Local Area Transport Energy Evaluation (LATEE)

New Zealand Warrant of Fitness Data and VKT Analysis Mapped to Census Unit Areas
Method Description and Validation

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Summary

A method to evaluate the household energy use for personal transport and assign that information to geospatial locations has been developed by the Advanced Energy and Material Systems Lab research team at the University of Canterbury. The project was part of the Towards Sustainable Urban Forms (TOTUS) research programme that aims to provide quantitative geospatial information about transportation energy consumption for planning purposes. The Local Area Transportation Energy Evaluation (LATEE) methodology uses data from the Ministry of Transport and Statistics New Zealand to calculate annual vehicle kilometres travelled (VKT) and assign average values to local census area units.

1. Introduction

The aim of the research is to quantify vehicle kilometres travelled (VKT) and travel-related private vehicle fuel consumption spatially at the census unit level. Other national-level data, where available, will be used to validate the methodology. Over the past decade in New Zealand, all vehicle owners have been required to have their vehicles evaluated for safety and road-worthiness by undergoing a Warrant of Fitness (WoF) inspection at a certified facility. The WOF inspection must be completed roughly every six months. The WOF report consists of data that is entered on-line and stored by the Ministry of Transport (MOT). The data includes the date, make and model of the vehicle, the registration address of the vehicle, and most importantly, the odometer reading. Thus, the consecutive WOF inspection reports for a given vehicle, registered at the same address would provide the VKT for the time between inspections by subtracting the odometer readings. In addition, using the vehicle information, an estimate of the fuel use can be made, and by using the registration address, the fuel use can be associated with a residential location.

This paper describes the methodology for extracting data useful for VKT analysis from the WoF data provided by MOT. There are many issues with interpreting the data and the entries made by WoF agents. The data is also analysed, geo-coded, and mapped to census area units to provide VKT maps. In mapping data several issues of protecting privacy and interpreting GIS data were also dealt with.

2. Data source descriptions and published studies

2.1 Published data sources for method validation

2.1.1 Vehicle travel sources

MOT (2013) publish aggregate VKT data for New Zealand vehicles for the years 2001 to 2011, for which “vehicle travel estimates have been calculated on the basis of the difference between successive warrant of fitness or certificate of fitness odometer readings” (pp. 64, MOT, 2013). The estimates are classified into categories based upon the vehicle type and mass; *Light Passenger Fleet* consists of vehicles of type *Passenger car/van* with a mass of less than or equal to 3500 kilograms. Vehicles that receive certificates of fitness that are part of the Light Passenger Fleet may include taxis and rental cars.

2.1.2 Fuel consumption sources

MOT (2013) publish high and low on-road petrol consumption estimates for the years 2001 to 2011. These values are based on total figures for petrol deliveries from which high and low estimates of off-road and non-travel consumption are deducted. MOT do not publish diesel consumption estimates.

MED (2012) publish petrol and diesel consumption estimates, also based on fuel deliveries, but use an assumption that a constant percentage of fuel is used for on-road light vehicle travel. It is assumed that 95% of petrol and 18% of diesel consumed is for this purpose. The dataset presented by the MED contains data from 1974 to 2011.

The Energy Efficiency and Conservation Authority (EECA) maintains a database of national energy use estimates, based upon national level data and specific information where available, which is broken down into categories including sector, technology, end use, region and fuel type (EECA, 2013a). The public interface to the database presents only information for the year ending March 2007.

Statistics NZ (2008) use MED energy supply data and allocate it to industry using the EECA Energy End Use Database to produce estimates of energy use by sector for the years 1997 to 2006.

2.2 Data source descriptions

2.2.1 Warrant of Fitness dataset

New Zealand law requires that all light vehicles are periodically inspected for a warrant of fitness (WoF), which tests for roadworthiness and safety. Inspections are currently required every 12 months for vehicles less than six years old, and every six months for vehicles over six years old. During each WoF inspection both the current vehicle odometer reading and the owner address are recorded.

The WoF data provided by the New Zealand Transport Agency consists of a CSV database, where the information contained within each row represents one WoF inspection, and contains the columns described in table 1. The dataset consists of 47 million WoF inspections for 4.4 million vehicles. The data represents WoF inspections from January 2002 to May 2012.

Table 1. Warrant of Fitness dataset included columns and descriptions

Column	**Description (if required)**
VEHICLE_ID	Unique identifier for each vehicle
DATE_OF_INSPECTION	
INSPECTION_TYPE	WOF (for all vehicles)
AVIC_ID	Testing station identifier
ODOMETER_READING	
ODOMETER_DISTANCE_UNIT	
ORIGINAL_COUNTRY	Vehicle country of origin
OWNER_TYPE	Individual, Company or Other
MOTIVE_POWER	Primary fuel
ALTERNATIVE_MOTIVE_POWER	Alternate fuel
STREET_ADDRESS_FIRST_LINE	
STREET_ADDRESS_SECOND_LINE	
STREET_ADDRESS_SUBURB	
STREET_ADDRESS_TOWN	
STREET_ADDRESS_POSTCODE	
VEHICLE_MAKE	
VEHICLE_MODEL	
VEHICLE_SUB_MODEL	
VEHICLE_TYPE	
VEHICLE_USAGE	
VEHICLE_KEY	
POWER_RATING	
VEHICLE_YEAR	
CC_RATING	
GROSS_VEHICLE_MASS	
FC_COMBINED	Fuel consumption (combined cycle)
FC_EXTRA_URBAN	Fuel consumption (extra urban cycle)
FC_URBAN	Fuel consumption (urban cycle)

A number of consistency and quality issues have been identified with the dataset:

- Addresses are recorded by the vehicle driver during the inspection, consequently, spelling and typographical errors are common, and variables such as the stated suburb can change between consecutive inspections.
- Odometer readings can be inconsistent. Assuming that inspection dates and vehicle details in the dataset are accurate, nine per cent of vehicles have at least one inconsistent odometer reading.
- Fuel consumption information in the dataset is only available for a limited number of vehicles and is often inconsistent; consecutive readings for the same vehicle can vary or the stated cycle type can change.
- Other variables also occasionally change for the same vehicle. This might indicate incorrect recording of the vehicle identifier.

Where informational variables for a vehicle such as the mass or engine capacity change, the most recent value is assumed to be correct.

2.2.2 Fuel economy data

The United States Environmental Protection Agency (EPA) publish fuel economy data for all vehicles from 1984 to present (EPA, 2013). This dataset contains information of economy, fuel type and engine capacity.

3. VKT and fuel consumption calculation

Vehicle travel and fuel consumption were calculated *per address* for privately owned vehicles at spatially located addresses. To allow validation of the results against other sources and estimation of sample losses within the conversion and classification process, a range of results with a *vehicle basis* were also calculated. Prior to use the WoF dataset was filtered to include only vehicles of type *Passenger car/van* with a mass less than or equal to 3500 kilograms, matching the MOT definition of Light Passenger Fleet. Yearly samples exceeding the 99th percentile values of VKT for vehicles, or number of vehicles or total VKT at addresses, are excluded. The process of filtering, classification, calculation, and resultant outputs is described in figure 1.

