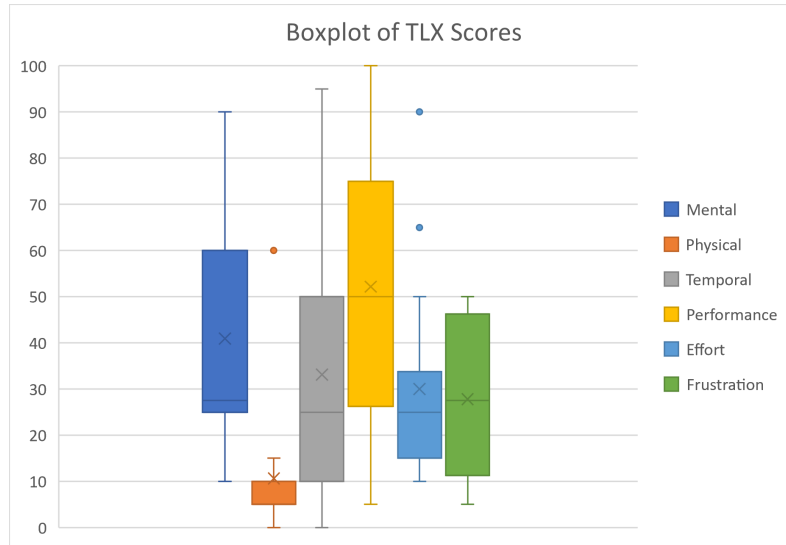


Figure 4.3: Boxplot of raw scores from the NASA-TLX. The lower the number the better. There is a high variation between responses for everything excepts Physical and Effort.

ing. It also addresses RQ2, where the lack of errors and intervention by the tester shows that the visualisation system is usable by a wide range of users with varying experience and analytics domain knowledge.

4.3.3 Task Loading Index

The task loading index is a measure of cognitive load on a user when performing a task [44]. It gives an indication of the users workload on 6 different factors. The summary of the scores are shown in Figure 4.3. The scores are calculated using the average of participant responses. While the TLX can be done with pairwise interactions of factors, raw scores calculated based purely on participants responses to rating the load of a factor are also just as useful [48].

Each of the factors are measured between 0-100, and are used to calculate the overall cognitive load score. For each of the factors except performance, a lower number is better. For performance, a higher number is better. The lower the final calculated overall score is, the lower the cognitive load, and therefore the more successful as the system is easier to use.

The task load index shows that the mental demand varied greatly depending on the user. The physical demand was low, as expected. The temporal demand, that is how rushed the user felt, had a high variance in the responses. Performance is again high in variation from user to user, however around 50% of participants found their performance to be around the average. Effort is low, which is good as the system aims to reduce effort for analysts. Frustration is relatively low as well, and comments during the study suggest that frustration may decrease more with more frequent use. This is still important to consider however, as first time usability leads to high retention of users.

The mental demand and performance are interesting as they had a high IQR range, indicating an inconsistent mental load and performance of participants. Interestingly, in the raw data those that scored the mental demand higher scored their performance lower, and vice versa. This indicates some sort of self bias, where users perceptions of themselves affected their responses. This is an issue with qualitative research. However, the mental demand is still lower than average at 40%, and the performance is slightly above average, at 52%. This shows that BEVis is relatively low for mental load, average for performance, and low for all

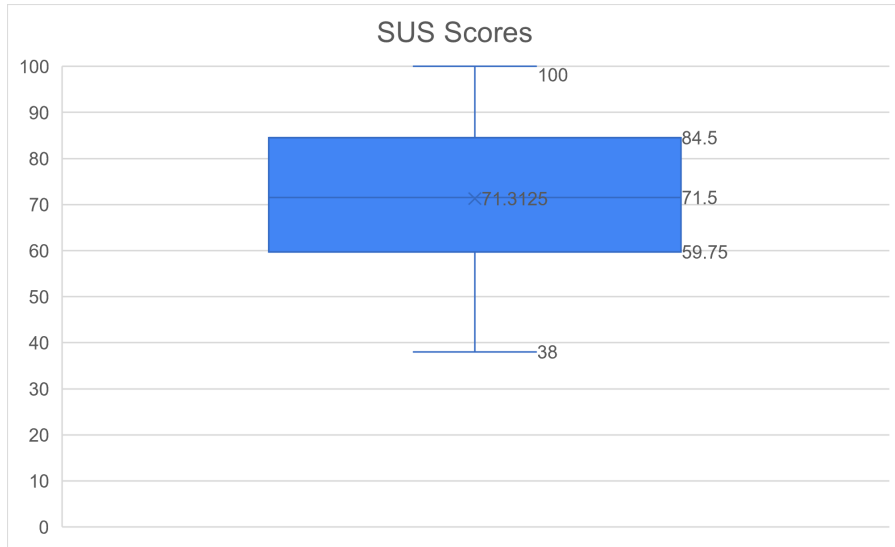


Figure 4.4: Boxplot of raw scores from the System Usability Scale. Higher is better.

