Report

Traffic and Emissions Modelling

Prepared for NZ Transport Agency (NZTA) (Client)

By Beca Infrastructure Ltd (Beca)

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1 Introduction

1.1 Background

Beca have been commissioned by NZ Transport Agency (NZTA) to work with Emissions Impossible Limited (EIL), air quality specialists, and Auckland University, to see how easily typical traffic model results can be loaded into EIL's Vehicle Emission Prediction Model (VEPM) by traffic modellers.

A VEPM predicts scenario specific network emissions for carbon monoxide (CO), carbon dioxide (CO_2), hydrocarbons (VOC), nitrogen oxides (NOx), exhaust particulates ($PM_{2.5}$), brake and tyre particulates (PM_{10}) and fuel consumption based on output traffic model travel speeds for a given year.

The normal existing process when calculating environmental emissions from a transport scheme is for traffic model results to be passed onto environmental specialists, who then separately calculate emissions and fuel consumption. This study tests the production and input of traffic model data by traffic modellers into VEPM.

The objective of the work is not to provide analysis of emission levels from a particular scheme but rather to analyse the practicalities of traffic modellers undertaking this process. The report details steps undertaken to use VEPM and describes a case study that has been undertaken using actual traffic model data. The model output is derived from the SATURN based Kirkbride traffic model previously used for an NZTA scheme assessment. The analysis in this report focuses on the production, processing and transfer of data from this traffic model to the VEPM and how emissions vary based on what processes, outputs and procedures are applied. This analysis therefore raises discussion areas and some suggested best practise when using the VEPM coupled with areas for future work.

1.2 Report Structure

The remainder of the report is structured as follows:

- Chapter 2 describes what traffic modelling is and the Kirkbride case study
- Chapter 3 details the process for generating data from a traffic model and inputting it into VEPM coupled with outlining the proposed methodology for testing various different processes for generating this data.
- Chapter 4 reports the results of these tests
- Chapter 5 highlights the key issues and findings
- Chapter 6 provides a conclusion and raises areas for further investigation

2 Traffic Modelling

2.1 What is Traffic Modelling

A traffic model can be defined as the loading of vehicles between different origin and destination zones onto a modelled highway network, this process is called the assignment. The network would typically include details with regard to travel speeds, capacities and intersection delays. A “Base” year traffic model is usually calibrated and validated against existing observed count and travel time data. A traffic model is run using mathematics with the objective of achieving equilibrium between supply (the network) and demand (vehicular trips).

A future year model is used to forecast future year traffic volumes which allows for traffic growth. A future year “Do Minimum” model is often developed first, which would include background traffic growth coupled with a network that includes only planned highway network improvements. The future year “Do Something” or “Option” Scenario would also include the specific highway scheme to be tested. The aim of traffic modelling is therefore to understand and develop an optimal road network with efficient movement of traffic and minimal congestion problems.

There are three broad categories of traffic model types which broadly cover their level of detail, operation and scale as well as a range of corresponding traffic modelling software. **Table 2-1** provides details of these.