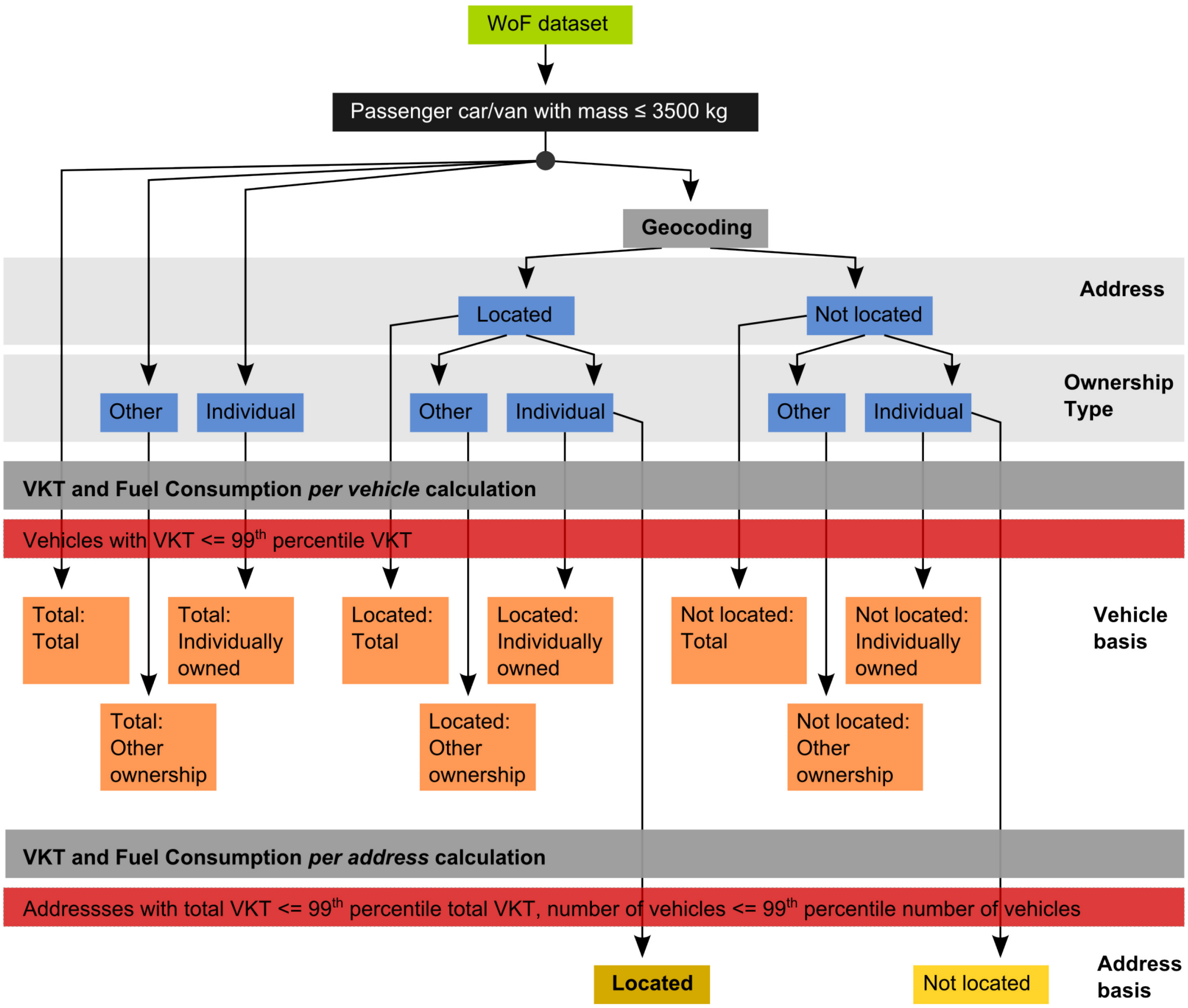

Figure 1. WoF dataset filtering, classification, calculation and output scheme

3.1 Geocoding

Geocoding is the process of determining the geographical coordinates for a given address. The geocoding functionality of ESRI ArcGIS was used to determine coordinates for vehicle addresses contained within the WoF database. Addresses for which coordinates were determined are classified as *located addresses*. Postal addresses in New Zealand rural areas, which are serviced by the rural delivery system, are not typically able to be geocoded.

3.2 VKT calculation

The VKT calculation is applied to a date-ordered list of WoF inspections for a given vehicle. The specific inspections comprising the list must meet specified criteria depending on the classification under analysis. For example, to analyse VKT where a vehicle is privately owned and located, only inspections for which the vehicle is privately owned and the current address was located are included in the list; if the vehicle moves to an unlocated address or changes ownership status those inspections not meeting the criteria are excluded.

The calculation algorithm is described in figure 2. The calculation assumes that odometer increases at a linear rate between inspections; it does not extrapolate VKT values beyond the inspection cycle or for gaps between inspections greater than the defined *maxDays* variable. Only one overall VKT value is calculated for each year. An example of the VKT calculation applied to sample data is presented in figure 3.

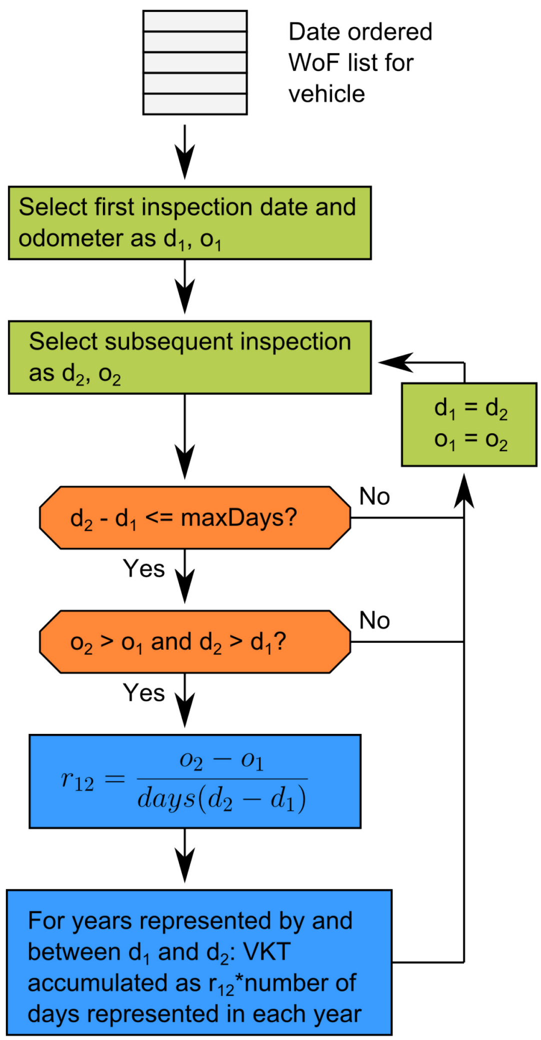

Figure 2. Flow diagram of VKT calculation algorithm.