other factors, leading to a low overall score of 29.58. This shows BEVis is low for cognitive load, and so has potential to reduce the cognitive load for analysts. This also addresses RQ1 & RQ2, showing an effective visualisation can be created for analysts and evaluating how effective a visualisation is for reducing cognitive load.

4.3.4 System Usability Scale

The system usability scale is used to measure the usability of a system. It has 10 questions on a scale from 1-5, from strongly agree to strongly disagree. The test aims to give an understanding of the effectiveness of the tool for a user, and their perception of it, if they might use it, etc.

A SUS score of 51 is a poor rating, 68 is an average rating and 80.3 is a great rating [49]. Over 68 is considered good but could use minor work.

Individual participants and their scores are shown below. One participant gave the tool a failing rating, 5 users gave the tool a below average rating, 5 users gave an above average rating, and 5 users gave an excellent rating. The average of all the users ratings was 72.4, so analysts consider this to be above average usability of tools they experience, and hence provides an answer to RQ2; the tool has above average usability compared with other applications.

As shown in the boxplot, 75% of participants rated the tool above 60, which is close to an average rating. Slightly more than 50% of participants gave the tool a rating of above 68, which is above average. This shows that the tool is usable, and therefore contributes to its effectiveness. The SUS mainly addresses RQ2, where BEVis is shown to be a usable tool for visualisations and insights gathering. The SUS also helps address RQ1, where BEVis is shown to be usable.

4.4 Qualitative Feedback

The user feedback during the user studies are discussed here. The feedback includes the responses from a set of survey questions asking for opinions on the tool, and feedback taken from each user during their study. The feedback is ordered according to which of the re-

requirements it best aligns with. This was done by analysing recordings and notes from user studies, and then drawn in a table under the requirement the feedback best aligned with. This could be done as each task was designed with the requirements in mind.

Req1 - Visualise trips, speed and emissions over days

Common feedback among participants was that this would be better achieved with less information in a single page. The design's intention is to have all of the relevant information available, however this is overwhelming for users.

A suggestion from participants to reduce the confusion, particularly as a new user, is to have tabs or dropdowns that can be toggled to make the extra graphs appear and disappear. This is something that was in the development backlog, however did not get implemented.

After some time, some users such as participant #13 and #16 began finding the extra graphs interesting, such as noticing that the electricians already on the network have a far lower average speed, and therefore are replacing slow services that would otherwise create more emissions than others.

Req2 - Visualise emissions associated to routes

Participants often found the equivalent measure difficult to understand. A suggestion from participant #7 & #16 was to provide an explanation of this in a popup window somewhere for users. Participant #13 pointed out this difficult to understand concept, saying *"Sometimes when there is something that is difficult like that I have seen a little window pop up to show you this is difficult"*.

Once users understood how this visualisation worked, often they would comment on how effective it is, and how interesting it is. Several took extra time to click through the heat squares out of interest.

Req3 - Select and deselect data of interest

Some of the feedback for the widgets and filters of the page include resetting after changes and size increases. Users liked the ability to move and close windows as they desired. Overall, the feedback was that there was some work needed for the filters and functions.

A suggestion from participant #10 and #16 was the ability to maximise a visualisation window, so it can be seen easier or used in a report.

Req4 - Visualise emissions with bus changes

This was a favourite feature of many users. *"It would be great to be able to print this off and take this to a meeting to show people the difference in emissions we're talking"* - PID 8. This shows the effectiveness of the visualisations, and how they meet this requirement.

More feedback was given about the replace single bus classes menu than the replace by class. Suggestions for the replace single vehicles (the menu for the vehicle emissions visualisation or bubble chart) include a search function to find bus numbers, and have the sorting respond to one of the features on the axis.

Req5 - Visualise emissions of single vehicles

Users were less fond of this visualisation. While users could answer questions using it, there was a lot of feedback regarding its function and design.