Table 2-1: Traffic Model Types and Software

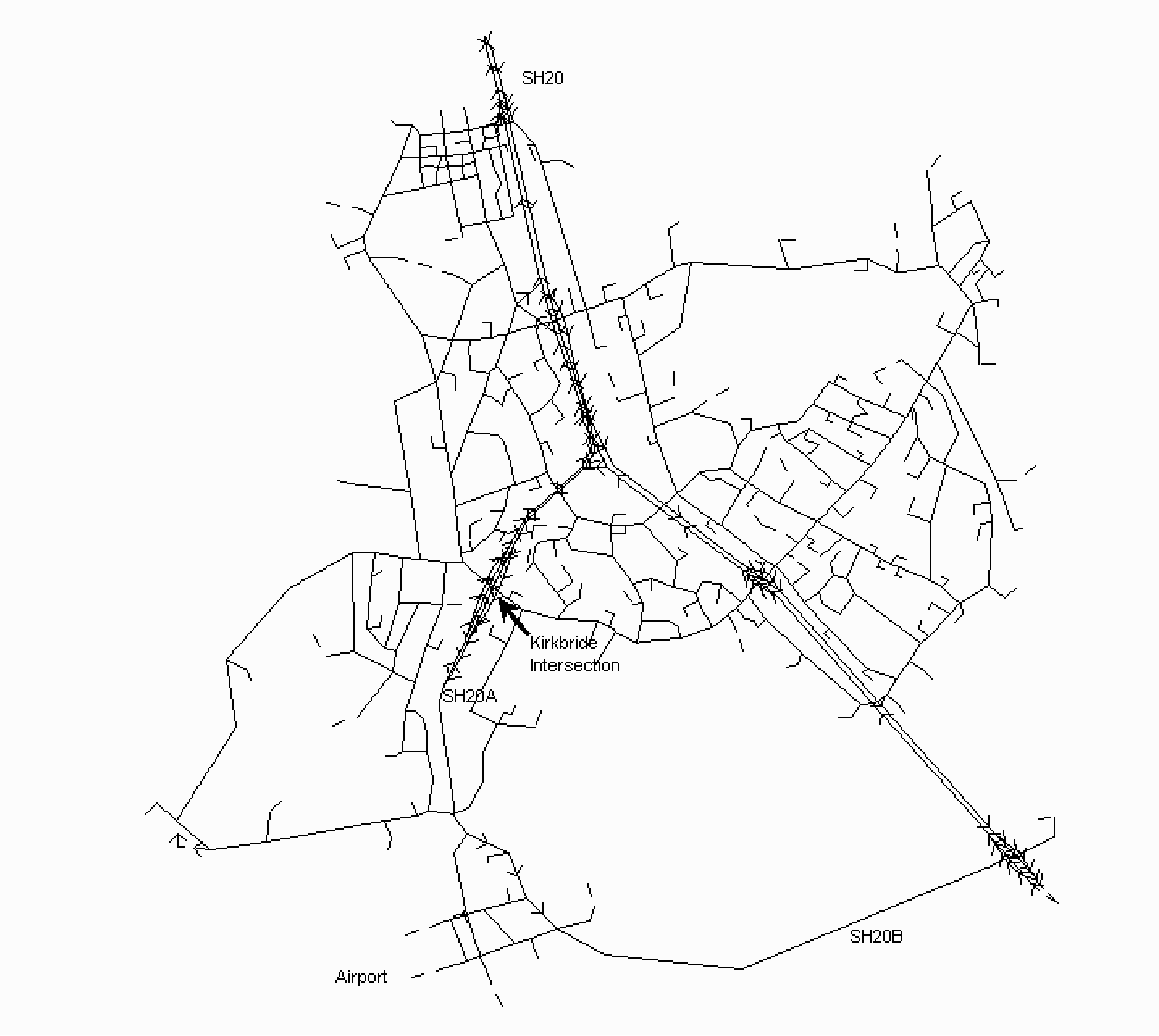
Traffic Model Type	Description	Typical Software
Macroscopic	Tend to be wider in geographic scale but the least detailed. The highway network is typically modelled using speed flow curves which define relationships between traffic speeds and flows by different road types. Vehicle demand is often assigned to the network at an hourly level for different time periods, possibly split by lights and heavies and/or journey purpose.	EMME, CUBE
Micro-simulation	This includes the modelling of individual vehicle movements which would allow for lane changing and acceleration and deceleration. Demand is typically profiled and would cover a time period (i.e. morning could be 2 hours - 7am to 9am). Greater detail is included in network coding with regard to signal timings and gap acceptance.	Paramics, Aimsun, Vissim
Mesoscopic	Combines the properties of macroscopic and micro-simulation. These models simulate individual vehicles but interactions are described at an aggregate level. A key distinction between mesoscopic and macroscopic is these models are able to forecast blocking back as a result of an overcapacity link or intersection and therefore forecast what flow can actually travel between origin and destination within	SATURN

	the model time period and what flow is queued up.	

2.2 Kirkbride Model

The SATURN based Kirkbide Model is being used as a case study for this work. It was developed in 2010 by Beca for NZTA in order to assess the Kirkbride Interchange scheme. The scheme was to grade separate the SH20A at Kirkbride Road, which is an existing signalised intersection in order to expedite travel times to and from the airport. The scheme also included the closure of the Montgomerie Drive intersection and Bader Drive northbound off ramp. The SATURN model network is shown in **Figure 2-1**.

Figure 2-1: Kirkbride SATURN Model Network



The SATURN modelled network is coded in “simulation” which means explicit modelling of intersection delays and capacity; based on input details of priority, roundabout and signalised intersections.

The Kirkbride model has a 2010 base year and 2016 and 2026 Do Minimum and Option scenarios. The SATURN model covers the following time periods

- AM: 1 hour average of 7-9 am
- PM: 1 hour average of 4-6 pm
- Interpeak: 1-hour average of 9 am – 4 pm

Additionally, 30-minute pre-peak models for the am and pm peak models are included to capture conditions at the start of the peak periods.

The models have two demand or user class matrices loaded for each time period:

- Light vehicles (cars and vans)
- Heavies vehicles (trucks)

It should be noted that buses are hard coded into modelled links as fixed flows based on their service frequencies, there is therefore no bus demand matrix.

The assignment is based on a generalised cost assignment, which is a function of time and distance. The model outputs for each modelled link (section of road) demand flow, which is the flow if all trip could travel between each origin and destination in the time period and the actual flow which is the amount forecast on that link in the time period. The difference between demand flow and actual flow in SATURN is “queued” flow, which is flow that gets stuck in the network, unable to reach the destination within the time period.