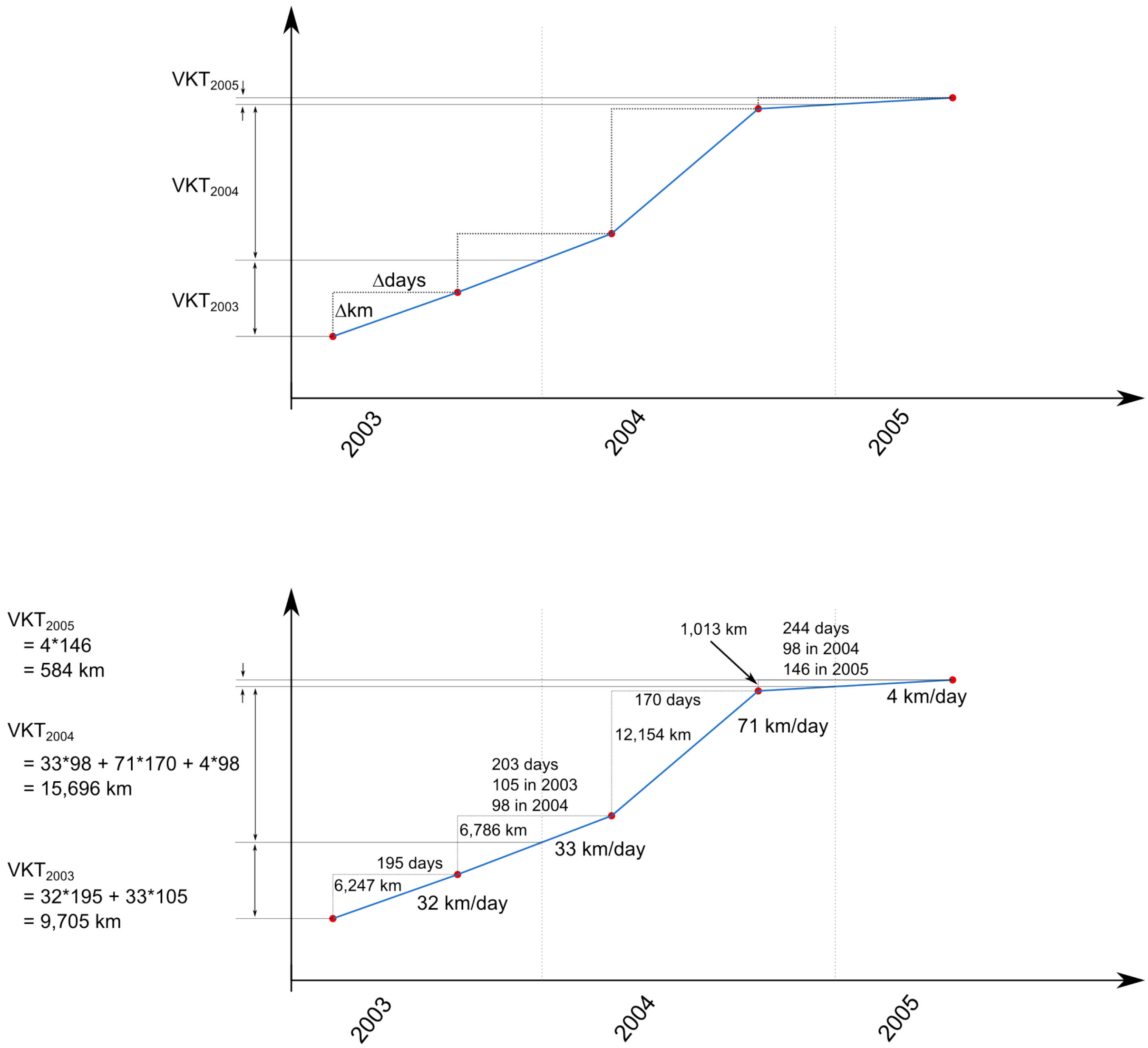

Figure 3. Example VKT calculation on sample data.

3.3 Fuel consumption calculation

A linear relation between engine size and fuel efficiency, derived from available data by fuel type, is used to estimate fuel consumption for vehicles. The fuel consumption, in Litres per year, for a vehicle of specified engine size and fuel type is given by:

$$\mathrm{FC} = \frac{\mathrm{VKT}}{100}(\mathrm{a} + \mathrm{b.CC})$$

where:

VKT is the vehicle travel in kilometres per year

a is the y-intercept of the engine size/fuel efficiency relation for the vehicle fuel type
b is the gradient of the engine size/fuel efficiency relation for the vehicle fuel type
CC is the engine size in cubic centimetres

The values of *a* and *b* used in the above equation are determined by fitting a linear trendline to US EPA data of fuel consumption versus engine size for each fuel type, and are presented in table 2. The values represent the 'combined cycle' fuel efficiency, which includes urban and extra-urban driving. Petrol is assumed to contain 35.08 MJ of energy per litre and diesel 38.45 MJ per litre of fuel (Statistics NZ, 2012).

Table 2. Fuel consumption versus engine size correlation factors

Fuel	a	b
Petrol	6.4	0.0019
Diesel	5.2	0.0013
CNG	8.4	0.0025
LPG	2.9	0.0031

3.4 Address basis calculation

The VKT and fuel consumption for an address is calculated by summing the travel characteristics of the individual vehicles at that address within each year. This process is performed by restricting the ordered list of inspections input to the VKT calculation to inspections for which the vehicle was located the address.

Both located and unlocated addresses are analysed in this manner; for located addresses the fixed address output by the geocoding service is used, while for unlocated addresses the raw address contained in the WoF dataset is used. To account for errors, yearly samples exceeding the 99th percentile values of number of vehicles or total VKT at addresses are excluded.

3.5 Spatial result presentation

Variables at the address level are currently averaged over time for each address by dividing the sum of a variable by the number of years for which the variable was recorded. For the purposes of confidentiality, household results are presented aggregated to the census area unit level. The number of vehicles and VKT samples are summed for each area, while VKT and fuel consumption figures are averaged over all households in each area. Only areas with a sample of greater than 60 addresses are displayed.

3.6 Calculation limitations

The current method does not attempt to specifically check or fix errors and inconsistencies in the input dataset, however the following steps act to reduce these:

- the geocoding service standardises addresses and can repair simple spelling errors
- negative VKT values, which indicate bad data, are excluded
- VKT and vehicle ownership values greater than 99th percentile values are excluded

4. Results

4.1 Sample size

The number of VKT results calculated from the database over time are presented in table 3. These figures indicate the number of vehicles for which a VKT could be calculated, which is less than the total number of vehicles. The number of VKT results calculated for individually owned vehicles at addresses is presented in table 4. Results in both tables are filtered to exclude values greater than the 99th percentile figure for the following categories:

- per vehicle results:
  - VKT 44,200 km/year
- per address results:
  - total household VKT 92,700km/year
  - number of vehicles at address 6

Table 3. Sample size (VKT samples) by ownership and located status classification

	Ownership	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Located	**Individual**	1,394,782	1,569,334	1,642,897	1,697,611	1,735,834	1,775,363	1,857,354	1,903,499	1,932,141	1,888,179
	Other	111,539	138,567	146,225	152,137	157,561	161,936	168,448	171,442	171,068	161,650
	Total	1,545,071	1,730,142	1,812,367	1,874,433	1,917,851	1,962,257	2,048,210	2,096,129	2,122,750	2,081,047
Not located	**Individual**	305,354	359,815	366,485	380,746	391,078	389,820	368,232	301,251	286,203	270,864
	Other	36,271	44,988	45,852	49,135	53,003	54,766	53,695	50,335	52,816	48,647
	Total	346,444	409,016	416,916	434,609	448,645	448,876	425,636	354,304	341,357	321,788
Total	**Individual**	1,745,994	1,916,252	1,997,482	2,066,167	2,116,534	2,153,838	2,179,511	2,188,318	2,208,534	2,161,155
	Other	155,176	188,893	198,537	208,375	218,767	224,884	229,992	230,534	231,460	217,627
	Total	1,952,456	2,125,437	2,217,707	2,297,748	2,358,893	2,401,368	2,428,652	2,435,020	2,454,309	2,412,081

The total number of results increases steadily over the study period, indicating growth in the vehicle fleet, individually owned and located vehicles form the greatest proportion of all vehicles. As vehicles change status the ability to calculate VKT may be lost, hence classified results do not add up to totals. Fewer VKT values are calculated in 2011. This is due to the dataset extending only to mid-2012, preventing 2011 VKT being calculated for vehicles that receive annual inspections in the latter half of the year.