The tooltips for this visualisation needs to show units more appropriately, as it is frustrating trying to read off the axis and not seeing units of what is shown. The time label needs a more appropriate position as users found it difficult to find and understand what it is.

Req6 - Quantify and compare buses in different ways

Effective for the first two visualisations, the final visualisation (the Emissions by Vehicle visualisation) was often commented on. The main issue for users was their difficulty in understanding how to control the axis'.

Participant #14 suggested moving the controls for the axis' in to another window, similar to the other functions that are all contained in windows.

Suggested Improvements

A suggestion from a participant was the ability to export the data or the visualisation to do more analysis on. This is a good suggestion and relates to Schneidermans information visualisation tasks [13], where a successful visualisation system allows users to export data for further analysis.

Another common improvement suggestion was to change the page layout, the perception being that widgets would be easier to find and visualisations easier to understand.

Users were often excited about the tool and keen to give additional feedback. A lot of this feedback was praise and comments on how the participant felt the tool may fit in to their work.

4.5 Discussion

User Evaluation

Overall, user feedback from the survey shows the tool to be successful. Extra comments from users include; *"Really good effort, I'd love to see this more accessible for more people"* - PID #5, *"Very cool"*, - PID #14 and *"I think this could be a very useful tool"* - PID #16. This shows that users like the tool, and if it were developed would likely be used. The overall positive responses show that the Bus Emissions Visualiser is a successful tool for the study tasks. This is supported by quotes from users such as saying the tool is *"Logical and easy to use,"* - PID #9, and *"A great piece of kit,"* - PID #3.

The overall score of the tool on the TLX is low, and shows that users have more success than other factors which is important. Reducing the mental, temporal, effort and frustration factors were all goals of the system to improve on current techniques. Without a benchmark to compare to, such as rating of TLX with spreadsheets to do similar tasks, it is difficult to definitively say that this system is effective. However since most of the functions this tool provides were not possible before its development, so perhaps the tool and this study can be used as a benchmark for future transport emissions visualisation designs.

The system usability scale indicates that the tool is well designed and needs only minor usability improvements. However the range of the scores of the users shows that some users may find the tool very difficult to use. To add to this, the standard deviation of the system usability scores is relatively high at 15.09, meaning there is a high variance in the data from user to user. The boxplot as shown in Figure 4.4, shows that the tool is rated above average by 50% of users, but below average for about 50% as well. This may not be a problem as from the study, participants stronger in transport analytics experience learnt the system faster, and they are the intended end user. As mentioned before, this is difficult to reason

about due to sample size. Still, as 75% of participants were just under 68 or better, the tools usability is considered above average for a software tool, with minor usability issues.

The scores of the visualisations and page features shows that the visualisations were above average, where the other features such as UI were slight less so. So the tool is successful at creating visualisations, and the page navigation and widgets could use some work to further improve the TLX and SUS scores from above. This is further supported by the errors of the participants with the study tasks, where 75% of users got 90%, or one question out of 9 wrong. The errors show that the users found the tool intuitive and was effective for the study tasks.

There is a brief overview of how to use the tool, however participants still had only limited training. A fix for this would be to incorporate a tutorial for first time users that steps through the program with popups, as suggested by several users as a fix for different issues. This way, new users would read the popups before being able to continue, and therefore have a better understanding of the tool before using it.

Participants would often spend extra time with the tool, and commented on features they liked. This shows that the tool is successful at providing interaction, as participants found value in reusing the tool out of curiosity. Comments from participants indicate that the most effective visualisation was the Emissions by Route visualisation, with the additional features to drill into the data. The least effective, frequently commented on as being less intuitive and more confusing to understand was the Emissions by Vehicle visualisation. This supports the feedback from the survey, where according to users the Emissions by Route is better than the Emissions by Vehicle visualisation.

Limitations

There is a lack of work guiding what is an acceptable threshold for workload in the TLX [50], which is a flaw in the study. However, by measuring the system there is some understanding of which are the most costly in terms of cognitive load on the user, and so work can be planned going forward to reduce some of these factors. A factor that may be worth reducing is the mental load, for example.

While the study has shown the tool to be relatively successful, the study focuses on specific tasks designed for analysts and not all the functions of the system. This is a limitation of this study and for a more comprehensive understanding of the tool and its success more tests would need to be conducted with a new set of tasks. A follow on study could also allow participants a longer time, such as a longitudinal study that gathers a richer dataset.