3 Methodology

3.1 Process

The following outlines the steps followed and required to predict scenario specific emissions:

1. Create an emission factor lookup table based on modelled years. This is generated from VEPM5.1 using the “Bulk Run” function and provides weighted average emission factors for all vehicles as well as heavy duty and light duty emission factors.
2. Output from SATURN, using a database dump (DBDUMP) of flows, distances and travel times on a link by link basis or alternatively use SATLOOK to output demand and skim distance and travel time matrices for each origin to destination pair. Flows on a link by link basis can be demand flow or actual flow, demand for each link or matrix or can either be total demand or split by user class.
3. For link by link calculations the link travel time is added to the volume averaged delay for each turn movement from that link. Alternatively the skimmed time matrices for each OD pair, is output, which includes both link travel time and intersection delays. Skim time and distance matrices are based on the lowest generalised cost between each OD pair, which is not necessarily the same as the shortest distance or travel time routes.
4. Average speed is calculated using the combined link and turn delay time and the distance. If the speed is below 10kph or above 99kph it is set at these thresholds, as this is the speed range for the lookup for emission factors.
5. The network emissions are therefore calculated for CO, CO_2, VOC, NO_X, PM2.5, PM and fuel consumption either through:

- Calculating a network wide average speed and multiplying the corresponding emission factors by total network vehicle kilometres **(Average network speed approach)**
- Calculating the emissions based on the average total vehicle speed for each individual link multiplied by the emission factors and then summing all the emissions by actual flow for each link **(Actual flow link by link approach)**
- Calculating the emissions for each user class (i.e. cars and trucks) speed for each individual link multiplied by the car and truck emission factors and then summing all the emissions by light and heavy vehicle flows for each link **(LCV + HCV link by link approach)**
- Calculating the emissions based on speed for each OD pair multiplied by the emission factors and then summing all the emissions by demand for each OD pair **(OD approach)**

3.2 Tests

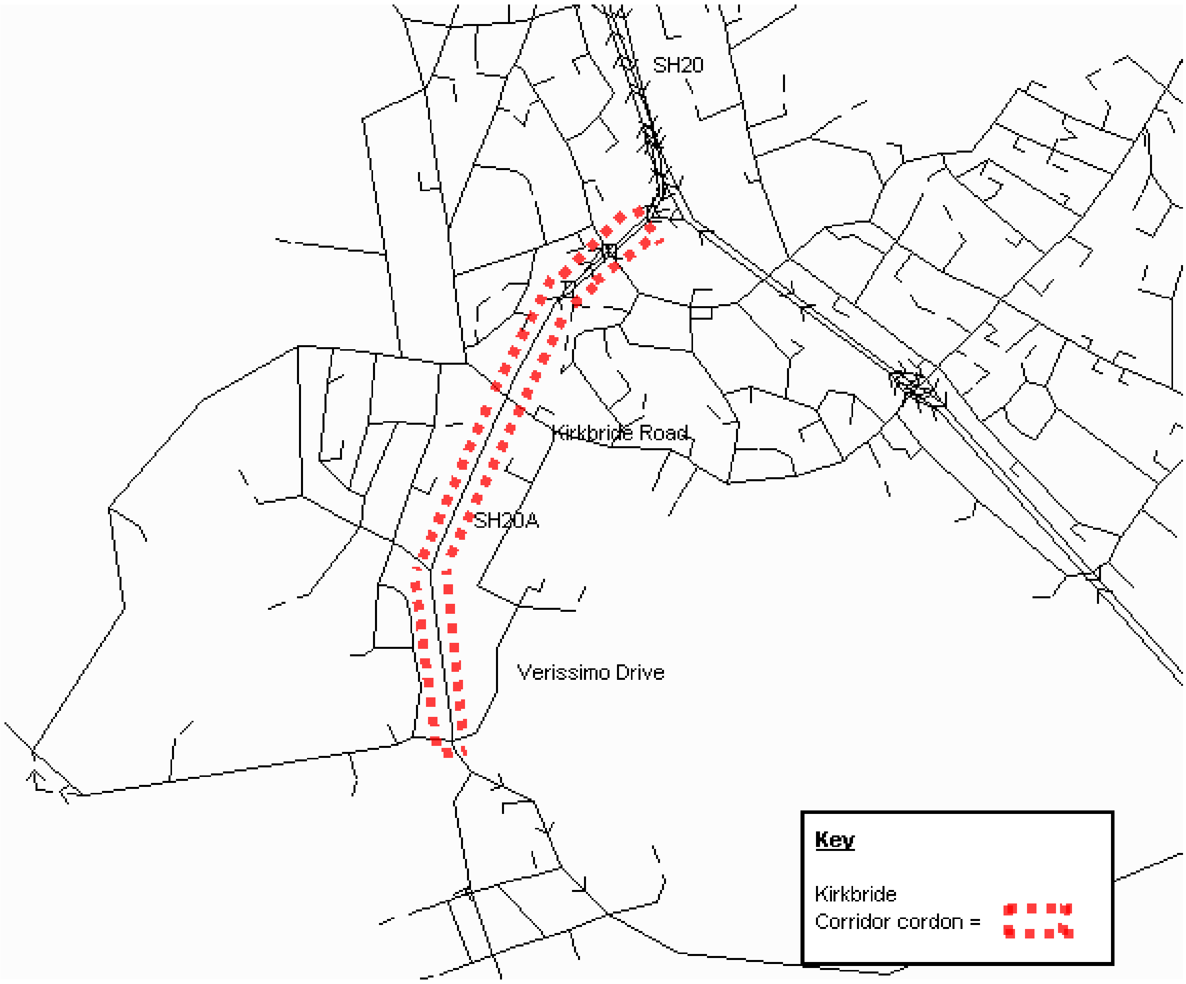
In order to see test what impact the different processes outlined in point 5 in Section 3.1 above have on the emission predictions, the following processes have been carried out using the 2016 AM peak Do Minimum and Option scenarios:

- Average network speed approach
- Actual flow link by link approach
- Demand flow link by link approach (using demand flow rather than actual flow)
- LCV + HCV link by link approach
- OD approach

An additional test was undertaken using a cordon of the Kirkbride model centred on the area around the scheme, namely along SH20a between SH20 in the north and Verisimo Drive roundabout in the

South. The corridor analysis was set up so as to have two way flows and full turning movements at all intersections, to be equivalent to how a highway scheme would be environmentally appraised with regard emissions. The objective was to see how emission varied at a more local level closer to the scheme and also allowing for how speeds vary when adopting different approach. **Figure 3-1** shows the cordoned SATURN network.

Figure 3-1 Kirkbride Corridor Cordon



The following processes were undertaken on the Kirkbride corridor:

- Average network speed approach (based on the wider network)
- Average network speed approach (based on the corridor network)
- Actual flow link by link approach (corridor network)
- LCV + HCV link by link approach (corridor network)

4 Results

4.1 2016 AM Do Minimum

Figure 4-1 and **Figure 4-2** show nitrous oxide and particulate emissions levels for the whole SATURN model network for the 2016 AM Do Minimum scenario for each approach. **Figure 4-3** provides fuel consumption output. **Appendix A** provides the absolute emission levels for all emissions for each approaches and tested scenario.

