AT Public Transport Emissions Analysis

Proof of Concept Report

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# Abstract

* Will vary depending on target audience.

# Background and Purpose

*Chris V – This section was mostly sourced from the background in the GWRC report from last year.*

There is currently a national drive to reduce emissions as a measure of mitigating human-induced climate change. Within the transport sector, public transport is an important method of reducing the emissions of the overall transport network. The majority of buses on New Zealand public transport networks are diesel. Therefore, improving national and regional understanding of the emissions of buses on the public transport network can assist with planning and decision-making at a high level to meet emission reduction goals.

The most accurate methodology to estimate emission quantities is to examine fuel consumption of the buses on a public transport network. However, this approach has several limitations. These include:

* Buses on the network are typically used for other purposes (e.g., private charters, rail replacements, special services). The emissions generated by these activities are not attributable to the public bus network.
* Fuel consumption data can be commercially sensitive under certain contractual frameworks.
* This data is not typically collected centrally by the public organisation operating the entire network.

As a result, a software-based approach using network operation data in conjunction with formulae from the European Union EMEP/EEA air pollutant emission inventory guidebook [1] may be more suitable. This approach is likely to be easier to implement and roll out at a large scale while maintaining acceptable levels of accuracy.

A successful trial was undertaken by Greater Wellington Regional Council (GWRC) and Victoria University of Wellington (VUW) in 2019 to use a software-based approach to calculate the present and historical emissions of the public transport bus fleet across the Wellington region. As a result of this trial, NZTA Waka Kotahi has requested a proof-of-concept study to examine whether this model can be applied to the Auckland region. This work was undertaken in collaboration with VUW and supervised by Chris Vallyon.

This pilot study will examine the emissions generated by two bus operators on the Auckland network, Go Bus and Ritchies. Collectively, they service approximately a third of the trips across the Auckland bus network. Auckland Transport manages the public transport network across Auckland. They will provide the operational data that will be processed into the inputs for the emissions model. The emissions model then uses these inputs to generate an estimate of the emissions generated by each bus on a given trip instance. The output from the model can then be aggregated upwards to provide an estimate for the emissions generated by a given vehicle, a given route, or over the entire network.

This report will outline the methodology used to produce this model. In the instance where provided data may be incomplete or limited, any assumptions and interpolations required in order to generate a complete model will be described.

# Definitions

**Deployed Application** - The live version of our research tools hosted on external servers. These applications are accessible through the web.

**Local Application** - A local application is an application run on your own machine. The local application requires a running environment (outlined in the setup/requirements section) and the code base to be on your computer.

**Trip** - A sequence of two or more stops scheduled to be completed at a specific time on a route, repeated across multiple dates.

**Trip Instance** - The completion of a trip by a vehicle on a specific date.

**Route** - A route is a group of trips that are considered a part of the same service. They are displayed to passengers under a single name/code.

**Service** - A service is a set of dates that a given trip operates on.

**UUID** - Universal Unique Identifier. A number that uniquely identifies a single item within a dataset.

**AT API** - The Auckland Transport Developer’s Portal API. A publicly available API that allows software to request AT public transport data.

# Methodology

The methodology used to apply the model to the Auckland context can be separated into the following steps:

1. Procurement of raw operational data from the AT API, vehicle information from AT (as at Dec 2020), and passenger kilometre data.
2. Processing and filtering this data to our sample for the study. The two providers (Ritchies and GoBus) were selected as they provided TARE Weights for their vehicles. We form the operational data to match our data specification, and perform sanity checks on data (missing schedule trips, real time observations, etc). This step is referred to as **pre-processing**.
3. Building a software pipeline using a combination of a database backend (we have experimented with MySQL, PostgreSQL and implemented in MongoDB), a backend technology (we have used Nodejs to implement the *pre-processing step* described above, and Python to implement the backend for the online application) and a frontend to interact with the pipeline.
4. Finally, we reproduced this pipeline in a deployed application allowing processing of correctly formatted data automatically. We used a previously developed Emissions visualisation tool to visualise large scale emissions based on the processed operational data.

The aim of the first step is to collate and generate several data fields for each trip in the analysed dataset. We defined a trip instance as a sequence of two or more stops undertaken by a specific vehicle on a specific time and date. A database schema with the required fields and formats for the model developed is included in section 3.3.

## The Data Pipeline

There are two categories of data used within this model. It should be noted that both types of necessary for the model to work correctly and provide comprehensible outputs.

The data inputs to the emissions model are as follows:

* EURO classification of the engine of the vehicle that carried out the trip.
* Average speed (in kmph) of the vehicle over the entire trip.
* The distance of the trip in km.
* Tare weight (in kg) of the vehicle that carried out the trip.
* Passenger loading represented by the total distance travelled by individual passengers on the trip in km.

The data fields that assist with filtering and visualisation are:

* Date the trip occurred on.
* The departure time of the vehicle from the first stop on the route.
* The name of the route that the trip services.
* The vehicle ID number that identifies the vehicle that carried out the trip within the operator’s fleet list.

The emissions model was developed during the Wellington trial and reused on the Auckland bus operational data. This model is based on formulae from the European Union EMEP/EEA air pollutant emission inventory guidebook [1] and Ministry of Transport data on the NZ personal vehicle fleet in 2017 [2]. The model estimates the following quantities for each trip:

* Fuel consumed in litres.
* The carbon dioxide equivalent (CO2-equiv) generated in kg. This is the sum of CO2 and the CO2 equivalent of other greenhouse gases (methane & nitrous oxide) produced by the combustion of diesel and engine lubricants.
* The quantities of each of the non- CO2 greenhouse gases (methane and nitrous oxide) produced in kg.
* The quantities of pollutant gases (carbon monoxide, nitrogen oxides, hydrocarbons, and airborne particulate matter) produced in kg. These gases have a detrimental environmental and health impact in the environment they are emitted in.
* The CO2-equivalent generated if each passenger had instead travelled in an average personal car as the sole occupant. This is intended as an estimate for the carbon cost of not running a given trip.

A summary diagram showing the process of building our model for this study is shown below. The learnings from this exercise led to the development of the data specification in section 3.3.

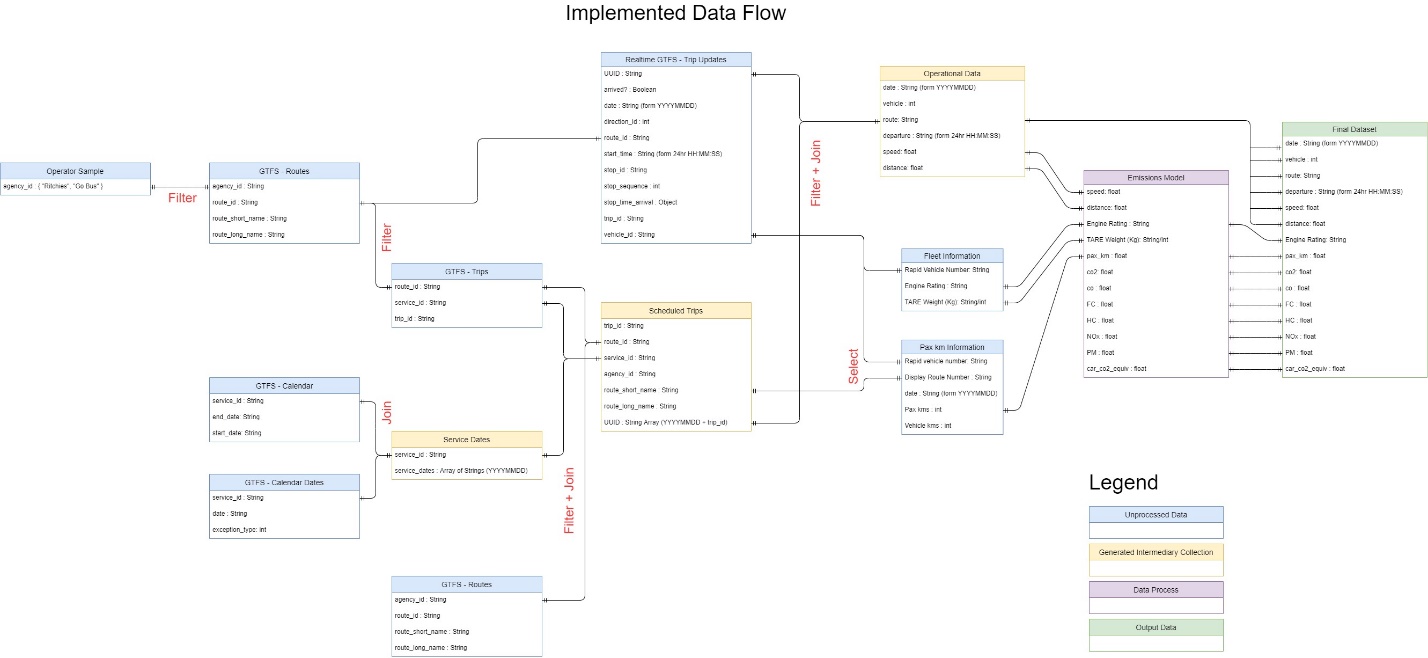


Figure 1 - Model summary

The outputs from the model are visualised in a tool called “BEVis” that is a research tool was developed as an extension of the Wellington trial. These visualisations are displayed later in the report.