Another limitation of the study is the lack of information about participants experience with information visualisation and data. This means that it is more difficult to reason about suggestions made by participants, as there is less contextual information about them and why they might be offering certain feedback. This may also help to understand why certain users have more difficulty than others, or reason about outliers in the user study data.

The study uses a convenience sample of only people in Wellington, only one place with unique bus operations and data. To gain a greater understand of BEVis's effectiveness, using more participants from other PT planners would be useful, such as Auckland Transport. The study mitigates this as much as possible by using participants from 5 different organisations, to get a range of analysts.

Chapter 5

Conclusions and Future Work

5.1 Conclusions

Transportation is a large discipline with many factors to consider including demand, efficiency of service and operations, scheduling, and budgets. This project introduced BEVis, a tool to take in PT operations emissions data, visualise it, facilitate manipulation of the data and inform decision makers. In building such a tool, new analysis can be incorporated to existing techniques to improve PT operations, specifically emissions analysis. Using visualisation techniques, BEVis creates interactive information visualisations that can supplement current analysis methods to improve analysis, reporting and insights gathering.

BEVis shows the load on analysts as they try to discover new insights can be lowered, and that such a system is more effective at providing initial insights than current techniques. BEVis also demonstrates the advantage of having a reusable software model for sensitivity testing (ie changing bus classes), something previously extremely difficult to do. This feature brings real value to the emissions visualisations as now analysts may be able to reason about which buses are best for replacement as new buses are purchased for use.

We conducted pilot and user studies, to refine the tool and prove that BEVis is an effective solution to the problem, and addresses the research questions in §1.2. The success of the 16 study participants in the tasks shows the tool is fit-for-purpose. The feedback concerning users perceptions of the quality and effectiveness of the visualisations proves this design is an improvement over current techniques. Using the participants responses to the system usability scale, task loading index and errors in the user study to evaluate the tool has shown it to be successful at meeting the requirements in §3.1.

Addressing the research questions from §1.2, this report has shown that an effective visualisation system can be created for insights gathering, proven by the errors of participants when answering questions where 75% scored about 90% (or made one error). The errors show that BEVis is an effective visualisation system, and its usability and visualisation effectiveness as measured by the Likert scales prove this, where participants agreed that the visualisations were effective, leaning towards extremely effective, and answering RQ1. The tool has also been shown to be usable, with an above average system usability score and a low to average score on the NASA TLX. The TLX and SUS answer RQ2, where the usability of BEVis is shown to be above average, and relatively low for cognitive load.

BEVis provides proof of the value in investigating emissions visualisations further, and can be used as a guide or codebase to be extended in the future for further analysis and development of visualisation tools in the transport and transport emissions analytics space, as suggested by Pack [1]. The visualisations implemented and their evaluation provide examples for future work as well, as now there is an understanding of effectiveness of visualisation types for transport data in a transport analytics context.

5.2 Future Work

Going forward, BEVis may be useful to use to provide a formal benchmark for the system usability scale and task loading index of similar visualisation systems. This will give an indication of if the tool is faster for initial insights than other techniques.

It could also be used in a longitudinal study, where more participants over a longer period of time experience the tool [51]. This gives a different type of study with richer dataset for analysis and can provide more indepth feedback over a longer period of time. This dataset can be used to perform a quantitative analysis on the tool.

This tool can be used as a base for further analysis such as an analysis of speed (higher speed, lower emisisions). During user testing, a participant from GWRC pointed out organisation units, which are groups of routes providers use to deploy buses. A bus may operate on more than one route, but all routes a bus operates on is part of a single organisational unit. To further improve the replacement function, more filters could be introduced, such as filtering by organisational unit.

In order to get real value from the tool, allowing exporting of datasets created by the tool to draw visualisations would be useful. This is one of Schneidermans [13] visualisation tasks, and this way, users can export data for their own analysis. This facilitates reporting for decision making and communication with stakeholders.

Major improvements from the development backlog that would be useful in the future to improve the tool are adjustable size and addable windows, each with different filters applied. This is useful for users to find their own insights, and means that users could create their own visualisation dashboards. This also allows creating different versions of the same visualisation, for example comparing AM and PM peak emissions by drawing two Emissions by Class visualisations side by side; one with a filter on trip time for 6:00am - 9:00am, and one with a filter 3pm - 6pm.