Table 4. Sample size (VKT samples) for individually owned vehicles at addresses by address location status

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Located	1,213,390	1,457,200	1,515,898	1,569,084	1,604,706	1,635,075	1,779,282	1,777,794	1,779,891	1,710,529
Not located	41,692	47,951	51,636	55,745	60,392	64,859	72,838	75,310	76,961	74,545

The results presented in table 4 are lower than the raw vehicle results because the initial results only asses if the vehicle was at any located address, the latter values require that the vehicle is at the *same* located address for a VKT to be calculated. Samples calculated by vehicle fuel type are presented in table 5.

Table 5. Sample size (VKT samples) for individually owned, located vehicles by fuel type

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Petrol	1,302,459	1,457,315	1,518,049	1,562,725	1,595,803	1,633,756	1,712,091	1,757,541	1,787,810	1,753,108
LPG	203	212	197	185	177	212	244	304	341	348
Diesel	91,952	11,1647	124,523	134,591	139,772	141,320	144,944	145,587	143,925	134,660
CNG	34	32	28	20	14	13	8	8	8	8
Electric	14	14	13	10	11	13	16	16	16	17

The majority of individually owned and located vehicles in the New Zealand light passenger fleet are petrol-fueled. However, the proportion of diesel vehicles is slowly increasing. The number of liquid propane gas (LPG) vehicles is growing, while the number of compressed natural gas (CNG) vehicles is decreasing. The number of electric vehicles increases slightly over the study period.

4.2 Preliminary results

Average VKT per vehicle, for all sampled vehicles, is presented in figure 4. VKT results are not presented for 2002 as it is the start of all inspection cycles, which causes unrepresentatively low VKT results as most vehicles only have odometer changes for part of the year represented. This effect is also observed in 2011 for vehicles that receive only annual inspections, as only the first half of 2012 is represented in the data.

A comparison of the extent to which vehicles with different classifications travel is presented in figure 5; values are typically lower than the average for all vehicles, presented in figure 4, which is a result of vehicle status changes. The purpose of this comparison is to determine if there were any specific groups of vehicles that are excluded from the analysis by the classification scheme. The data indicates that non-individually owned vehicles, which include company or organisation vehicles, travel on average more than the individually owned vehicles. However, non-individually owned vehicles form a small proportion of the light passenger fleet. Vehicles at unlocated addresses travel more than vehicles at located addresses. Travel by individually owned vehicles exhibits a marked dip in 2008.

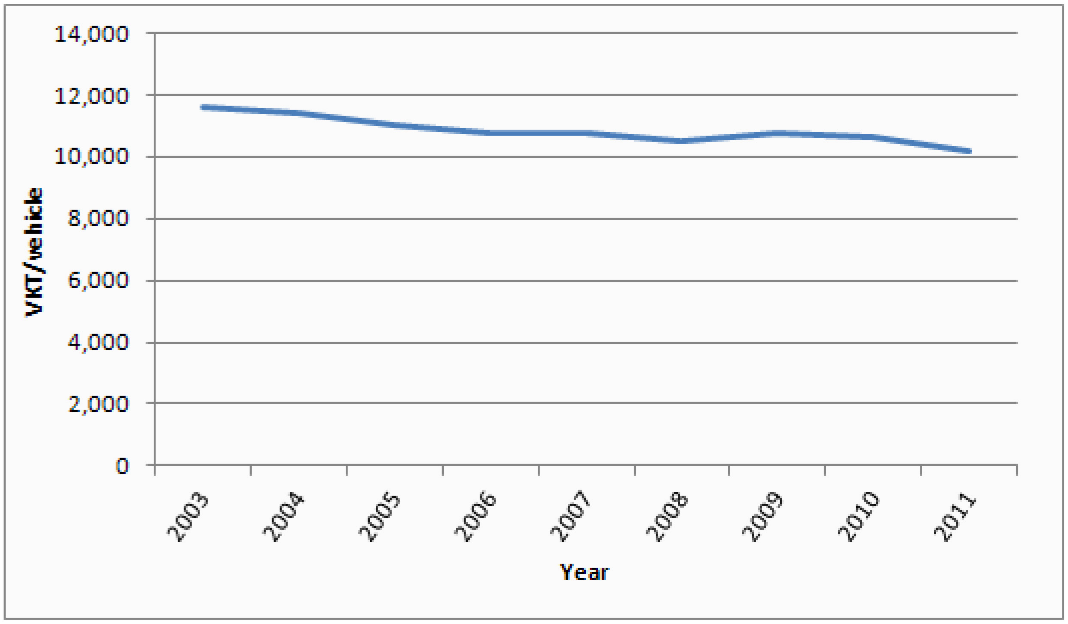

Figure 4. Average annual VKT per vehicle, all vehicles.

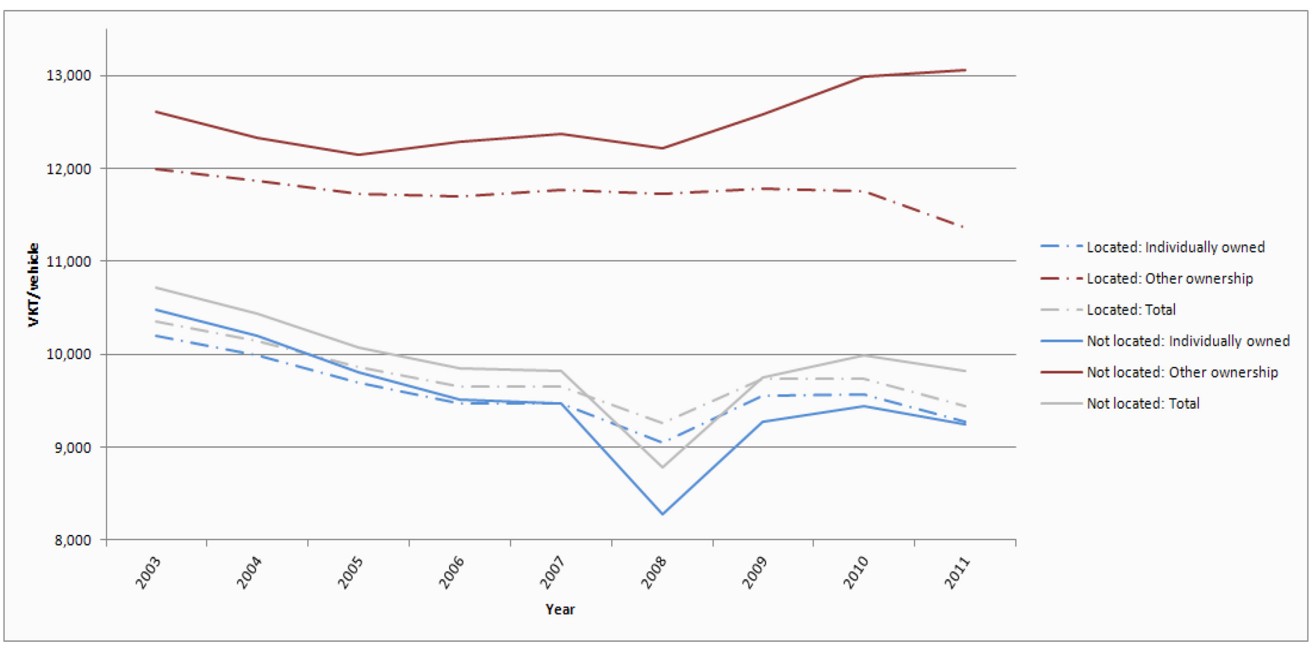

Figure 5. Average annual VKT per vehicle by classification type.