The rest of this section will describe the implementation of this methodology that we developed and utilised over the course of this study.

## Data Sources

Most of the data used for our study was retrieved from the AT developer’s portal API. GTFS and real-time data was utilised to generate a complete dataset of scheduled and observed trips. The following schedule data was retrieved from several of the GTFS APIs:

Table 1 - GTFS APIs on the AT API

|  |  |  |  |
| --- | --- | --- | --- |
| API Endpoint | Data Field | Data Type | Description |
| Trips | trip\_id | String | Unique identifier for the scheduled trip. |
| Trips | route\_id | String | Unique identifier for the route the trip services. |
| Trips | service\_id | String | Unique identifier for the service schedule that the trip operates. |
| Routes | route\_id | String | As above - Used to join data from different API endpoints. |
| Routes | route\_short\_name | String | The short name of the route the trip serviced. |
| Routes | agency\_id | String | The code for the bus operator that operates a given route. |
| Calendar | service\_id | String | As above - Used to join data from different API endpoints. |
| Calendar | start\_date | String | The date that a service schedule begins operating. |
| Calendar | end\_date | String | The date that a service schedule stops operating. |
| Calendar | [Weekday-name] | boolean | A field for each day of the week with a boolean (1 or 0) indicating whether the service operates on that day. |
| CalendarDate | service\_id | String | As above - Used to join data from different API endpoints. |
| CalendarDate | date | String | The date that an exception to the regular service schedule occurs. |
| CalendarDate | exception\_type | integer | The type of exception that occurs. E.g., whether a service runs when it would not be regularly scheduled or vice versa. |

The following data was retrieved from the real-time trip updates API:

Table 2 - Fields in the data retrieved from the real-time API

|  |  |  |
| --- | --- | --- |
| Data Field | Data Type | Description |
| trip\_id | String | Unique identifier for the scheduled trip. |
| date | String | The date that a given trip occurred. |
| arrived? | Boolean | Boolean indicating whether a trip is recorded as completed (arrived at the final stop in the sequence). |
| start\_time | String | The time that the trip began. |
| stop\_time\_arrival | int | The most recent stop time for the bus on the trip. This value is provided as an epoch timestamp. |
| vehicle\_id | String | The “Rapid Vehicle Number” uniquely identifies a vehicle within the entire Auckland bus fleet. |

This data has been collected since 14/12/2020 until 05/02/2021. Starting from 23/12/2020 until 24/01/2021, the dataset is complete (aside from downtime which is discussed later). **Outside of this range the dataset may be incomplete.**

In addition to the data publicly available via the Developer’s Portal, two further sets of data were received directly from Auckland Transport. They are the Auckland Bus Operator fleet list and passenger km (pax\_km) data. The fleet list contained the following data relevant to the study:

Table 3 - Fields in fleet list data

|  |  |
| --- | --- |
| Data Field | Description |
| Rapid Vehicle Number | The “Rapid Vehicle Number” that uniquely identifies a vehicle within the entire Auckland bus fleet. |
| agency\_id | The code identifying the vehicle’s operator. |
| Engine Rating | The EURO classification of the vehicle’s engine. \* |
| TARE Weight (Kg) | The weight of the unloaded bus in kg. |

The pax\_km data passenger km and vehicle distance data for the date range of 12/24/2020 through to 30/12/2020. The data provided was aggregated to contain values for a given vehicle on a given route over the entire date range. The relevant data fields are shown below:

Table 4 - Fields in passenger km / distance data

|  |  |
| --- | --- |
| Data Field | Description |
| Rapid vehicle number | The number that uniquely identifies a vehicle within the entire Auckland bus fleet. |
| Display Route Number | A short numeric code that represents the route. This code corresponds to the “route\_short\_name” from the Routes GTFS API endpoint. |
| Vehicle trips | The number of trips completed by the vehicle on the route over the specified date range. |
| Vehicle kms | The total distance travelled by the vehicle on the route over the specified date range. |
| Pax kms | The total distance travelled by passengers on the vehicle on the route over the specified date range. |

## The Data Specification

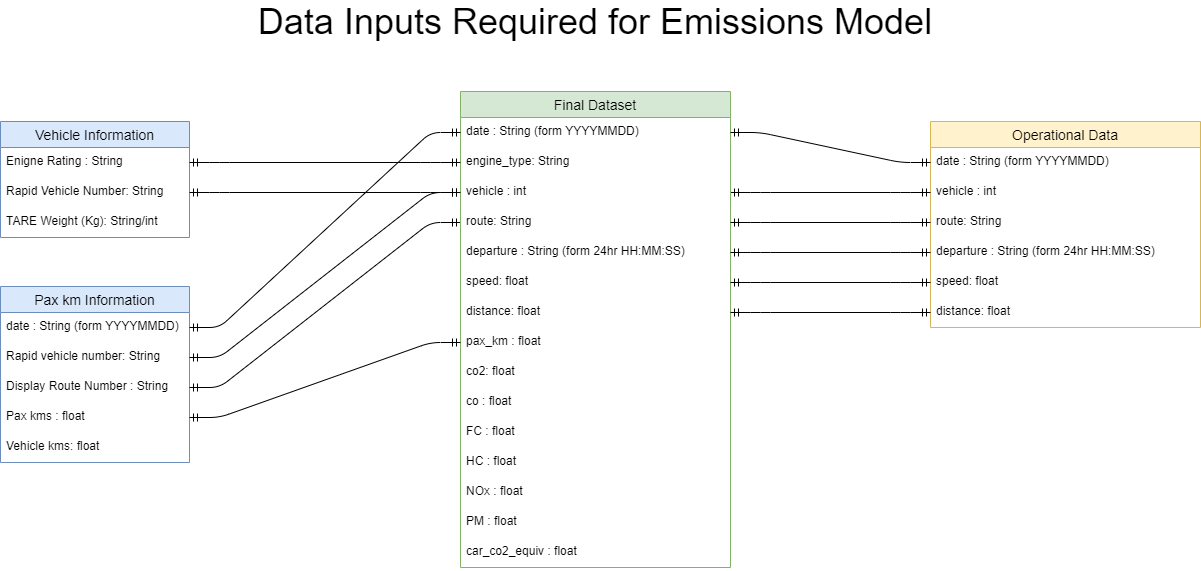


Figure 2 - Data Inputs to Emissions Model

The data specification is a data model describing the required format for input data in our application. There are three data sources:

* Operational Data
* Vehicle Data
* Pax Data

The specifications for each dataset are **exactly** as described in the tables and diagram above. The files must be a csv format, with no commas in any of the string values. Json data is not accepted, for example. The order of the columns in the csv does not matter, however all headers in the tables below **must** be present and use the specified spelling. The units are also described below.

**Operational Data**

Table 5 - Operational Data Specification

|  |  |  |
| --- | --- | --- |
| Data Field | Units | Format |
| date | days | String: YYYYMMDD |
| vehicle | - | String |
| route | - | String |
| departure | - | 24hr HH:MM:SS |
| speed | - | km/h |
| distance | - | km |

A sample of the processed operational data from our exercise is below:

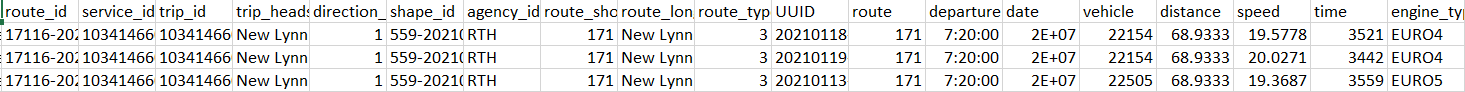


Figure 3 - Operational Data Sample

**Vehicle Data**

Table 6 - Vehicle Data Specification

|  |  |  |
| --- | --- | --- |
| Data Fields | Units | Format |
| Engine Rating | String | must be one of: ‘PRE-EURO’, ‘EURO1’, ‘EURO2’, ‘EURO3’, ‘EURO4’, ‘EURO5’, ‘EURO6’, ‘EV’, or ‘ELECTRIC’ |
| Rapid Vehicle Number | - | String |
| TARE Weight (Kg) | kg | String |

Below is a sample of vehicle data from our data for this project:

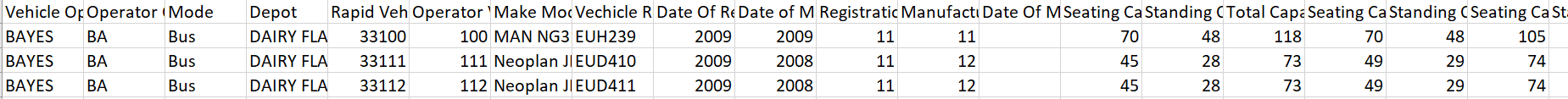


Figure 4 - Vehicle Data Sample

**Pax Km Information**

Table 7 - Pax\_km Data Specification

|  |  |  |
| --- | --- | --- |
| Data Fields | Units | Format |
| date | - | String: YYYYMMDD |
| Rapid vehicle number | - | String |
| Display Route Number | - | String |
| Pax kms | Passenger / km | int |
| Vehicle kms | km | int |

Below is a sample from our data for this project:

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Mode | Year | Month | Display Route Number | PTOM vehicle type | Rapid vehicle number | Vehicle trips | Vehicle kms | Pax | Pax kms |
| Bus | 2020 | 12 | 101 | LB-D | 14011 | 1 | 19.576 | 2 | 7.255 |
| Bus | 2020 | 12 | 101 | LB-D | 14041 | 1 | 20.058 | 3 | 10.149 |
| Bus | 2020 | 12 | 101 | LB-D | 14049 | 1 | 19.576 | 2 | 10.337 |
| Bus | 2020 | 12 | 101 | LB-D | 14053 | 2 | 30.087 | 4 | 14.59 |

This data specification has been used to implement the pipeline on a deployed application. The use of this deployed application is described in the following section.