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Appendices

Appendix A

Human Ethics Application



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 : Dr Craig Anslow; Principal Investigator
Other Personnel : Christopher William Todd; Honours Student
Dr Stuart Marshall; Head of School (or delegate)

Research Form

Application Type

Is this application for:*

- Research Teaching only

Please select '**Research**' below and then select '**Save**' to access the rest of the form.

*

Research

Amend or Extend

Amendment/Extension

Amendment/Extension Application

Please summarise the changes you are applying for. When you have completed this amendment section you will need to review the whole form before signing off.

Which of the following are you applying for?*

- Amendment
 Extension

This question is not answered.

Amendment Details

- Are you seeking to change the personnel on your project?
 Are you proposing changes to the core project details e.g. title, aims and objectives, funding?
 Are you proposing changes to participant selection, recruitment, data collection or procedures?
 Do your changes impact on participant anonymity and confidentiality?
 Do your changes impact on informed consent or risks of harm?
 Do your changes impact on your Treaty of Waitangi obligations?
 Are you proposing changes to the storage, access, use or disposal of data?
 Are you proposing changes to the dissemination of your project?
 Are you applying for an amendment for an aspect of your project not listed above?

This question is not answered.

Explain in detail the amendment you are requesting and why it is necessary.

This question is not answered.

Please go through the application form and edit any of the sections you are requesting to amend.

It is worth checking the whole form to ensure it is up to date with the amended version of your project.

Ensure you have uploaded any relevant supporting documents for your amendment, for example, altered information sheets, consent forms and recruitment documents. Ensure you sign off, before submitting your amendment.

Combine amended documents and upload here. Please include a date in the document title.

This question is not answered.

Extension Details

Explain the extension you are requesting and why it is necessary:

This question is not answered.

What is the new nominated end date for your Human Ethics approval?

This question is not answered.

Combine all documents related to the extension, include a date in the title, and upload here.

This question is not answered.

Research Overview

Application Details

1. Application ID

2. Title of project

*(Click the ? icon for more info)**

3. School or research centre*

4. The following questions will help the committee assess whether your application is categorised as a Category A (more than low risk) or Category B (low risk).

Please check all of the boxes that apply. You will be asked for more information about some of these questions later in the application.

Check the box if your study:

4a Is health research*

Yes No

This question is not answered.

4b Is an intervention study*

Yes No

This question is not answered.

4c Involves the use, collection or storage of human tissue*

Yes No

This question is not answered.

4d Involves processes that use EEG, ECG, MRI, TMS, FMRI, EMG, radiation, invasive or surface recordings*

Yes No

This question is not answered.

4e Involves collection of information about illegal behaviour, or information that has been obtained illegally*

Yes No

This question is not answered.

4f Involves people who are not giving consent to be part of the study (other than observational research in a public place)*

Yes No

This question is not answered.

4g Involves participants under the age of 16*

Yes No

This question is not answered.

4g (i) Will a parent/guardian be asked to give consent for the child/young person to participate in research?*

Yes No N/A

This question is not answered.

4g (ii) Will more than one meeting be held with the child/young people without others present? *

Yes No N/A

This question is not answered.

4h Involves participants whose ability to consent freely is compromised due to context (e.g. people in prison), or a limited capability to make independent rational decisions (e.g. those with a serious intellectual disability).*

Yes No

This question is not answered.

4i Involves the use of concealment or covert observations, including those conducted online or conducted in social media. *

Yes No

This question is not answered.

4j Involves the use of previously collected personal information, other data, or biological samples for the collection of which there was no explicit consent for use in research.*

Yes No

This question is not answered.

4k Involves deception of the participants, including concealment of the true purpose of the research*

Yes No

This question is not answered.

4l Involves the use of highly sensitive information (see policy for definition)*

Yes No

This question is not answered.

4m Involves a focus on, has particular importance for, or impacts on Māori*

Yes No

This question is not answered.

4n Involves any other group (for example cultural or religious), other than Māori, and has the potential to cause discomfort or disruption to members of that group*

Yes No

This question is not answered.

4o Involves any direct financial interest in the outcome of the research by any member of the research team or external sponsor*

Yes No

This question is not answered.

4p Involve a conflict of interest or the appearance of a conflict of interest for the researcher (for example, where the researcher is also the lecturer/teacher/treatment provider/colleague/manager or employer of the participants)*

Yes No

This question is not answered.

4q Involve any situation which may put the researcher at risk of harm (e.g. overseas in politically unstable countries)*

Yes No

This question is not answered.