Results of average annual VKT per vehicle by fuel type are shown in figure 6. Diesel vehicles on average drive approximately 2,000 km further than petrol vehicles, while exhibiting the same downward trend over the study period. LPG vehicles drive furthest, while electric vehicles drive the least. Fuel consumption by type, as shown in figure 7, indicates that although diesel vehicles drive further, their greater efficiency results in a similar overall fuel consumption as petrol vehicles.

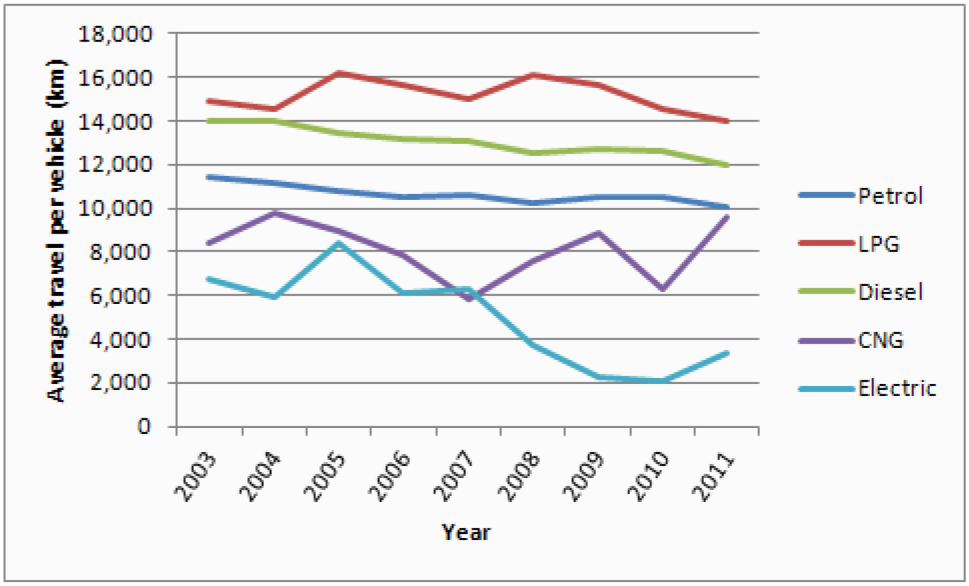

Figure 6. Average annual VKT per vehicle by fuel type, all vehicles.

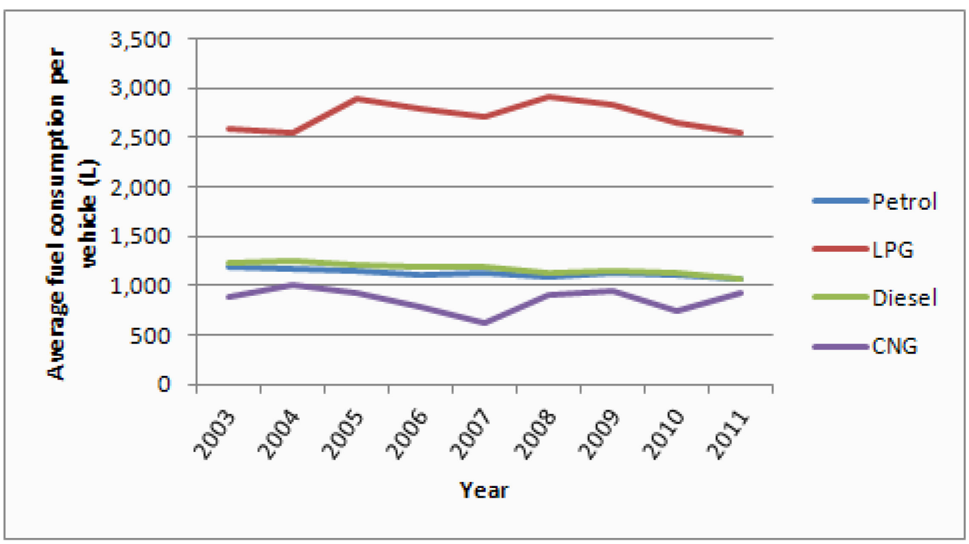

Figure 7. Average annual fuel consumption per vehicle by fuel type, all vehicles.

4.3 Comparison of preliminary results with published data

This section compares the calculated results with published estimates of vehicle VKT and fuel consumption. The number of light passenger fleet vehicles represented in the calculated values and published by the Ministry of Transport (MOT) are compared in table 6. The calculated values show between 140,000 and 200,000 fewer vehicles than the MOT results, which is due to the inclusion in the MOT dataset of those vehicles that receive certificate of fitness inspections, such as taxis and rental cars.

Table 6. Sample size (VKT samples), calculated values versus published

	2003	2004	2005	2006	2007	2008	2009	2010	2011
Calculated	2,125,437	2,217,707	2,297,748	2,358,893	2,401,368	2,428,652	2,435,020	2,454,309	2,412,081
MOT, 2012	2,325,289	2,414,187	2,496,240	2,537,898	2,581,526	2,585,179	2,575,438	2,599,806	2,607,266

Calculated average VKT per vehicle for all vehicles is compared to published MOT data in figure 8. The calculated values are consistently about 1,500 annual kilometres lower than the MOT values. This difference is due to MOT data including high travelling vehicles such as taxis and rental cars. In consequence the MOT data provides a better estimate of all vehicle travel on New Zealand roads, but the calculated values provide a better estimate of household vehicle travel. Both the calculated and MOT VKT values follow the same trend.

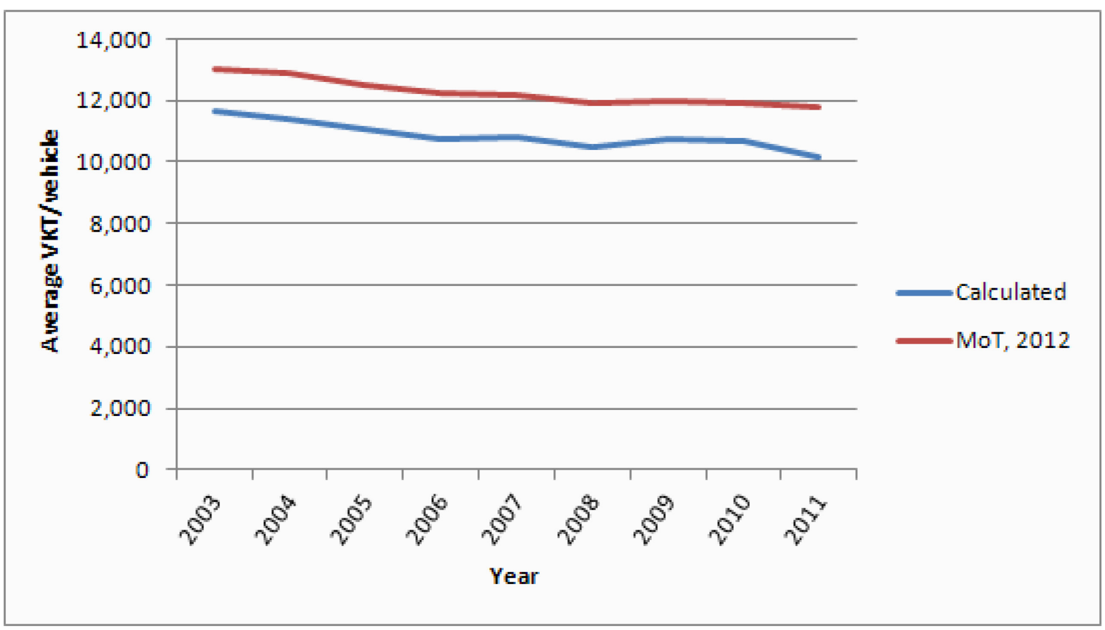

Figure 8. Comparison of LATEE calculated average vehicle travel to published data.