## Setting Up the Pipeline

**Note** There is a fundamental limitation to both projects. We are limited by the available fleet information, and therefore to extend any of the tools developed here to include more service operators the tools will need to be updated.

**Local Project**

The local project still works on local machines. However, the database is always going to be the MongoAtlas database setup for the original project. If you need to change anything about the database, please email Chris Todd at [chriswilltodd@gmail.com](mailto:chriswilltodd@gmail.com).

**Requirements**

Python >= 3.8

The codebase for the deployed pipeline is available through git.

1. Download git.
2. Open git and navigate to your desired directory.
3. enter the command:

git clone https://github.com/chriswtodd/BEVis.git

**First time python Setup:**

Install the required python libraries:

pip install requirements.txt

Start the local development server on localhost:

python app.py

The website will start on http://localhost:5000/fleet\_view

The local application is used in the same way as the Deployed Application.

**Deployed application**

The deployed application is available at:

<https://warm-temple-67996.herokuapp.com/fleet_view>

To process data on the version of the tool you are running:

1. Open the control window using the menu button in the top right corner.

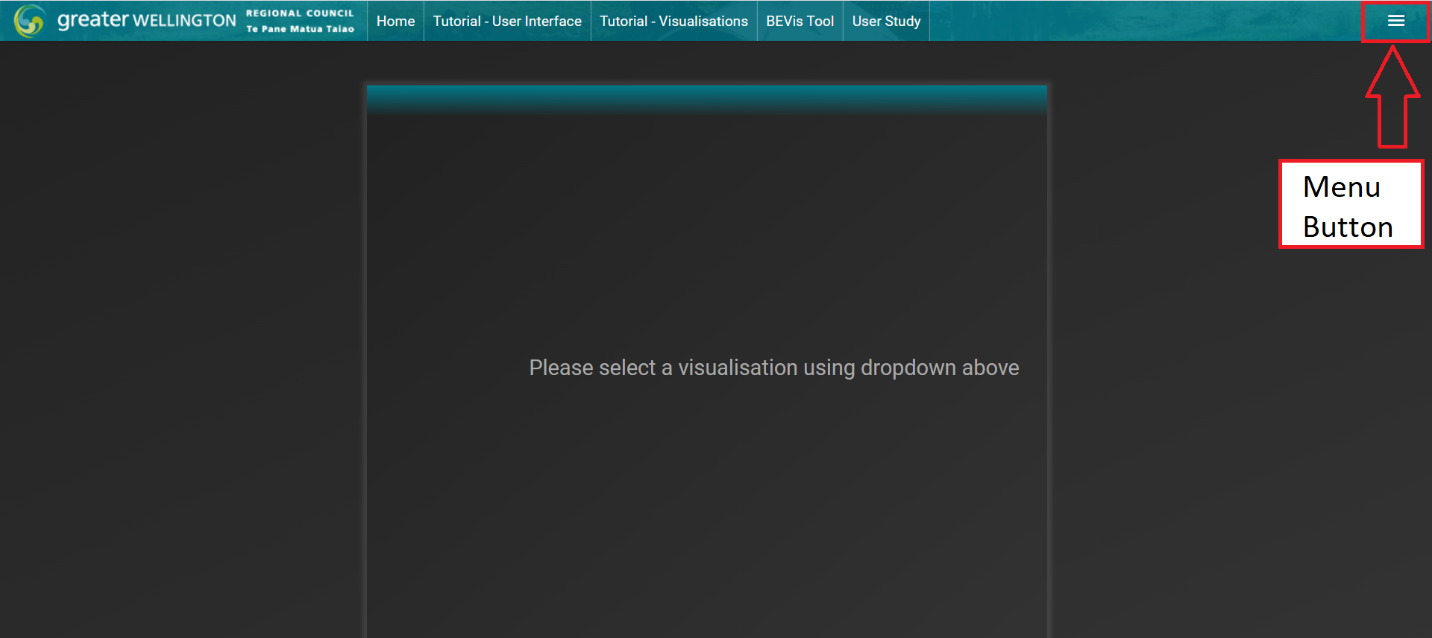


Figure 5 - Menu button in BEVis

1. Select your dataset.
   * Datasets “Metlink Data” and “Auckland Transport Data” are pre-processed; you can use the visualisations immediately.
   * Custom data can be loaded into the tool and the tool will attempt to create the data needed, which then can be used in the visualisations.
2. If you wish to use custom data:

* Load operational data in the first load file selector.
* Fleet List data is loaded in the second file selector.
* Pax List data is loaded in the third file selector.
* Press the “Process Custom Data” button and wait.
* *Please be patient*. If the window says it is unresponsive, select *keep waiting*. It will eventually finish. The browser will give you an alert when the pipeline is finished. Only then can you use the tool again.