4r Involve a reasonable expectation that participants may experience (at a greater level than in everyday life) physical discomfort, emotional discomfort, or psychological or spiritual harm (e.g. asking participants to recall upsetting events)*

Yes No

This question is not answered.

Relationship to other Projects

5. Does this application relate to any previous applications submitted to an ethics committee (at VUW or other Institute)?*

Yes

No

This question is not answered.

Personnel

Personnel

To add other researchers, enter their user name, if known, or search for their first or last name (whichever is the most unusual). Click the search icon to run the search, and select the person from the list view. Click on **OK** at the bottom right corner to save the person record.

1	First Name	Craig
	Last Name	Anslow
	Full Name	Dr Craig Anslow
	AOU system code	Engineering and Computer Science
	Position	Principal Investigator
	Primary Investigator?	Yes
2	First Name	Christopher
	Last Name	Todd
	Full Name	Christopher William Todd
	AOU system code	Engineering and Computer Science
	Position	Honours Student
	Primary Investigator?	No

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

- Yes
 No

7. Is the principal investigator a student?*

- Yes
 No

Scope of Research

Project Details

8. Describe the aims and objectives of this 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

9. 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 development.

10. 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.*

This question is not answered.

Key Dates

If approved, this application will cover this research project from the date of approval for up to 3 years.

11. Proposed start date for data collection*

This question is not answered.

12. Proposed end date for data collection*

30/09/2018

13. Proposed end date for research project*

This question is not answered.

Proposed source of funding and other ethical considerations

14. Indicate any sources of funding

- 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

Tick all that apply:

- Internally funded
 Externally funded
 Self-funded

This question is not answered.

15. Is any professional code of ethics to be followed?*

- Yes
 No

16. 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

Data Collection

17. Please select all forms of data collection you will use in your project*

- Interviews
 Focus groups
 Questionnaires
 Observation
 Other

18. 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.

19. How many participants will be involved in your research?

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.

20. 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.

21. 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 experienced 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."

22. 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.

23. Will your research project take place overseas?*

- Yes
 No

24. 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

25. 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

26. 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

27. Will your participants receive any gifts/koha in return for participating?*

- Yes
 No

28. Will your participants receive any compensation for participation (for instance, meals, transport, or reimbursement of expenses)?*

- Yes
 No

28a. Give details of the compensation participants will receive.*

Students will receive supermarket vouchers in return for their participation.

29. 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

Treaty of Waitangi

30. 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.

Project Risks

Minimisation of Harm

31. Is it possible that participants may experience any physical discomfort as a result of the research?*

Yes

No

32. 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

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

Yes

No

34. 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

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

Yes

No

36. 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

37. 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

38. 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

38a. 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

38b. 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

39. 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

Data Management

Access, Storage, Use, and Disposal of Data

40. 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

41. 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

42. 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

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

*

17/11/2018

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

- Yes
- No

45. 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

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

- Yes
- No

47. 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

Dissemination

48. 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.

49. 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

49a. Describe how the results will be disseminated*

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

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

- Yes
- No

Supporting Documents

Documents

51. Please upload any documents relating to this application. Sample documents are available on the [Human Ethics web page](#).

- Ensure that your files are small enough to upload easily, and in formats which reviewers can easily download and review.
- To upload a document click on the green arrow to the right of the named document. Follow the on screen instructions which will be displayed to upload a document.
- To replace a document, click the tick in the column to the right of the document you want to replace, and follow the screen instructions to continue.
- To add a new document click on 'New Document', at top right of the documents table. You **must** enter the document name in the box that appears. Click on 'OK'. Click on the green arrow which appears to the right of the file name to continue.
- 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	✓	

Application Sign Off

Appendix B

Information Sheet and Consent Form

Understanding Environmental Benefits of Bus Mobility Through Visualisation

INFORMATION SHEET FOR PARTICIPANTS

You are invited to take part in this research. Please read this information before deciding whether or not to take part. If you decide to participate, thank you. If you decide not to participate, thank you for considering this request.

Who am I?

My name is Chris Todd and I am an Honours student in the Bachelor of Engineering (Honours) at Victoria University of Wellington. This research project is work towards my honours project.

What is the aim of the project?

This product is for exploring data related to the Wellington Public Bus Transport Network. Your participation will support this research by facilitating evaluation of the prototype developed.

The product is intended for use by public transport analysts.

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

How can you help?