Total calculated petrol and diesel energy consumption are compared to various published values in figures 8 and 9. Calculated petrol consumption is lower than expected, as it is based on all WoF-inspected vehicles, including non-individually owned vehicles. This means that the values *should* be higher than the 'household' results presented by Statistics NZ and EECA. Published figures for diesel consumption exhibit greater spread than those for petrol, presumably due to differing methods for allocating shares of light vehicle diesel as a proportion of the total. Calculated diesel consumption is significantly lower than other calculated values. The difference between MOT and MED estimates of total petrol consumption are due to different methods of apportioning off-road travel.

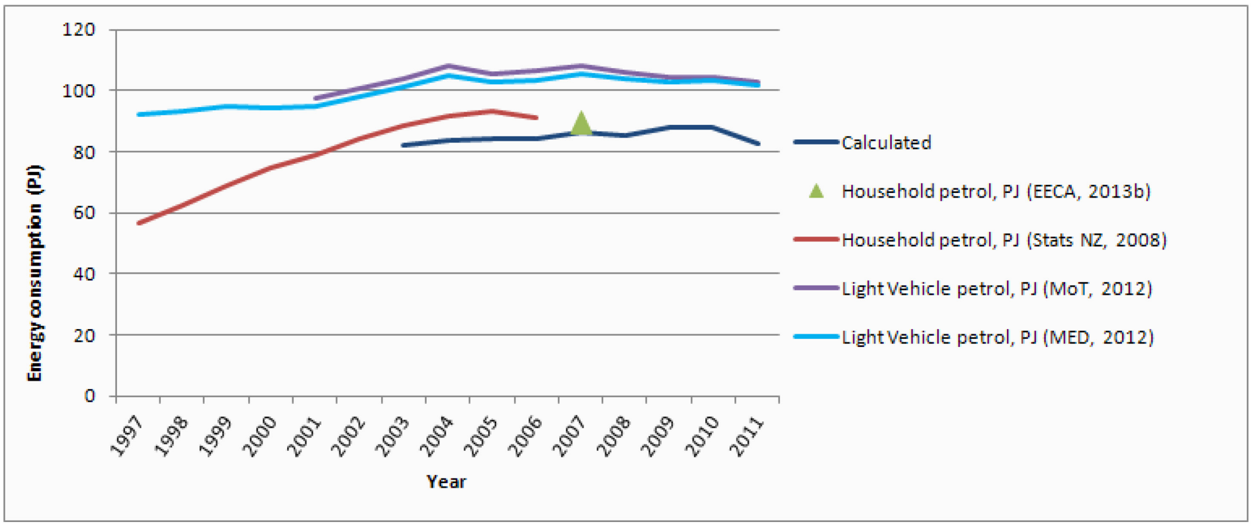

Figure 9. Comparison of LATEE Calculated total petrol consumption for all vehicles to published data.

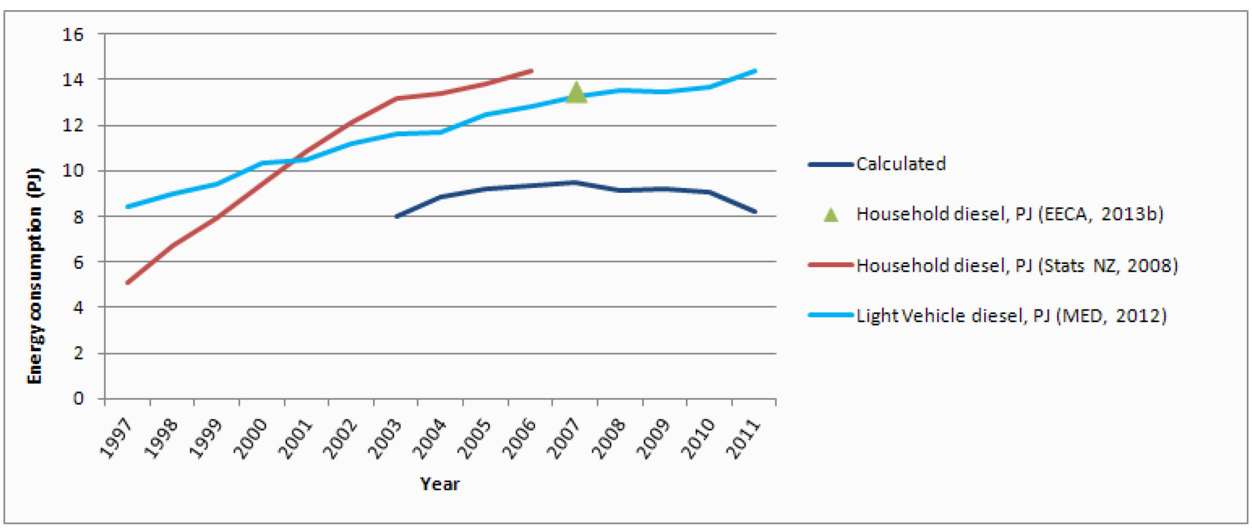

Figure 10. Comparison of LATEE Calculated total diesel consumption for all vehicles to published data.

4.3 Spatial results

The LATEE method resulted in 74% of 5.6 million input addresses being successfully geocoded. The geocoding process standardises addresses and can correct minor errors, producing 1.6 million distinct located addresses. If any address had VKT or number of vehicles greater than the 99th percentile values in a year, its data for that year was discarded. This process removed 2,500 geocoded addresses which exceeded these criteria for all years. The number of addresses with VKT samples calculated over time is presented in table 7.

Table 7. Sample size (addresses with VKT calculated) by located status

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Located	782,252	870,632	896,153	918,949	935,491	952,040	1,052,504	1,029,584	1,023,462	995,552	719,303
Not located	206,372	247,759	254,665	267,259	275,654	280,862	279,192	222,417	206,420	197,215	121,933

Average VKT per address over time is shown in figure 11. The result indicates a slight decline over time for both located and not located addresses, while both exhibit a marked temporary drop in VKT in 2008, of around 2,000-3,000 km per address. This dip may be due to the fuel price rises experienced at this time.