Figure 4-1: 2016 AM Do Minimum Nitrous Oxide Emissions by Approach

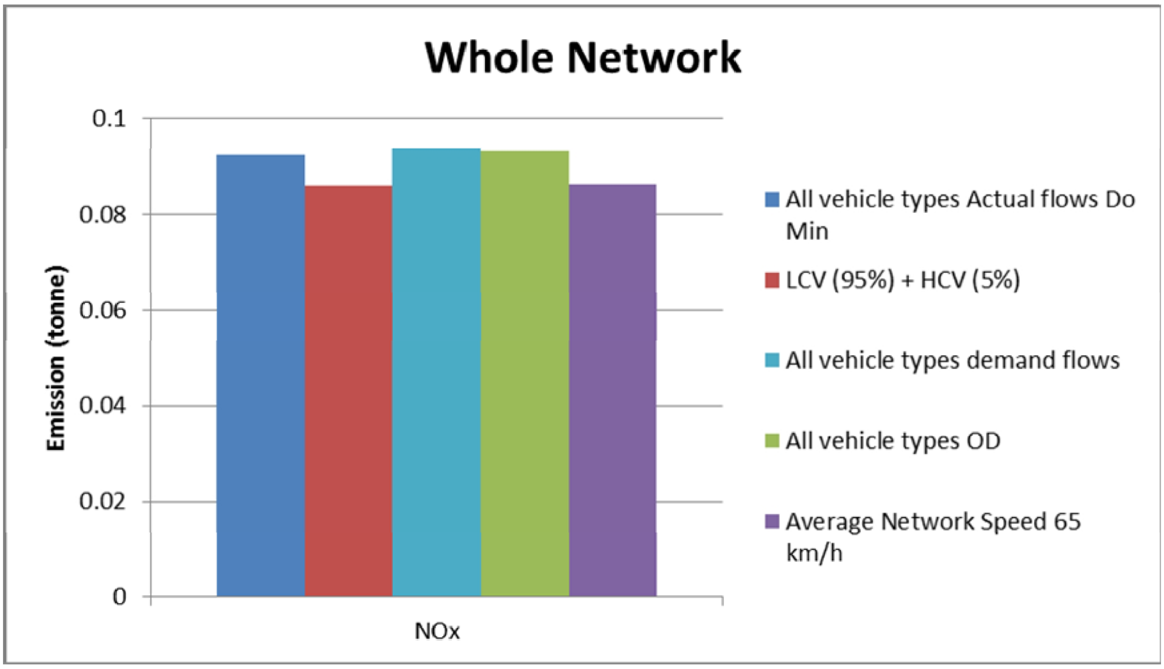


Figure 4-2: 2016 AM Do Minimum Particulate Emissions by Approach

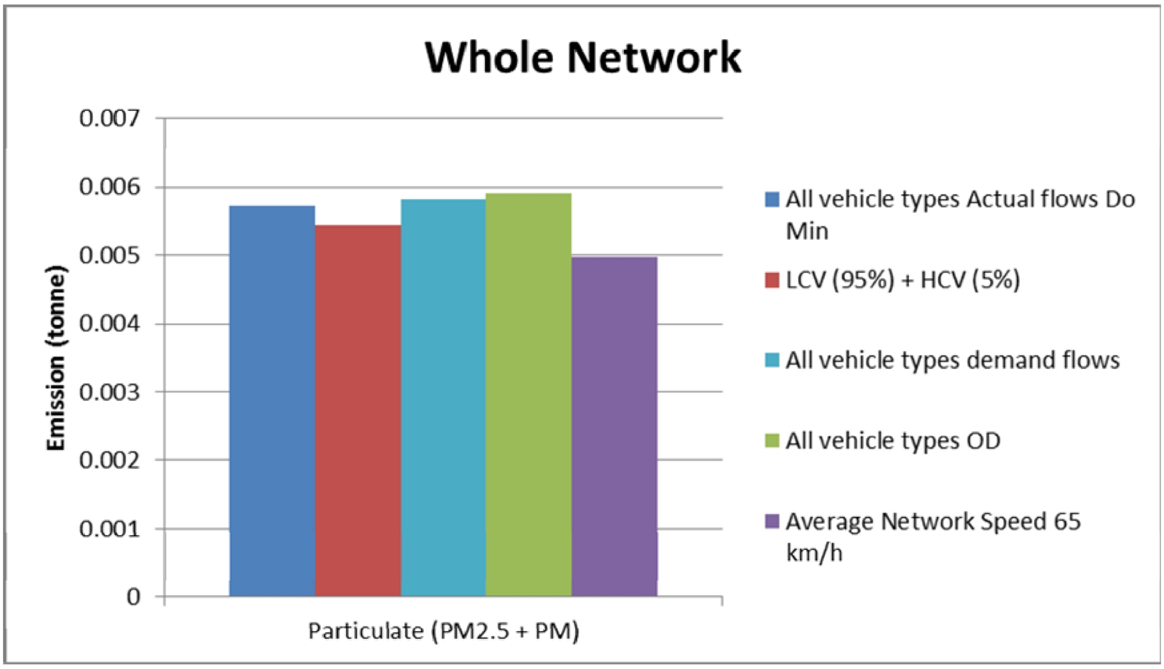


Figure 4-3: 2016 AM Do Minimum Fuel Consumption by Approach

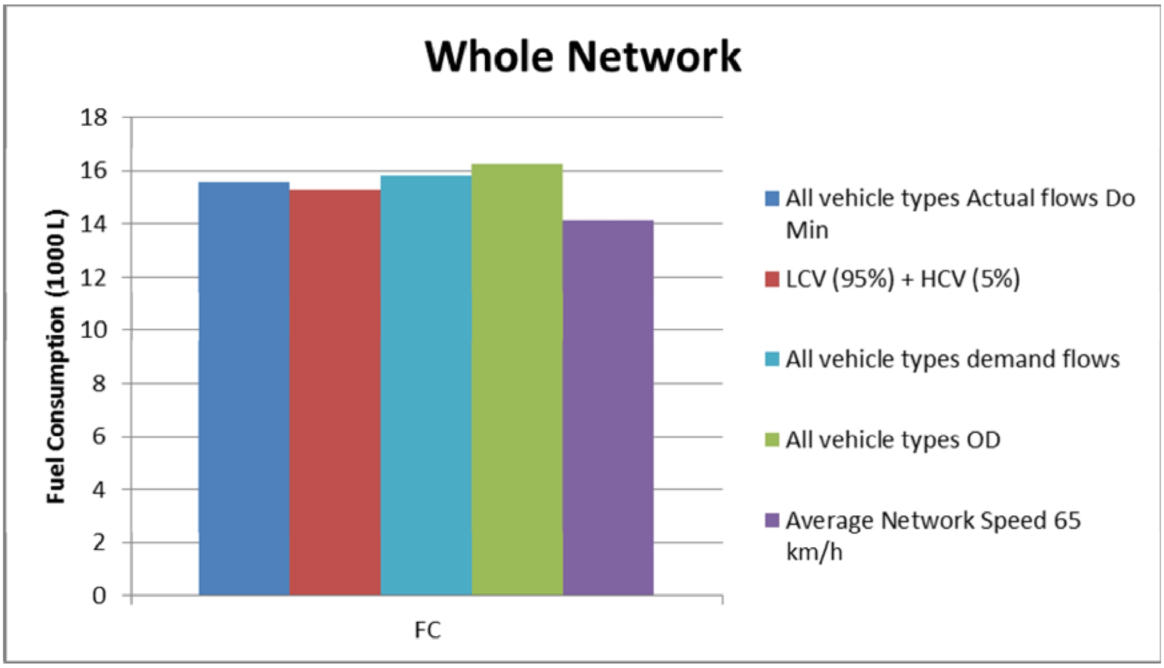


Table 4-1 shows the percentage difference in emission levels between the actual flow link by link approach and the other approaches for the 2016 AM Do Minimum scenario. It also shows the change in fuel consumption (FC) and vehicle kilometres (VKT).