You have been invited to participate because people like yourself will be the end user. If you agree to take part you will be asked to use the system on a computer which we will provide at Greater Wellington Regional Council, 14 Walter Street. You will complete a number of tasks using the Bus Emissions Visualiser web application prototype and complete a questionnaire on it's effectiveness. The study will take 30-45 minutes. I will record video of the computer monitor and audio for the duration of the study with your permission and write it up later. It would benefit the research if you are able to narrate our experience using the application. You can choose to not answer any question or stop the study at any time, without giving a reason. You can withdraw from the study by contacting me at any time within two weeks after completing the study. If you withdraw, the information you provided will be destroyed or returned to you.

What will happen to the information you give?

This research is confidential. This means that the researchers named below 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.

Only my supervisors and I, the transcriber (who will be required to sign a confidentiality agreement) will access the notes, recording and/or transcript of the interview and user test. The material I collect will be kept securely and destroyed on 01/10/20.

What will the project produce?

The information from my research will be used in an Honours report. The conclusions drawn from this research will contribute to the development of the Bus Emissions Visualiser web application.

If you accept this invitation, what are your rights as a research participant?

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;
- stop the interview or test at any time;
- ask for the recorder to be turned off at any time during the interview or test;
- withdraw from the study within two weeks of completion;
- ask any questions about the study at any time;
- receive a copy of your recording;
- receive a copy of your interview transcript;
- receive a copy of the computer screen recording;
- be able to read any reports of this research by emailing the researcher to request a copy.

If you have any questions or problems, who can you contact?

If you have any questions, either now or in the future, please feel free to contact either:

Student:

Name: Chris Todd

University email address:

toddchri1@vuw.ac.nz

Supervisor:

Name: Dr. Craig Anslow

Role: Research Supervisor

School: School of Engineering and
Computer Science

Craig.Anslow@vuw.ac.nz

Human Ethics Committee information

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

Understanding Environmental Benefits of Bus Mobility Through Visualisation

CONSENT TO PARTICIPATE IN USER TESTING

This consent form will be held for 5 years.

Researcher: Chris Todd, School of Engineering and Computer Science, Victoria University of Wellington.

- I have read the Information Sheet and the project has been explained to me. My questions have been answered to my satisfaction. I understand that I can ask further questions at any time.
- I agree to take part in this user test and a video/audio recorded observational study.

I understand that:

- I may withdraw from this study at any point within two weeks of completing the study, and any information that I have provided will be returned to me or destroyed.
- The identifiable information I have provided will be destroyed by 31 December 2020.
- 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 and utmost care will be taken not to disclose any information that would identify me.
- I would like a copy of the transcript of my observational study: Yes No
- I would like to receive a copy of the final report and have added my email address below. Yes No

Signature of participant: _____

Name of participant: _____

Date: _____

Contact details: _____

Appendix C

User Survey

BEVis Evaluation Survey

This form is the formal user study of the BEVis research tool.

Please be sure to read and sign the papers provided to you by the tester.

Answer as many or as little questions as you like, you may stop the study at any point, and you may choose to receive a copy of all of the recordings from this session.

1. Please enter your name

2. What is your role?

3. What is your organisation?

4. What is your level of experience with transport planning or analytics?

Mark only one oval.

- No previous experience
- 0 - 1 years
- 1 - 3 years
- 3 - 5 years
- 5+ years

5. Gender

Mark only one oval.

- Female
- Male
- Prefer not to say
- Other: _____

6. Age

Mark only one oval.

- 20-30
- 30-40
- 40-50
- 50+
- Other: _____

BEVis Tasks

These are the tasks of the BEVis evaluation.

Task 1: Emissions - Class

This section concerns the Emissions - Class visualisation.

7. 1.1 What class of vehicle is used the most on the 23rd of March?

Mark only one oval.

- EURO2
- EURO3
- EURO4
- EURO5
- EURO6
- Electric

8. 1.2 What is the average speed for EURO6's and Electrics on the 23rd of March?

9. 1.3 On the same day (23rd of March), what is the total emissions for the EURO6's between 06:00am-09:00am?

Task 2: Emissions - Routes

This section concerns the Emissions - Routes visualisation.

10. 2.1 What was the worst performing bus route in terms of relative emissions on the 11th of March?

11. 2.2 At what time of the day on the 11th did this bus route (from 2.1) pollute the most, and what was the value of KG of CO₂?

12. 2.3 What would the KG of CO₂ of this bus route (from 2.1) be if 4 of the EURO6 buses were replaced with Electrics? Please give the approximate total emissions at the same point in time as in 2.2.