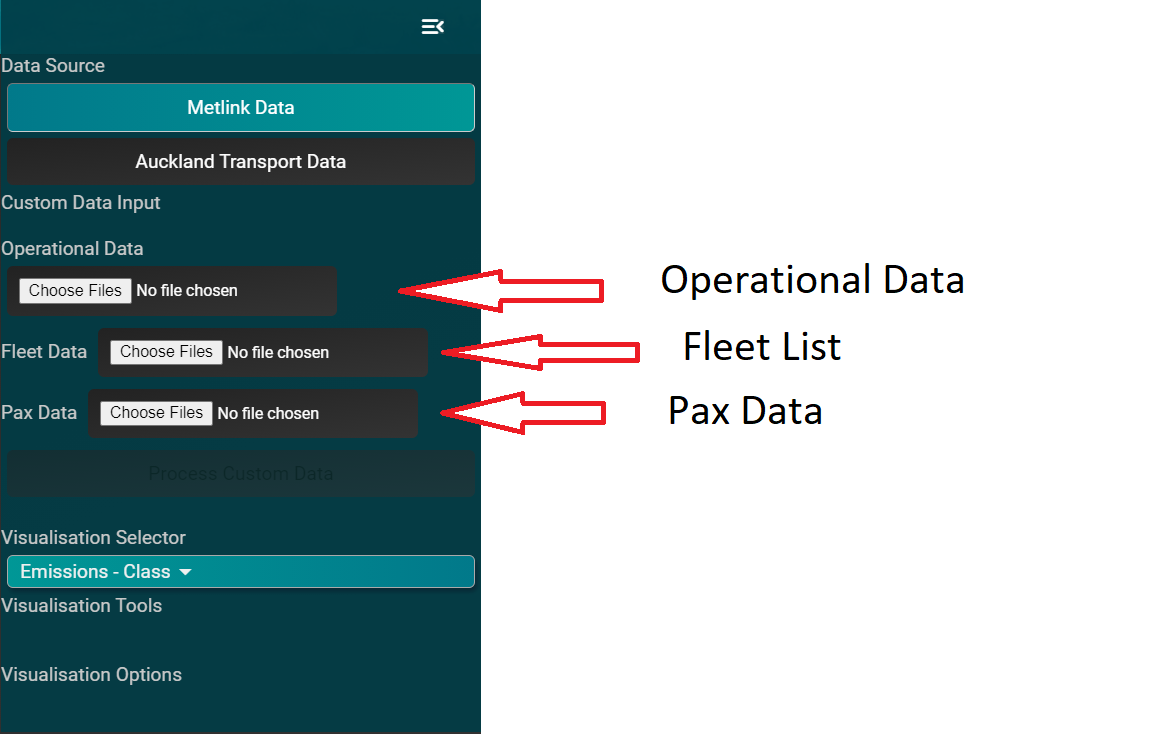


Figure 6 - Custom File Selectors in BEVis

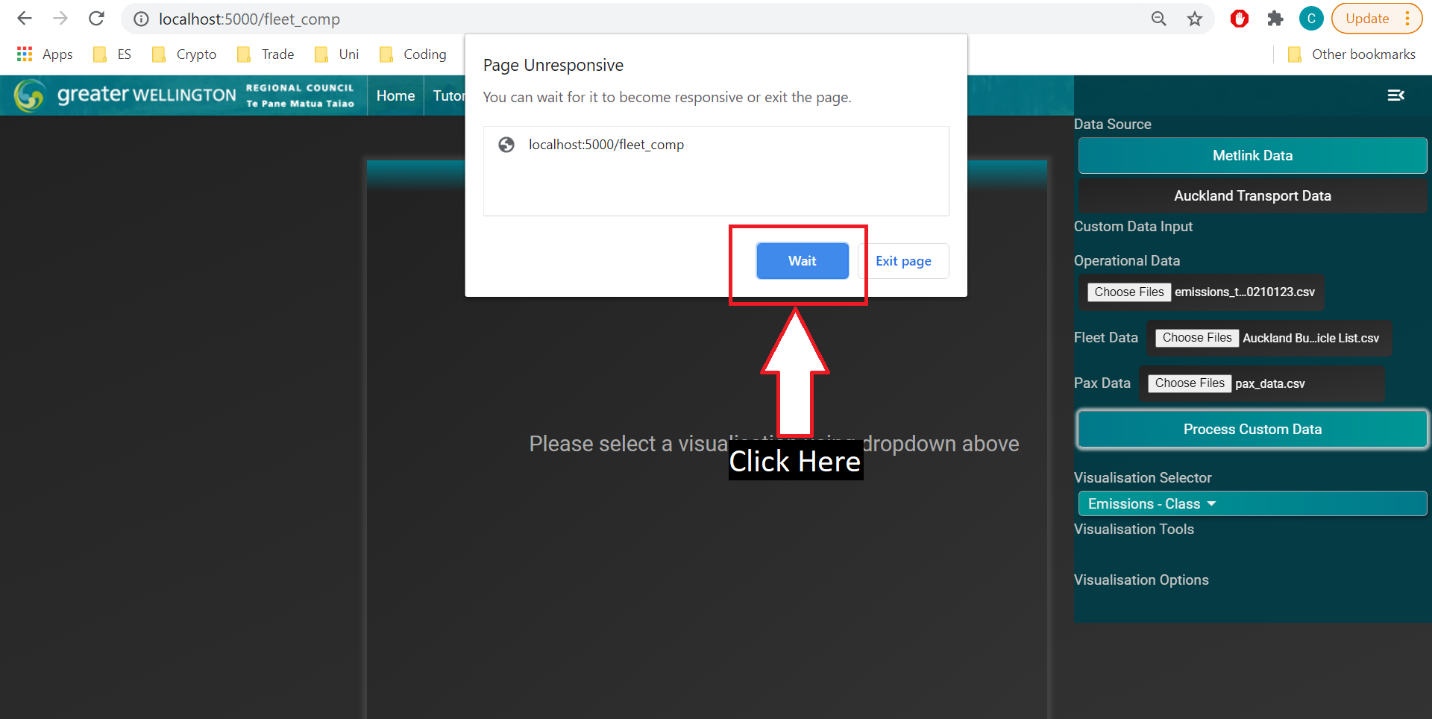


Figure 7 - Unresponsive popup while data is processing

1. When the pipeline is finished, a download window will open. There are 9 files in total, each a collection of potential errors or gaps in your dataset.

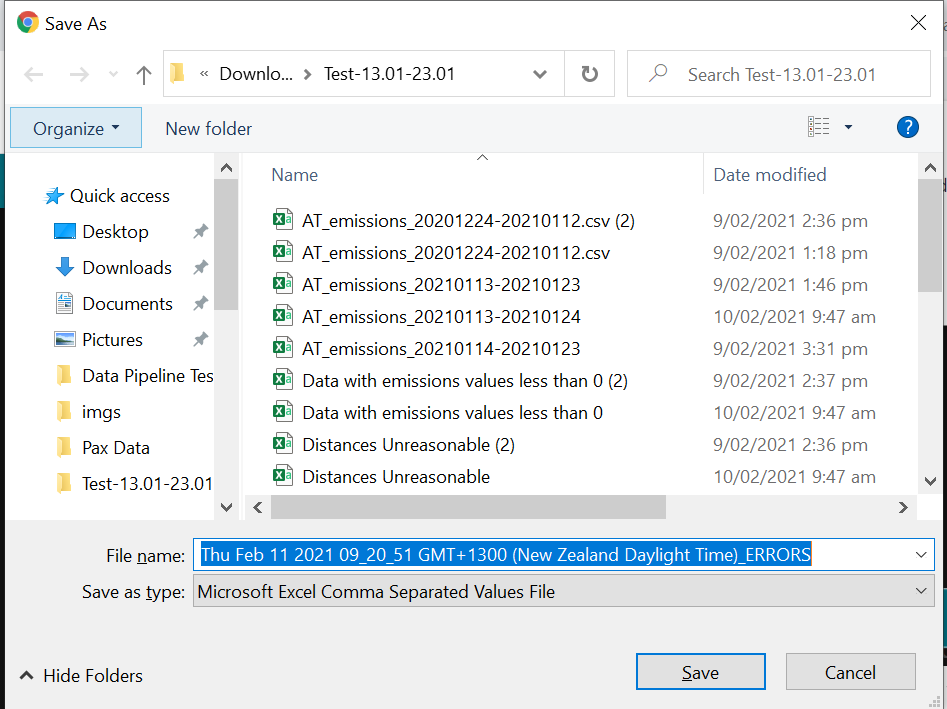


Figure 8 – Error files generated by BEVis in Custom Data mode

1. Select a visualisation using the dropdown at the bottom of the right-side menu.
2. Once the request is completed loading, you can interact with the data.

**Please note**: In order to use the data pipeline correctly please ensure your headers are correct, i.e., they exactly match the specification in section 3.3. Please be aware of the explicit use of chars such as ‘ ’, ‘\_’, and case sensitivity. A space at the end of titles for example, or an enter that is accidentally put in a cell, is enough to cause issues. If headers do not match, the pipeline cannot work.

## Using the Data Filtering Implementation

The data filtering implementation is a separate process to emissions calculations, as discussed in section 3. This is the process of taking raw data from operators or governing bodies and processing it to match the data specification in section 3.3.

For our project, we implemented a Nodejs application to pre-process the data. Node was chosen as a simple way to support the application with a backend. Since we were using JS on the front end, removing the Python stack (as is present in the deployed application) removes some of the overhead needed to develop on our code base. Nodejs provides convenient libraries for experimentation with SQL and MongoDB technologies, and an API building library express.js.

The repo contains the code used to scrape data from the Auckland Transport API then join this data with other data to create a single model of a sample of the bus operations on the Auckland Transport network between Dec 2020-Jan 2021. This formed the operational data for the emissions calculation model described above.

**Requirements**

The codebase for the pre-processing pipeline is available through git.

1. Download git.
2. Open git and navigate to your desired directory.
3. Enter the command:

git clone https://github.com/chriswtodd/ATE.git

Nodejs is used as the runtime environment for the program so this must be installed.

Nodejs is available for download [here](https://nodejs.org/en/download/).

**Installation and Running**

In a console, navigate to:

YourInstallationDirectory/ATE

Then enter:

npm install package.json

This will install all the necessary packages for our program.

In the console, while still located in /ATE folder, type:

node views/app.js

Navigate to:

localhost:3000

in your web browser to interact with the server now running on your machine.

Consult the readme available at “https://github.com/chriswtodd/ATE” for full instructions on use. A quick start guide is provided below.

**Quick Start Guide**

**Note** The csv produced by this pipeline has a JSON object, and that column (realtime\_observation) must be removed if you wish to use this data in the deployed application.

Our data pipeline is an implementation for us to show one way to completely generate the emissions of a given dataset. This serves as both the pre-processor and the processor (clean and join datasets to form the Operational Dataset and use Pax data with Fleet data to generate the emissions).

Acquiring data and calling endpoints until */join\_routes\_to\_final* serve as pre-processing. */join\_pax\_km* and */calculate\_emissions* perform the emissions calculating step.

Be aware you may change the connection object via *const client = new MongoClient(config.mongodb.uri, { useUnifiedTopology: true });* OR changing var *config.mongodb.uri* to your connection object.

## Acquiring Data

**Realtime Data**

The script realtimeScript*\RealtimeScript.js* must be run continuously to create the necessary data from the AT API. This can be deployed on a local machine and left running; however, this is vulnerable to power failures. It was previously run inside a screen env on a server master node for ~2months with approx. ~24hrs downtime.

The subscription key can be changed with the var at the top (search for “let key”).

**Schedule Data**

The script models\scheduleConfiguration.js can be run once every time the schedule changes.

***NOTE*** If the current datasets are between generation and the schedule changes (i.e., we once had trips scheduled for 24.01 but it change on 21.01) please run the /repair\_database endpoint to fix the dataset before generating the next.

## Importing Necessary Data

Data can be collected using the API Scripts or placed into a database. Please be careful with your database objects and ensure that your database names, URLs etc all match.

Once you have the data needed, the scripts will auto load the data for you, or data can be inserted using the mongoimport tool (Windows dist here: https://docs.mongodb.com/database-tools/installation/installation-windows/). Here is an example of the import URLs for our datasets:

mongoimport --db test --jsonArray --collection calendar --drop --file "calendar.json"

mongoimport --db test --jsonArray --collection calendarDate --drop --file "calendarDate.json"

mongoimport --db test --collection realtime\_raw --drop --file "realtime\_raw.json"

mongoimport --db test --jsonArray --collection routes --drop --file "routes.json"

mongoimport --db test --jsonArray --collection trips --drop --file "trips.json"

mongoimport --db test --jsonArray --collection versions --drop --file "versions.json"

***NOTE*** There is no connection URL in these imports so mongoimport will import these to a local db. Please ensure that your db connection objects are consistent across files and match the db you import these collections to.