Table 4-1: Percentage Difference in Emission Levels 2016 AM DM

Approach	CO	CO2	VOC	NOX	PM2.5	PM	FC	Particulate	VKT
LCV + HCV	1%	-2%	0%	-7%	-6%	-1%	-2%	-5%	0%
OD	4%	4%	11%	1%	3%	4%	4%	3%	4%
Average Network Speed (65kph)	-14%	-9%	-16%	-7%	-18%	0%	-9%	-13%	0%
Demand Flow link by link	2%	2%	2%	2%	2%	1%	2%	2%	1%

The following trends can be seen:

- The range in percentage change is between -18% and + 11%

- The OD approach produces the highest emissions in this scenario followed by the demand flow link by link approach
- The vehicle kilometres are higher with the OD approach against link by link approaches, as to be expected it is the same whether for actual flow or split by lights and heavies
- In this scenario using average network speed produces the lower emission prediction particularly for VOC and PM2.5.

4.2 2016 AM Option

Table 4-2 shows the percentage difference in emission levels between the actual flow link by link approach and the other approaches for the 2016 AM Do Option scenario. It also shows the change in fuel consumption (FC) and vehicle kilometres (VKT).

Table 4-2: Percentage Difference in Emission Levels 2016 AM Option

Approach	CO	CO2	VOC	NOX	PM2.5	PM	FC	Particulate	VKT
LCV + HCV	1%	-2%	0%	-7%	-6%	-1%	-2%	-5%	0%
OD	2%	3%	9%	0%	1%	4%	3%	2%	4%
Average Network Speed (65kph)	-14%	-9%	-15%	-7%	-17%	0%	-9%	-13%	0%
Demand Flow link by link	1%	1%	2%	1%	1%	1%	1%	1%	1%

The following trends can be seen from the Option Scenario:

- The range in percentage change is between -17% and +9%
- Splitting the link by link approach from actual flow into flow by lights and heavies reduces the emissions for NOx and PM2.5 by 7% and 6% respectively
- The OD approach produces the highest emissions levels and VKT whereas the average network speed produces the lowest.
- The trends are similar to the Do Minimum Scenario.

4.3 Scheme Emissions

Table 4-3 shows the percentage change in emission levels based on the difference between the 2016 AM Do Minimum and Option emissions from using an actual flow link by link approach and the other approaches. Overall there was little actual change in emission between scenarios (-2% to +1%) however the focus of this analysis is the percentage change between approaches.

Table 4-3: Change in Emissions

Approach	CO	CO2	VOC	NOX	PM2.5	PM	FC
All Vehicle Actual Flow	0.00403	0.26509	0.00010	0.00082	0.00003	0.00001	0.11132
LCV + HCV	5%	-5%	6%	-11%	14%	-2%	-4%
OD	-196%	-133%	-657%	-46%	-230%	-36%	-135%
Average Network Speed (65kph)	-4%	18%	133%	-2%	14%	0%	19%
Demand Flow link by link	-40%	-46%	-103%	-36%	-50%	-34%	-46%

The following trends can be seen:

- The percentage change range is between 133% and -657%
- The OD approach has the highest negative percentage change VOC has the highest percentage change
-
- Overall there is little change between the two scenarios, with a range of percentage change between -2% and +1%
- The percentage change between the scenarios is less than the percentage change between approaches which demonstrates consistency for each approach and that the scheme does not have a great effect on emissions
- Generally there was a slight reduction in emissions with the OD approach as a result of the scheme; the highest percentage reduction was with VOC, whereas the other approaches had a slight percentage increase in emissions with the scheme.

4.4 Corridor Level

Table 4-4 shows the percentage difference in emission levels between the actual flow link by link approach and the other approaches for the 2016 AM Do Minimum scenario cordoned at a local corridor level as per **Figure 3-1**. It also shows the change in fuel consumption (FC) and vehicle kilometres (VKT).