- 13. 2.4 What would the total number of electric trips on this bus route (from 2.1) be if 4 of the EURO6 buses were replaced with Electrics?

Task 3: Emissions - Vehicles

This section concerns the Emissions - Vehicles visualisation.

- 14. 3.1 Which vehicle number was responsible for the greatest contributions to emissions for the month of January 2019? What were the approximate total of emissions in January 2019?

- 15. 3.2 Approximately how many pax (passengers) km per unit emissions did the vehicle 3004 produce in March?

- 16. 3.3 What would the approximate pax (passenger) km per unit emissions be for the vehicle 3004 for March if it were electric?

BEVis Post Evaluation Survey

Thanks for completing the tasks! Please fill out this brief questionnaire on your experience using the tool. You are welcome to further explore the 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.

BEVis Interaction Questions

This section has general questions about how you interacted with the tool.

17. I found the visualisations effective at communicating more information than spreadsheets.

Mark only one oval.

	1	2	3	4	5	
Strongly disagree	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Strongly agree

18. Overall I found the visualisations effective for the tasks of the study.

Mark only one oval.

	1	2	3	4	5	
Strongly disagree	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Strongly agree

19. I found the navigation/layout of the page effective when using visualisations.

Mark only one oval.

	1	2	3	4	5	
Strongly disagree	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Strongly agree

20. I found the tools/widgets effective when interacting with visualisations (Route Filter, Replace Bus Filter).

Mark only one oval.

	1	2	3	4	5	
Strongly disagree	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Strongly agree

21. Do you have any other feedback concerning the interaction with the tool?

Effectiveness of each visualisation

This section concerns how effective the visualisations were for their tasks.

22. Emissions - Class Visualisation : How effective was the visualisation at achieving the study tasks?

Mark only one oval.

	1	2	3	4	5	
Very Ineffective	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Very Effective

23. Emissions - Route Visualisation : How effective was the visualisation at achieving the study tasks?

Mark only one oval.

	1	2	3	4	5	
Very Ineffective	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Very Effective

24. Emissions - Vehicles Visualisation : How effective was the visualisation at achieving the study tasks?

Mark only one oval.

	1	2	3	4	5	
Very Ineffective	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Very Effective

25. Any other comments concerning the effectiveness of the visualisations?

Task Load Index

This section concerns how performant the tool was for the tasks.

Please answer these questions with a number between 0 and 20, 0 being not difficult at all, 20 being extremely difficult.

26. Mental demand - How much thinking, deciding, or calculating was required to perform the task?

27. Physical demand - What was the amount and intensity of physical activity required to complete the task?

28. Temporal demand - What was the amount of time pressure involved in completing the task?

29. Effort - how hard does the participant have to work to maintain their level of performance?

30. Performance - What was your level of success in completing the tasks?

31. How insecure, discouraged, irritated, stressed or annoying was the task?

System Usability Scale Evaluation

This section concerns how usable and well designed you felt the tool was.

32. I think that I would like to use the system

Mark only one oval.

1 2 3 4 5

Strongly disagree Strongly agree

33. I found the system unnecessarily complex

Mark only one oval.

1 2 3 4 5

Strongly disagree Strongly agree

34. I thought the system was easy to use

Mark only one oval.

	1	2	3	4	5	
Strongly disagree	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Strongly agree

35. I think that I would need the support of a technical person to be able to use the system

Mark only one oval.

	1	2	3	4	5	
Strongly disagree	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Strongly agree

36. I found the various functions of the system were well integrated.

Mark only one oval.

	1	2	3	4	5	
Strongly disagree	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Strongly agree

37. I thought there was too much inconsistency in this system.

Mark only one oval.

	1	2	3	4	5	
Strongly disagree	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Strongly agree

38. I would imagine many people would learn to use this system quickly.

Mark only one oval.

	1	2	3	4	5	
Strongly disagree	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Strongly agree

39. I found the system very cumbersome.

Mark only one oval.

	1	2	3	4	5	
Strongly disagree	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Strongly agree

40. I felt very confident using the system

Mark only one oval.

	1	2	3	4	5	
Strongly disagree	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Strongly agree

41. I needed to learn a lot of things before I could get going with the system.

Mark only one oval.

	1	2	3	4	5	
Strongly disagree	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Strongly agree

Final Comments

42. Any other comments on the tool overall?

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