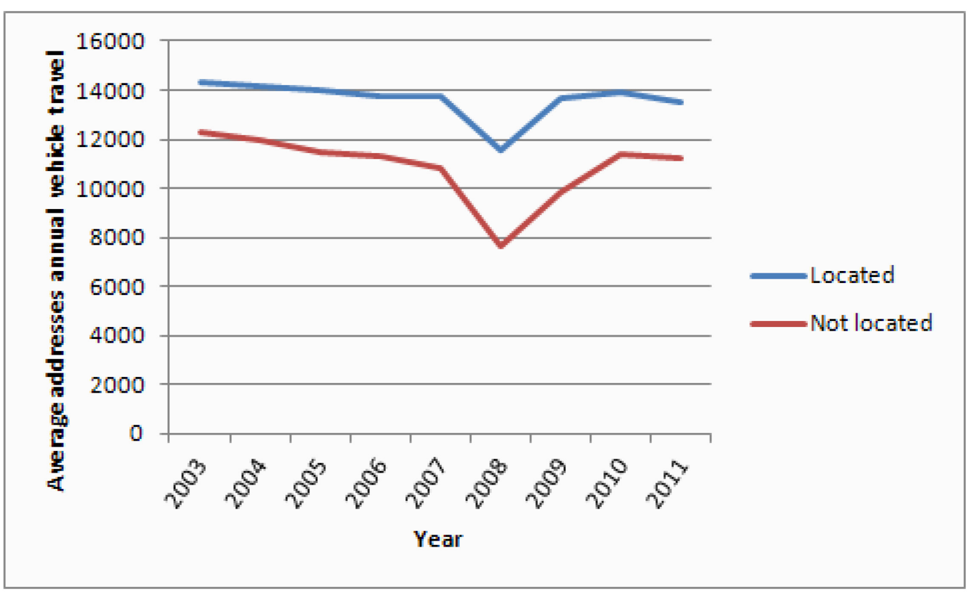

Figure 11. Average address VKT over time

Average VKT per address within census area units in the cities of Dunedin, Auckland, Wellington, and Christchurch are presented in figures 12, 13, 14 and 15, respectively. Christchurch, Wellington and Dunedin all exhibit lower VKT in central areas, and generally higher VKT in areas further from the centre. Households in the CBD of Auckland exhibit moderate amounts of travel, while areas immediately to the south show high levels of travel. Further from the CBD pockets of lower VKT are found around suburban centres, and in some locations near rail infrastructure.