Table 4-4: Percentage Difference in Emission Levels for the Kirkbride Corridor

Approach	CO	CO2	VOC	NOX	PM2.5	PM	FC	Particulate	VKT

LCV + HCV	2%	-4%	0%	-11%	-9%	-1%	-3%	-7%	0%
Average corridor speed (78kph)	-18%	-12%	-22%	-9%	-23%	0%	-12%	-17%	0%
Average Network speed (65kph)	-18%	-13%	-15%	-13%	-25%	0%	-13%	-19%	0%

The following trends can be seen from the Cordoned Do Minimum scenario:

- The range is between -25% and +2%
- The average network speed is 65kph compared to the 78kph average corridor speed, the former therefore produces lower emissions
- Undertaking a link by link approach split by LCVs and HCVs generally reduces the forecast emissions with the exception of CO (2% more) and VOC (the same)

It should be noted that an OD analysis was not undertaken. Potentially a cordoned OD matrix could be assigned to the cordon network.

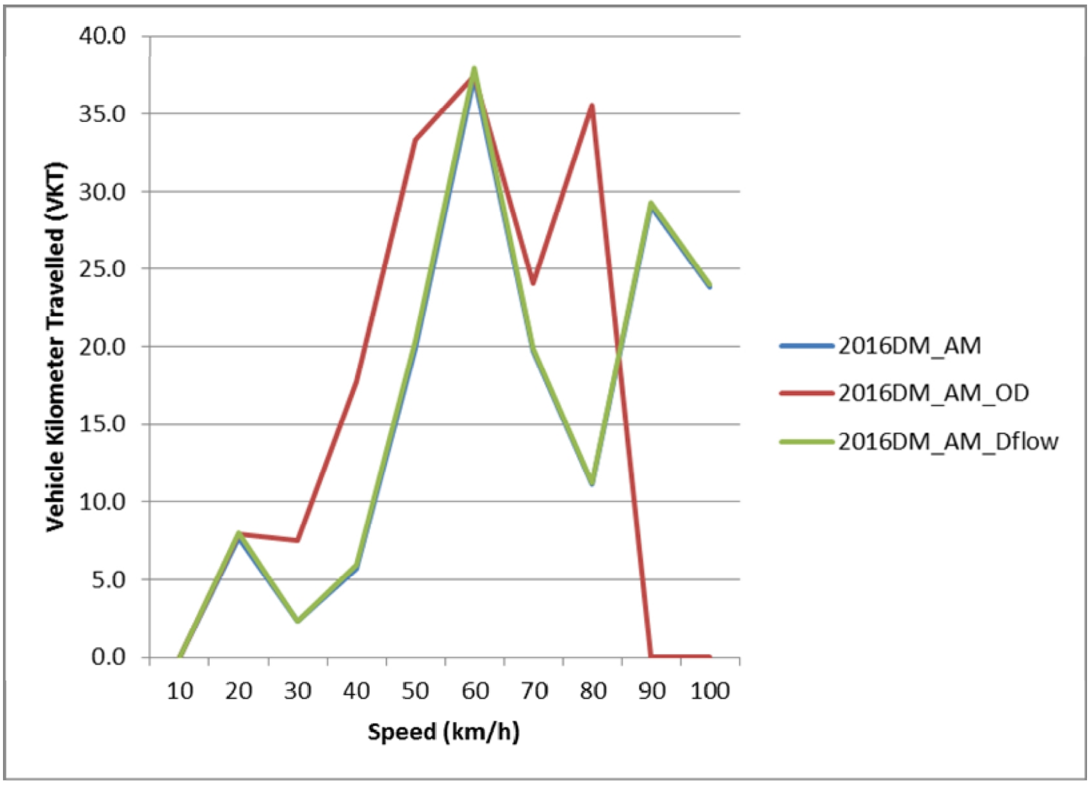
5 Findings

5.1 Key Findings

Key findings from the results are:

- The corridor analysis underlines the importance of isolating local speeds and conditions close to a scheme that is being assessed. Using a default network average speed was shown to underestimate emissions in the local Kirkbride corridor.
- Splitting the link by link approach from aggregated flows, travel times and distances into HCV and LCV equivalent data in the Kirkbride model was generally shown to reduce emission predictions. There would be value in adjusting the assumed split in the VEPM emission factor tables (93% and 7%) to match the LCV/HCV split in the model (95% and 5%) and re-running the analysis.
- Using demand flows resulted in more emissions than using actual flows due to the higher flows. This raises an interesting discussion point as to when it is appropriate to use which. Normally flows and emissions would be factored from a one hour level to a time period level (i.e. say averaged hour from 7 to 9am to the full 2 hours). This would also happen for Inter-peak and PM time periods which would then be added together to get daily flows, which are then annualised. Is it questionable whether it is right to use demand flows which in reality do not occur within the one hour modelled time period? Nor would they match with equivalent count data, however they do in effect become lost trips. It really depends how the factoring to time period and daily level has been derived from count data as to which method is appropriate and what modelled times there are. In a micro-simulation model which would typically cover two or three hours and cover a smaller area, this is less of an issue as all traffic would normally travel between origin and destination within the modelled times.
- The OD approach showed the highest emissions in both the Do Minimum and Option scenarios. It is noted that this approach is in effect demand flow. The higher emissions are due to the higher vehicle kilometres with this approach, they are 4% higher. This is due to the use of demand flow and because the distance skim matrices also include the centroid connector distances which are 50 metres each in length. The centroid connector is the fictitious link between a zone centroid and the network, which could represent for example the average distance from a suburban house onto the local collector roads (i.e. the residential drives and roads not included in the modelled network). Each OD pair therefore has an additional 100 metre trip, as a centroid connector is traversed (skimmed) at both origin and destination ends of the trip. These centroid connectors do not get included in the link by link approaches.
- Using OD speeds is more likely to result in speeds closer to an average as it is over a longer distance compared to a link by link approach which may have a wider distribution of speeds, as they are a greater number of links. **Figure 5-1** shows the distribution of vehicle kilometres travelled and speed for 2016 AM Do Minimum link by link (both actual flow and demand flow) and OD approaches. As can be seen there is a wider variety of vehicles travelling at faster speeds with the link by link approach as might be expected, although the pattern in not that pronounced.