The vehicle fleet list is currently implemented in the pipeline on the deployed app as a static file that must be loaded into the tool on a one-off basis. It is required to follow the data specification in section 3.3. If there is an issue with the dataset, the pipeline can warn you about errors related to headers being incorrect, vehicle TARE Weights being unreasonable (>100000kg, or 100 Tonnes), and vehicles with invalid engine types (the valid list of engine types is included in section 3.3).

The main endpoints to generate the necessary dataset are (in order of execution):

* /generate\_schedule
* /join\_raw\_routes\_to\_final
* /join\_pax\_km
* /calculate\_emissions

In order to use these end points, we need the schedule information in the format specified, and the raw information placed into the same MongoDB Database.

The connection object within views\app.js at the top must be changed to suit your connection to your database. It currently looks like const client = new MongoClient(config.testing.uri, { useUnifiedTopology: true });. It may have a different first argument (the connection uri). The db object (search for “let dbo”) must also be changed to the correct collection for your data.

The pipeline has some dependencies on hardcoded dates. This is mainly due to time constraints. Please change the hard coded dates in the four endpoints above to suit your dataset, otherwise the pipeline will not work. The locations of the hardcoded dates in the code is described the next section.

Finally, calling the 4 endpoints above in order will generate the completed dataset.

## Developing the pre-processing pipeline

This pre-processing pipeline has the potential to be reused for several datasets. All of which are produced from the AT developer’s API.

Firstly, we must run the scheduleConfigure.js script. This will give the GTFS information as specified previously in section 3.2. This script could be automated in the future. One issue that would be faced is how to go about repairing the database. Care needs to be taken to regenerate the sets of correct UUIDs after an unexpected schedule change.

Another issue that will need to be fixed is the main four endpoints reliance on hard coded dates. There are at least **eight** instances of hard coded values. In /generate\_schedule, the date filtering range should be changed, around line 546. This is the same as the calendarDate date field matches, around line 634, 658/659. In join\_raw\_routes\_to\_final, the date objects need to be changed on line 1348. On line 1372/1373 the value at the end of the conditional ‘$and’ needs to be changed to the correct dates. Finally, on line 1485, the dates for the match need to be changed.

As it stands, the code is not yet developed enough to be able to handle these edge cases. However, it could be considered as an example going forward for similar data cleaning exercises. Other additions to improve this pipeline include: data filtering options provided on the front end; interactive error messages; and automated data cleaning (e.g., detect dates in the wrong format and correct them).

# Implementation

## Data Storage & Access

Managing a dataset of this size and complexity requires careful consideration. Our chosen approach is to use a database instance to house the data, and a software tool to facilitate use of the data. Database technologies considered for this study were: MySQL & MongoDB.  
MySQL was considered as it is an implementation of SQL. SQL in conjunction with a relational database is the most popular database management system, particularly for large-scale enterprise contexts. This option was not pursued as even if we did use a SQL technology to implement the database, we believe the cost of writing queries would become a bottleneck in the future without good support in the technology for data warehouse analysis.  
PostgreSQL is another SQL specification tech. This was considered because of the data warehousing methods provided. PostgreSQL required paid hosting as well, and so we did not use this for our implementation.  
MongoDB is a NoSQL database management system and the most popular NoSQL database available. It is widely used in several contexts although typically not in legacy systems or contexts where data integrity must be maintained (e.g., healthcare & finance).

Although SQL would more closely relate to the database systems currently in use by transport agencies, MongoDB was selected for use in this project. This was primarily due to the higher quality free option available and pre-existing skillsets allowing for greater progress to be made during the short timeframe of the project.

The suite of functions and tools provided by MongoDB is similar to the level of PostgreSQL as well, so we have access to powerful data aggregation and manipulation functions. This makes it well suited to web application development.

## Data Collation within the Model

**Note** The following section outlines how the inputs to the emissions model were derived from the data sources (outlined above) within the context of a proof of concept. As there are multiple data sources with several different unique identifiers this process was relatively complex. We believe a large-scale implementation of this particular method would not scale appropriately to the required dataset. However, it is included here as an example of the pre-processing that is required to form datasets to our specification.

**Collation of Schedule Data**  
Scheduled (GTFS) data was initially collected and used to form a collection of scheduled trip instances. The scheduled data was collected when a version change occurred. The general process to generate the scheduled trip instances is as follows:

* The trips are joined to the routes using the *route\_id* and then filtered using the *agency\_id* to identify the set of trips operated by providers of interest (Ritchies & Go Bus in our case).
* The dates of the trips are added from the schedule using the *service\_id*. The set of dates for a service is created by: getting the service days from the calendar collection; then adding/removing exceptions specified in *CalendarDates*.
* Each scheduled trip instance is assigned a universal unique identifier (UUID). The trip instances can be uniquely identified using a concatenation of the date the trip instance occurred and its trip\_id (as shown below).

Unique Trip Instance Identifier format - **[Date]\_[Trip\_id]**

The UUIDs were used to identify the proportion of scheduled trips that were observed in the real-time data. There were ~49/86000, or ~0.05% of scheduled trip instances not observed. Due to a lack of information regarding these trip instances the only reasonable assumption we can make is that they actually did not run (e.g., they were cancelled or unable to service the trip instance).

We concluded that the real-time data was the best available representation of the actual activity on the network. As a result, the collected schedule data was only used for validation purposes rather than emissions calculations.

**Collation of Real-time Data**  
We collected real-time data using automated scripts. The real-time script, responsible for requesting API information every 30s was hosted on VUW’s main node of their dedicated server (the “barretts” machine). The real-time data was posted directly to MongoAtlas, a live deployed implementation of a clustered MongoDB database in a single collection.

The real-time trip instances were joined to the GTFS routes collection using the *route\_id*. Then, they were filtered to the relevant operators using the *agency\_id* in the GTFS routes data. This produces a collection of observed trip instances by Ritchies & Go Bus. These trip instances contained:

* Date
* Vehicle ID
* Route name
* Trip start time
* Trip duration - Derived from the start and end times present in each trip instance

The UUID described previously was assigned to each trip instance in the real-time data.

The vehicle data is joined to each trip instance using the *vehicle\_id*. This provides each trip instance with the tare weight and the EURO rating of the vehicle that served it.

The final data to create the required datasets is the distance and pax\_km data. The provided data was aggregated to the route-vehicle level. I.e., the data contained the distance travelled by a particular vehicle on a particular route over the reviewed time period. As the emissions model operates on trip instances, this required some assumptions about how to apply the distance and pax\_km values to individual trip instances. Distance is based on the average distance travelled on a route across all vehicles. Pax\_km is based on the average distance travelled per route, *per bus*. A summary processing pax\_km is:

* Identify the *vehicle\_id* and the *route\_short\_name* for each real-time trip instance.
* Use these two values to identify the corresponding entry in the pax\_km data.
* Calculate the average pax\_km per trip by dividing the total pax\_km by the *Vehicle trips* field. The average pax\_km are then assigned to the relevant trip instance.

There appears to be distance discrepancies, and errors introduced by leading 0 issues. There appears to be only a single route that is missing distance information with our current technique (32 total trips), however being unable to access AT’s data extraction method we have no way of knowing they are not accidentally aggregating their data incorrectly. Some examples include routes 031 by RTH and 31 by GBT, or 75 by GBT and 075 by NZB. This appears to be an issue stemming from the route table on the developer API (this API provided the routes with leading zeros which were indicated to be school services *Chris V - refer to your emails if you need a reminder on this*).

The assumptions and resulting consequences inherent in this process are detailed further in the section 5 of this report. Each trip instance now has the required data for the emissions model to estimate the generated emissions for each trip instance. A summary diagram of the full procedure is included in Figure 1.

## Implementation of Emission Impossible’s Emission Calculations

*Chris V – This section was mostly reproduced from the GWRC report from last year with some modifications to make it suit this context*

### Background Information

Emissions Impossible (EI) are an environmental consultant contracted by GWRC to produce emissions profiles for the Wellington public bus fleet. The emissions model used in this study applies the same underlying calculations produced by EI. These emission profiles are used to determine emission quantities from a given bus at the trip instance level. Each bus is assigned an emissions profile based on their size and engine EURO-rating. The emission profiles cover the pollutants and greenhouse gases in the table below. Each profile outputs emission intensities (in grams per kilometre) for this set of gases based on the average speed of the bus over a given trip. These emission intensities can be used to determine the quantity of pollutants emitted over the length of a trip.

Table 8 Emissions calculated by EI's emission profiles

|  |  |
| --- | --- |
| **Pollutants** | **Greenhouse Gases** |
| Carbon Monoxide,  Nitrogen Oxides,  Hydrocarbons,  Particulate Matter | Fuel Consumption,  Methane (CH4),  Nitrous Oxide (N2O) |

We emulated EI’s emissions calculation methodology with our software tool. This methodology was derived from the spreadsheet provided by EI. For the emission profiles and their sources, refer to the spreadsheet provided by EI. The only modifications we made were in instances where there was an identified gap in EI’s methodology. A general description of EI’s emission methodology and our modifications is included below.

### Description of EI’s Methodology

The general process is to generate the total emissions over a period of time is to analyse each trip instance to find the emissions produced by the bus on that trip. These trip emissions can then be summed to produce totals over given time periods. Each trip instance has a vehicle ID (rapid vehicle number) associated with it. Information about the vehicle that carried out a trip is then looked up in the fleet list and the vehicle’s emissions profile is found.