Figure 5-1 Vehicle Kilometres against Speed



5.2 Issues

A few issues with regard to using VEPM and SATURN were encountered whilst undertaking the various processes and approaches to predict emissions from the Kirkbride SATURN model output, these were:

- VEPM uses average speeds however SATURN is based on link speeds and node delay this does not allow for acceleration and deceleration effects which would be captured for example in a micro-simulation model. A number of short links exist in the Kirkbride model like many such models. Each link might have a resultant cruise speed higher than could realistically be reached in the distance from stop line to stop line, although network attributes are calibrated and adjusted to make some allowance for this.
- Most traffic models do not include a consideration of gradients and emissions change based on the gradient.
- VEPM splits vehicles into multiple user classes such as light duty vehicles, diesel car, petrol cars, hybrid and electric vehicles etc, whereas most traffic models use “all vehicles” or at most they split demand into light and heavies and no further classification is used. This therefore requires default vehicle distribution type profiles to be used which may not reflect reality.
- SATURN forecasts demand and actual flows which is the sum of user class flow plus bus flow. As buses are fixed flows in SATURN, based on service headway, they are not assigned from an OD demand matrix therefore the OD approach does not include bus demands. The importance of this point will depend on the location of the modelled network and the percentage of buses to total traffic, likely to be an issue in city centre locations.
- SATURN uses Passenger car Units rather than vehicles, HCV flows and demands therefore needed to be divided by two to equate to actual vehicles

6 Recommendations

6.1 Conclusions

The following conclusions have been found from work carried out to date:

- Where vehicle operating costs are already being processed on a link by link process the VEPM procedures can be readily applied in a similar way
- The analysis should separate light and heavy vehicles if the models are able to do so
- If it is necessary to do an all vehicle analysis because the models cannot separate them then it is important to use local data on the percentage split between lights and heavies
- A link by link approach provides the most flexible approach as it allows for a number of ways of aggregating the data such as sub-regions and through particular intersections or corridors.
- An alternative method using origin destination approach is possible but only for network wide aggregations
- In the link by link method consideration of centroid connectors is important in terms of their inclusion and whether speed and times are included and hot versus cold running. In the OD approach centroid connectors are included.
- OD and link by link approaches give different output but we don't know which one is more accurate
- At an aggregate level the two different methods (link by link vs OD) can give very different outcomes in term of the overall net change due to a scheme. This depends on the size of the model relative to the scheme. This sensitivity suggests aggregation should not be made over too larger area.
- It is important to use corridor average speeds if looking at a particular corridor rather than applying a network average speed, and this average speed will vary from corridor to corridor
- Splitting the link by link approach by lights and heavies reduces emission forecasts for nitrous oxides and $PM_{2.5}$
- Using demand flow will produce higher emissions than actual flow however it is debatable which one should be used, dependent on how annualisation factors have been calculated from traffic count data
- It is not possible to do the OD approach in SATURN that would include bus flows; furthermore it would be useful to know what VEPM factors to apply to bus flows, which could be undertaken on a link by link approach.

6.2 Further Work

This work has uncovered potential areas for further investigation, this would include:

- Undertaking similar analysis using a micro-simulation model which allows for acceleration and deceleration and have a very different form of output than other model requiring different analysis processes. These are commonly used tools and would be useful to see how easy it would be to transfer model data to VEPM and how approaches would change emission prediction
- Furthermore tests on Inter-peak and PM time period could be carried out in order to see whether the conclusions hold firm over different time periods and to investigate the factoring of emissions from time period level to daily level and whether to use demand or actual flows.

- Investigation into the value and implications of separating cold starts and hot running
- We could prepare a step by step guide for implementation of VEPM
- Investigation of the implication of developing regression functions to replace the lookup tables on average speed. These would allow easier application in some software.

Appendix A

Emission Analysis