The emissions profile for a given bus is determined by the buses size and the engine EURO-rating. The emissions profile is essentially a set of equations with various weighted factors for each emission that are dependent on the speed of the vehicle.

There are two possible sizes for the emissions profile: “small” and “standard”. This size is determined by the GWRC contractual size of a given bus within the fleet list. If a bus is contractually a “small vehicle” then EI classify the bus as “small”. All other contractual sizes of bus (including medium, large, and double decker) are classified as “standard”. It should be noted that the contractual size of the bus is determined by maximum passenger capacity rather than weight, which means that there is some overlap in terms of the vehicle weights e.g., some buses have a lower occupancy but are still relatively heavy for the amount of people they are licensed to carry.

The EURO-rating of the engine is a measure of the European emissions standard that a given vehicle meets, based on the age and technology that went into the construction of the vehicle. Within the historic fleet there are a range of Euro I through to Euro VI vehicles as well as some “PRE-Euro” buses. In general, as the Euro rating increases, the pollutant emissions decrease significantly. However, the difference in Euro classification is less noticeable for greenhouse gases, with only some small decrease at slower speeds.

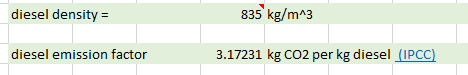
The average speed is calculated based on provided route distances and trip durations observed in the real-time data. Then this speed was rounded to the nearest 2 kmph. The speed and mass of the vehicle are entered into the emissions profile (for the specific Euro Class) in order to produce pollutant and greenhouse gas emission emissions for each trip. These intensities are in grams of emissions per kilometre. The emissions for the trip are therefore calculated as the per km emissions, times the length of the trip.

The weight factor is calculated based on the loaded weight of the bus. This loaded weight is composed of the tare weight of the bus summed with the weight of the driver and the average number of passengers on the bus over the trip.

However, a formula was only provided for the “standard” buses (included below). The spreadsheet set the weight factor for all “small” buses to 1.

The emission intensities are multiplied by the weight factor and the service distance of the trip to find the total emissions of a given trip. This process is repeated for every trip within the examined date range by our analysis tool.

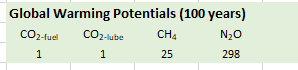
In terms of greenhouse gases, the emission profiles generate fuel consumption quantities in grams per km. This mass of diesel fuel is converted into a quantity of carbon dioxide (CO2) emitted using an emission factor. EI included a mass to volume conversion factor so we could generate fuel consumption totals in litres. Both factors are shown below.



EI also accounts for the CO2 produced as a typical diesel bus consumes lubricant oil. This emission factor is shown below.



The other significant warming gases produced by diesel buses, CH4 and N2O, are included in the emission calculations. These gases were multiplied by their global warming potentials (shown below) to find their CO2-equivalents. These figures were then summed with the CO2 produced by fuel and lubricant consumption to find the total CO2-equivalent for the trip.



If a given trip was carried out by an Electric Bus, EI applied the following assumptions:

* Electric buses produce no pollutant gases and consume no lubricant oil.
* Electric buses use 1 kWh of electricity per km travelled.
* 1 kWh of electricity produces **110 grams** (109g excluding transmission loss) of carbon dioxide-equivalent greenhouse gases (based on 2019 data from the Ministry for Business Innovation and Employment [2]).

We implemented most of these assumptions within our tool and account for electric buses within our emissions totals. The only assumption we changed was to update the carbon cost of electricity to 2019 data from the Ministry of Business, Innovation and Employment [3].

### Modifications in the model’s Methodology

The original EI model used contractual bus sizing to select the method for applying variations in weight to the emission factors. It was decided to use the weight factor equation shown in the previous section for all the buses in the fleet. The contractual sizing is occasionally not representative of the actual size of a given bus. Therefore, using the vehicle’s tare weight combined with passenger loading provides a significantly more representative indication of the size and weight of a given bus. It should be noted, this introduces the assumption that emissions generated respond *linearly* to variations in gross vehicle weight for all bus sizes.

The other modification to the original model was to not round the average speeds to the nearest 2 kmph. The emission profiles are designed to apply to a range of speeds and a valid reason could not be identified for reducing the precision of the analysis. As a result, we use unrounded average speeds in our model.

# Assumptions and Interpolations

TODO Add results of comparison to real fuel consumption data (if we receive the data)

## Missing Information

We have identified several types of missing information within our dataset. The first dataset runs from 24/12/2020 – 12/01/2021 and contains a total of ~86000 trip instances. The table below outlines the missing data identified; the quantity of data missing; the implications of the missing data; and any assumptions made to work around the missing data.

Table 9 - Missing Data

|  |  |  |  |
| --- | --- | --- | --- |
| Missing data | No. of trip instances affected in full set / 86000 (& in 24/12 - 30/12 date range) | Implications | Solution |
| Vehicle information | 5849 (0) | We cannot assign a vehicle number to the trip; therefore, we cannot assign a EURO class to the trip instance. | Interpolate the trips without info by assigning EURO classes at the same proportion to the missing trips as those present in the data. |
| Real time measurement | 5849 (0) | This means that this trip should have occurred according to our formed schedule but was not in the real time dataset. | Ignore this, as we are focusing on observed trips. If there is no trip observed, we assume for some reason it was cancelled. |
| Missing from schedule | 6 (0) | This trip occurred and we have a real time observation for it, however it is not in the schedule. It will be missing a scheduled start time. | Using trip\_id we can match these trips to other similar trip instances in the schedule and use their start\_times. |
| Any stop information | 49 (0) | This trip was both in the schedule and the real time, however it does not record any stop information. This means we cannot calculate the speed of the bus. | Assume no stop information is present due to the trip instance being cancelled. We cannot do anything with this observation. |
| Final stop information | 7302 (0) | This trip was not recorded finishing its journey. This can be an issue with missing stops, finishing early, or geofencing. | Assume that every trip with recorded stop information completes the entire trip. It may be possible to determine incomplete trip distances. However, the probability of an incomplete trip is very low relative to number of recorded incomplete trips. This results in time measurements being slightly underestimated. However, we know this is not a huge issue, as average speeds are still reasonable (as observed in the output visualisations). |

**Additional notes**  
In the generated dataset, missing real-time measurements were the **only** cause of missing vehicle information. As such, we did not need to interpolate missing vehicle information with this dataset. The suggested methodology used for the Wellington study is included for reference below.

Use observed trip instances in the existing data to generate a probability distribution of the EURO classes for a given trip. Then use a random number generator to assign a EURO class to the given trip instance. For example, if 70% of other trip instances were operated by a EURO3 class vehicle then there is a 70% chance that the random number generator would return a value that assigns a EURO3 to the trip instance without vehicle data.

Regarding the missing real-time information, the assumption was made that if it was not in the real-time trip updates data then the trip did not run for some reason. This introduces the possibility that trips occurred but were not recorded. However, to remove this possibility we would need to assume all scheduled trips were operated and include them in the emissions total. As this model is based on observed trips rather than scheduled trips, this was deemed unnecessary. If the probability that a scheduled service did not run is lower than the probability of an unobserved trip occurring on the network, then it would be worth considering changing the model to suit this scenario.

## Scheduled Trip Distances

There are two available sources for distance data for the trips in the real-time data. These are:

* The distances included in the distance/pax\_km data supplied by AT.
* Generated distances based on shape files available from GTFS API.

The latter option was initially used to generate distances for the real-time trips in the dataset. There is a GTFS endpoint on the AT API that returns the shape file (i.e., a list of coordinates) when queried with a *trip\_id*. The process to calculate the distance was as follows:

* Find the distance between each sequential pair of coordinates in the shape file. The calculations were carried out using a geographical calculation library in JavaScript.
* Sum the distances between the coordinates to find the total distance of trip.
* Assign the distances to the real-time trips by *trip\_id*.

Upon comparison with the supplied distances, it was found the AT distances were significantly larger than the distances generated from the shape files. As the pax\_km values are linked to the distances supplied by AT, the supplied distances were used to estimate the emissions. This ensured consistency across analysis exercises; hence this option facilitates comparison.  
The distances generated from shape files may be relatively inaccurate. However, considering the magnitude of the difference between the two sets of distances it may be worth confirming the validity of the distance generation methodology used by AT. A notable data outlier that seems invalid the NX1 route with an average trip distance of 11,000 kilometres.

## Passenger Km

Passenger km (pax\_km) is the cumulative distance travelled by passengers on a particular trip instance and are an important part of the emissions model’s analysis and visualisation. They have an impact on the quantity of emissions generated by increasing the weight of the vehicle. They also provide insight into the net emissions generated by a given trip instance (i.e., whether emissions were reduced overall by running a particular bus service).

Pax\_km is incorporated into the model by dividing pax\_km by the trip distance to generate *ave\_pax\_loading*. Ave\_pax\_loading is the equivalent number of passengers that would have travelled on a vehicle for the entirety of the trip instance. This allows the average additional weight on the vehicle due to passenger loading to be calculated and used in the model. For reference, each passenger is assumed to be 80kg.

We received the distance and pax\_km data aggregated to the route and vehicle level. The trip instance assignment of pax\_km and distance outlined in the methodology inherently assumes that each trip instance on a route travels the same distance and has the same average passenger loading. This is unlikely to be true, however a more precise approach cannot be achieved without additional data.

## Emissions Model

The following sub-section outlines the assumptions that are inherent in the underlying model that estimates the emissions.

The model estimates the emissions per *trip instance* based on average speed and distance. This level of granularity results in the following factors being excluded from the analysis:

* **Variable road gradient, speed, and stop/dwell times over the course of a trip instance** - Road gradients and speed variation have a significant impact on emissions due to the additional energy required to travel up hills and accelerate. However, accurate real time data (including accelerometer and speed information) with sufficiently short intervals between data points would be required to carry out this level of analysis. At the time of the study, this data does not exist or was unavailable. The Emissions model also cannot currently accept this level of detail in the input data. Further review would be required prior to being updated to accept this additional data to ensure it remains aligned with the relevant EU standards.
* **Driver Behaviour** - Driver behaviour has a significant influence on emissions due to difference in frequency and intensity of the acceleration/deceleration of the bus. However, the operational data to carry out this analysis does not exist, and this level of complexity is beyond the current scope of our analysis.
* **Environmental & Weather Conditions** - The ambient temperature and differences in traction due to weather variations could potentially make a marginal difference to the efficiency of an engine and its emissions. The study did not include a collation of historic meteorological data and nor were we able to source any information on how weather conditions might alter emissions. As a result, this additional level of complexity is beyond the current scope of our analysis.

**Dead Running**

Dead running is a necessary part of operating a public bus network. There are regular occasions where buses need to be operated without passenger on-board such as, during repositioning and travelling to/from the depot. We have assumed that dead running amounts to ***15%*** of the distance travelled on scheduled services. This proportion was used for the Wellington study and likely requires updating for the Auckland context.

**Derivation of the offset emissions**

Generating the CO2-equivalent offset for a given trip instance assumes that **each passenger would instead drive the same distance as the sole occupant in an average NZ car**. I.e., the total pax\_km distance is driven by an average NZ car. This is a relatively rough comparison; however, it was deemed acceptable given the scope of the analysis.

The “average” NZ car was found in a Ministry of Transport report on the NZ Vehicle Fleet from 2017 [2]. The average fuel economy of the light petrol fleet in 2017 was estimated as *9.2 litres per 100km.* The conversion factor between grams of CO2 per km is *22.961 multiplied by the petrol consumption in litres per 100km*. This gives the following figure for the emissions intensity of the average car in the NZ fleet:

**211.2 grams of CO2 per km driven**

This value was applied in the model to identify the quantity of CO2 saved by providing a given trip instance. This enabled the generation of a heat map, displayed in the next section, that displays the effectiveness of each route in reducing emissions on the overall transport network.

# Outputs and Visualisations of the Analysis Tool

Some images of example visualisations produced with the previously developed visualisation tools are included below.

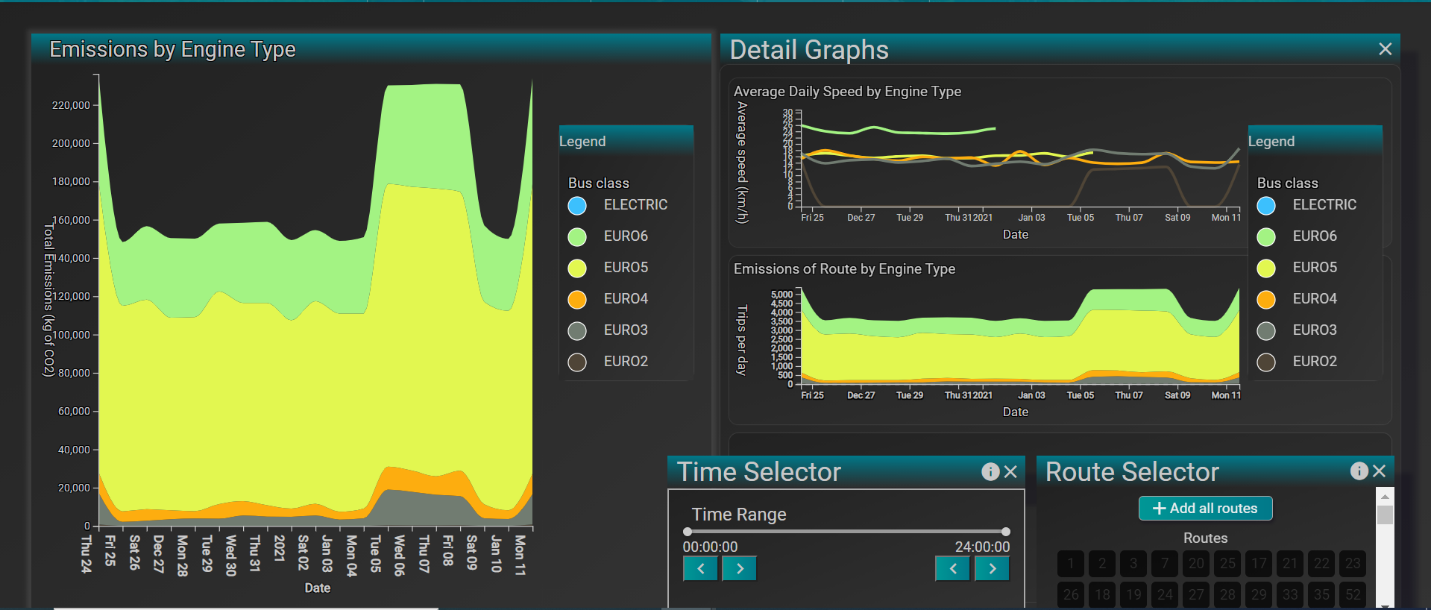


Figure 9 - Steam chart of emissions from Ritchies and Go Bus from 23/12/2020 to 12/01/2021

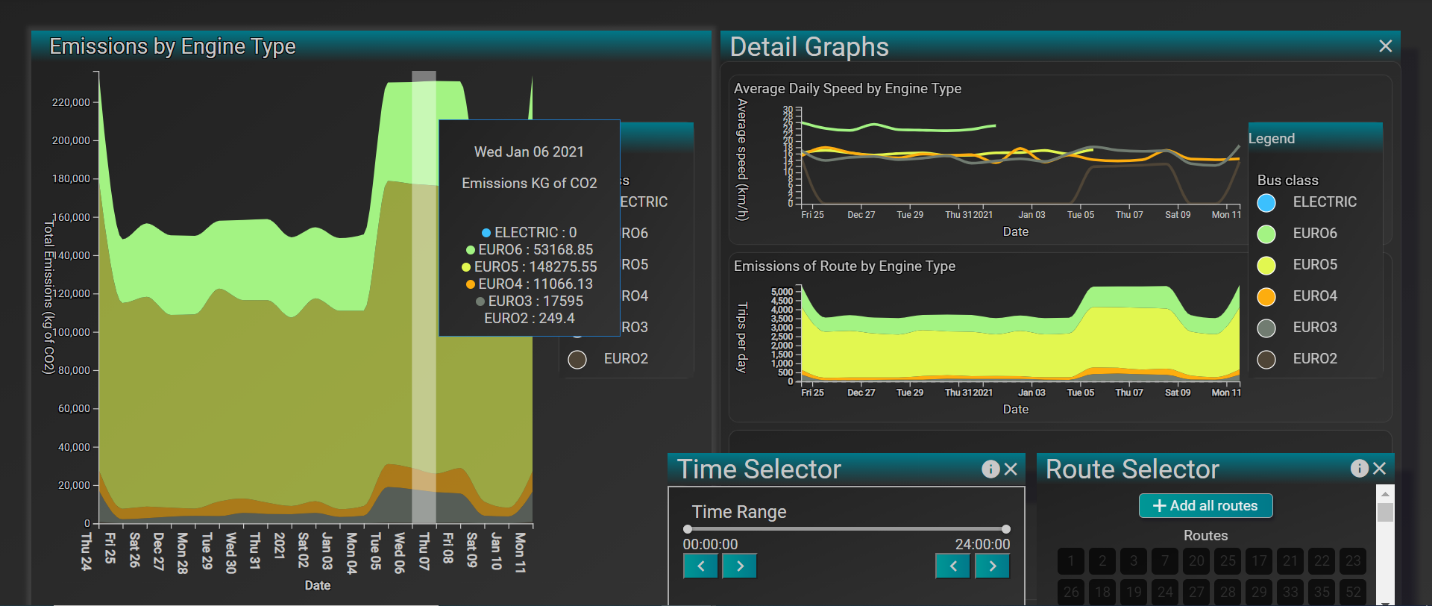


Figure 10 - Steam chart with highlighted tooltip displayed

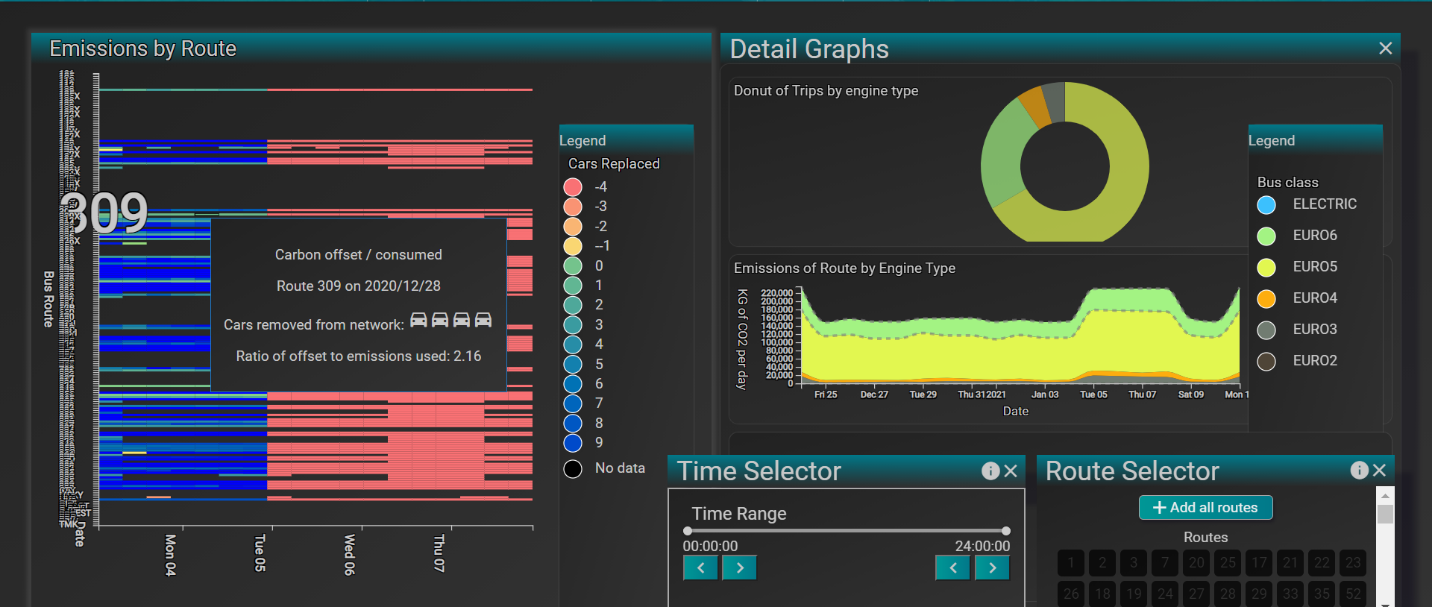


Figure 11- Heat chart of emissions from Ritchies and Go Bus from 23/12/2020 to 12/01/2021

## Datasets Produced

*This section is included purely as a reference for the data sets collected on the laptop used by Chris Todd.*

There are several datasets that have been generated from this exercise. All necessary datasets for the pre-processing pipeline are in the dataBackups folder, or the public/data folder in the projects directory.

ATEBackups at C: is a folder that contains all the generated datasets from the pipeline.

exampleOutput at C: is a folder that contains the example outputs from the test data run through the deployed pipeline.

ATEBackups:

* Complete\_Raw - The complete raw dataset collected. Complete from 23/12/2020 - 24/01/2021. There are several other days data present however these may not be complete.
* Complete\_datasets - Datasets produced from feeding the result of the pre-processing pipeline into the deployed pipeline.
* Daily Raw - Collections of trips separated by day.
* Daily Schedule - Collections of trips separated by data.
* Data Pipeline Test - Datasets used to test the deployed pipeline.
* Fleet Lists - Vehicle fleet lists provided by AT/other providers.
* Pax Data - Passenger km data provided by AT.
* Schedule\_01.13 – AT’s scheduled services beginning on the 13th of Jan 2021
* Schedule\_12.23 - AT’s scheduled services beginning 23rd of Dec 2020
* Test Data\_13.01-23.01 - The schedule and raw real-time information pulled from the AT API that was used to verify the function of the pre-processing pipeline, with the result of which being fed into the deployed pipeline. Files of note:
* emissions\_AT\_20201224-20210112-OurDistances - A file that used the pre-processing pipeline with our distances calculated from shape file distances and was fed into the deployed pipeline.
* downloadDataFromMongo - Batch script to automatically export data from mongoDB. Requires mongoexport.
* testMongoSchedule - Batch script to automatically import data from mongoDB. Requires mongoimport.

exampleOutput:

* Emissions\_AT\_20201223-20210112 - The results of running the pre-processing pipeline on the schedule and real-time data applicable to the date range, then calculating emissions using the deployed pipeline
* Emissions\_AT\_20201223-20210112 - See above
* FakeDataOutput - See above

# Recommendations for Future Analysis

**Assign each trip instance a Universal Unique Identifier (UUID)**

If each trip instance is assigned a UUID when it is scheduled, this would vastly improve reporting and decrease time spent on data analysis tasks.  
For example, UUIDS allow a list of all scheduled trip instances to be easily generated. This list can be cross referenced with the real-time observations to determine the following: - The number of scheduled trip instances not observed in the real time data. From this data, a likely cause for missing real-time data can be determined (e.g., cancelled trip instances or faulty real-time data collection). - The number of unscheduled services operated on the network.

**Introduce nationwide data standards for operational bus data**

A nationwide standard format for bus operations data would streamline the development of an enterprise solution for this model. As outlined in this report, the emissions model requires input data in a certain format. If the operational data format was standardised, this would significantly reduce the amount of pre-processing required. A standard format may also assist the developers in automatically identifying the completeness of the data set.  
It should be noted that formatting operational data to meet the standard will likely incur costs at the regional level. As such, it may be worth comparing the costs required to develop the enterprise solution with and without a data standard. It is the authors’ opinion that introducing a data standard is likely to reduce costs overall. Firstly, the standard can be designed to be generated by pre-existing staff within the regional public transport operators. Utilising the internal workforce is likely to be more economical than using contracted software developers to complete a similar task. Secondly, a national data standard would promote the development of software tools to meet business needs outside of emissions accounting.

**Identify data sources within the public transport sector that would benefit from standardisation**

As public transport telemetry becomes more advanced and widespread, greater quantities of operational data will be collected by public transport operators. As referenced previously, data in a standard format is significantly easier to process and analyse. As a result, it may be worthwhile to identify developing data streams and produce a corresponding standard. Conforming data to a standard is relatively straightforward at the point of collection. The early implementation of a data standard will reduce the work required to process the data to meet this standard.  
Examples of upcoming data streams include: real-time movement data generated by on-board accelerometers and battery usage data from electric vehicles.

**The Vehicle Fleet List**

The vehicle fleet list could be further improved, either within the research tool or the commercial tool. Within the research tool, one of the main limiting factors for a better implementation of the list was the limited database size. Assuming this is still an issue, a local file collection could be created and appended to each time that the vehicle list is updated or changed. This approach is limited by the size of the files, and as the collection grows the time taken to run the pipeline will grow exponentially due to the limited handling functions provided by JavaScript (our front-end tech). A solution to this would be using a database.

Using a database would scale well to include all the vehicle fleets in the country. This also means that the overhead of having files and separating vehicle fleets can be simplified by introducing tables (or collections in MongoDB). The disadvantage is the maintenance and infrastructure required to run a database.

**Other Recommendations**

We are using a database-centric approach and being advised by a relatively new industry professional. Databases were the best middle ground solution we have found. Due to the interest in front-end processing and other similar functions which will be difficult in my view to extend further than what is already implemented (the calculation pipeline is already O(n^2) and generally very slow, hence the exponential slow down). I believe perhaps creating a dedicated application in a different technology may offer another solution. Using C as an example, a skilled C developer could make a similar application that instead of running in a browser runs as a dedicated application that can be installed. This means that the app will run faster, and certainly will process data on the local machine faster, however you may have issues hosting it on the web, and supporting the application moving forward.

Databases and hosted solutions are difficult to use for free. They are however cheap. We are already pushing the limits of free subscriptions to database tech such as MongoAtlas. Our projects currently hold ~1GB of data across 2 different databases hosted in an AWS data warehouse in Sydney, with a limited bandwidth and a shared distributed cluster. The distributed cluster is due to the free tier we are using, and means the infrastructure powering our database is shared with others. At scale, this will obviously be problematic. The data size is one of the reasons the vehicle fleet list is not implemented as described above.

# Conclusions

The software-based approach outlined in this report for calculating public bus emissions on a large scale is viable. The model used for this study is based on internationally recognised emissions estimation techniques and **(pending fuel sanity check)** the outputs have been validated against fuel consumption data. The most significant challenges in scaling this solution to a national level relate to the pre-processing, filtering, manipulation, and storage of very large quantities of data. The authors believe this task can be accomplished by a software development team with cooperation from the regional transport operators. Further investigation into the costs of implementing an enterprise solution are still required.

# References

|  |  |
| --- | --- |
| [1] | European Environment Agency, “Technical guidance to prepare national emission inventories,” Publications Office of the European Union, Luxembourg, 2019. |
| [2] | Ministry of Transport, “Annual Fleet Statistics,” New Zealand Government, Wellington, 2017. |
| [3] | Ministry of Business, Innovation & Employment, “New Zealand energy sector greenhouse gas emissions,” 2019. [Online]. Available: https://www.mbie.govt.nz/building-and-energy/energy-and-natural-resources/energy-statistics-and-modelling/energy-statistics/new-zealand-energy-sector-greenhouse-gas-emissions/. [Accessed 2020]. |