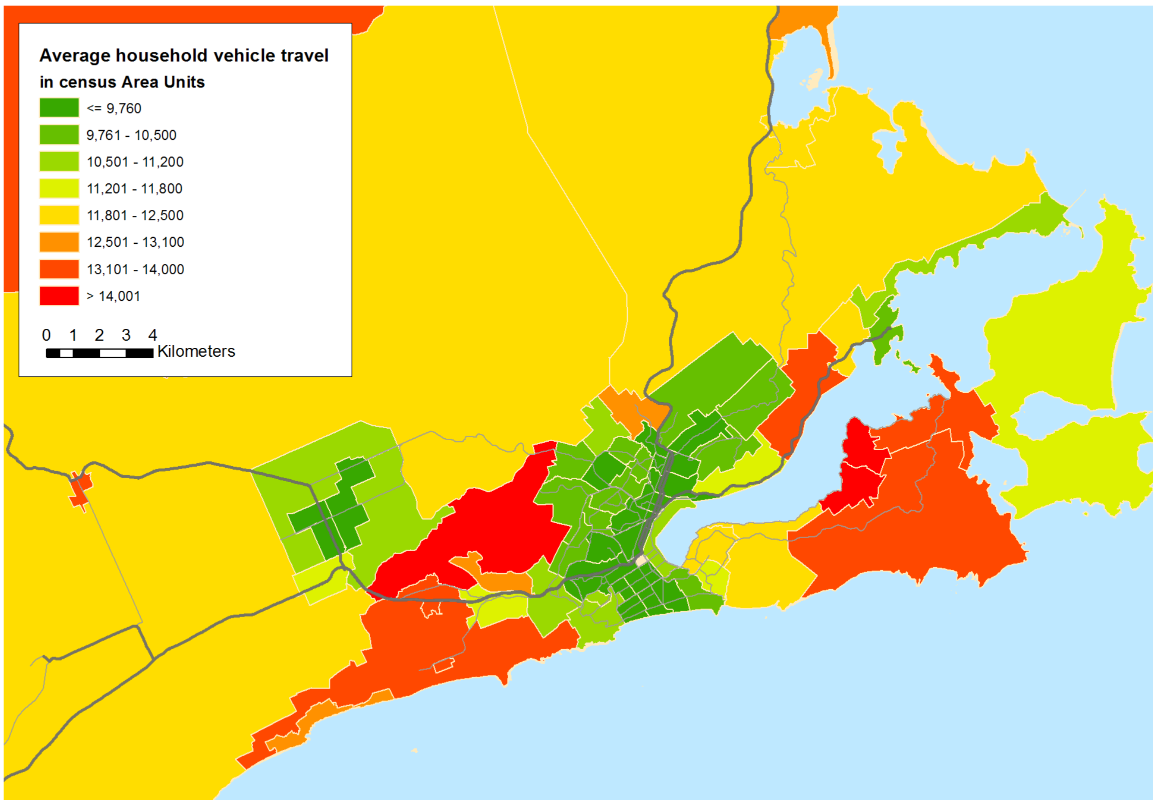

Figure 12. Average household VKT in Dunedin area

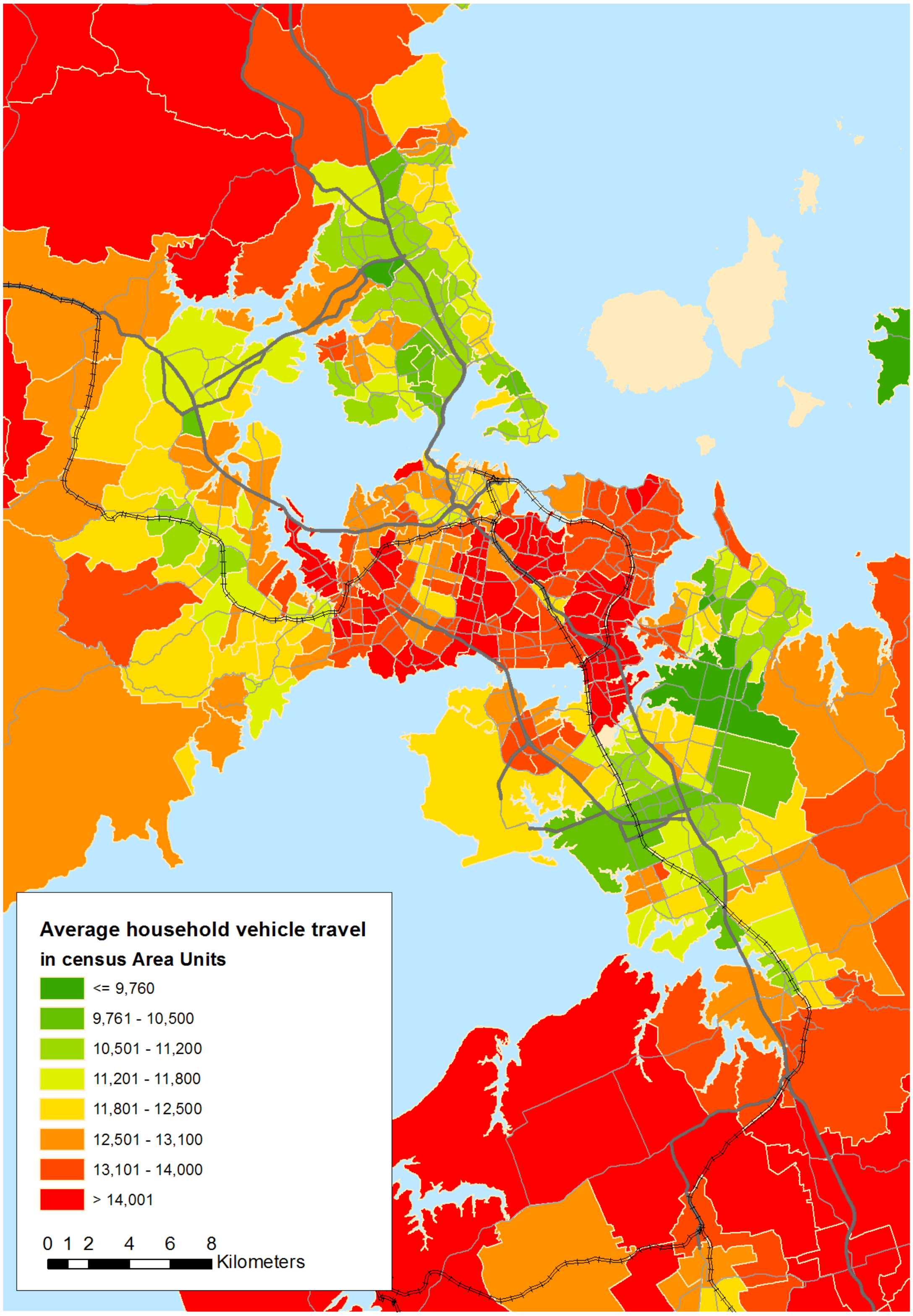

Figure 13. Average household VKT in Auckland area

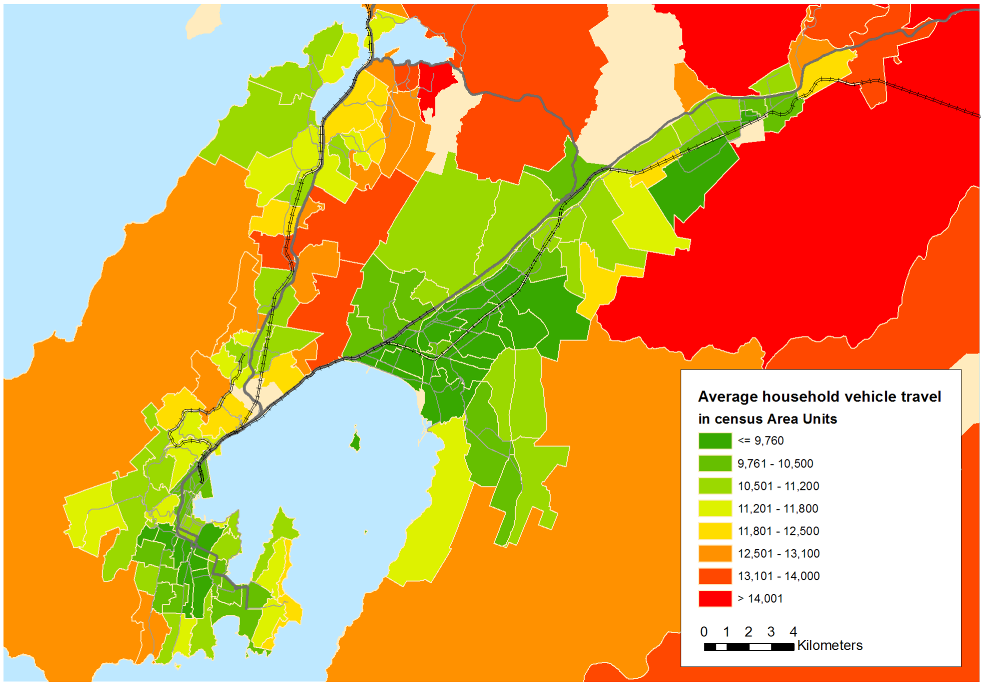

Figure 14. Average household VKT in Wellington area

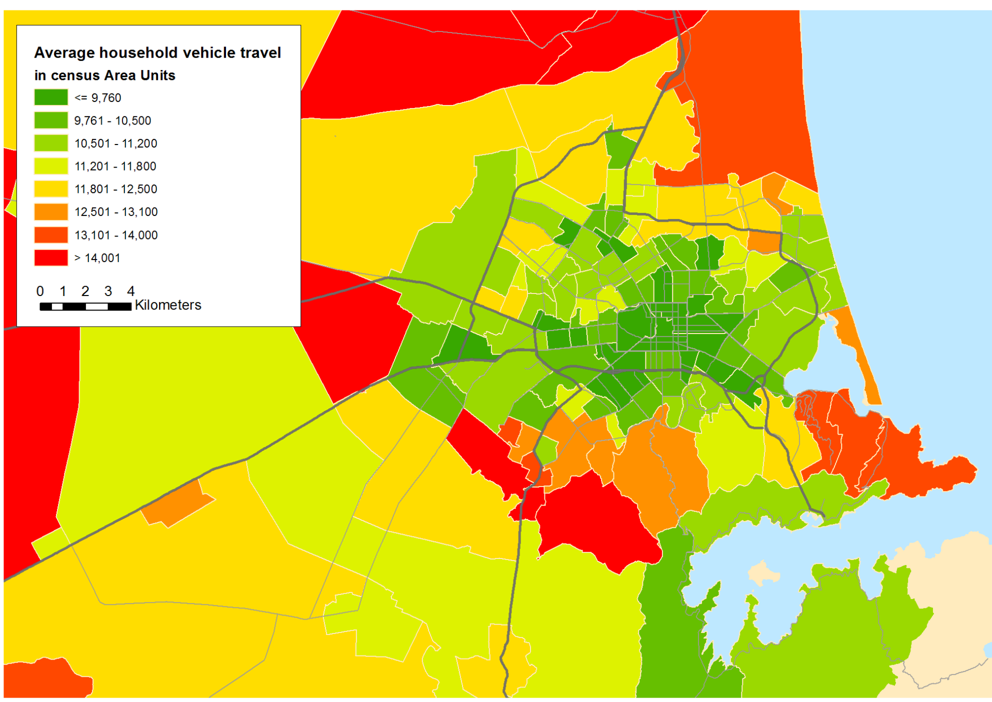

Figure 15. Average household VKT in Christchurch area

5. Discussion

The analysis of average vehicle travel by classification indicates little difference in the amount of travel between vehicles at located and unlocated addresses for individually owned vehicles. Non-individually owned vehicles travel significantly further, which is expected, given these include vehicles such as company cars. Compared to figure 5, figure 11 presents a much lower VKT for non-located addresses than located addresses. This is expected as non-geocoded addresses do not have addresses standardised or spelling mistakes fixed there is a higher chance of sample loss arising from these errors.

The comparison of calculated number of vehicles and VKT with published results highlights the differences in the input datasets, with the Ministry of Transport (MOT) dataset including high-travelling vehicles, such as taxis and rental cars, that receive certificate of fitness inspections. Consequently, the calculated LATEE results provide a better estimate of household travel than the MOT values, which indicate overall travel on New Zealand's roads. The comparison of fuel consumption results with published data indicates that the calculated values are lower than expected, particularly when compared with sources of 'household' data. The calculated results should have been greater than household estimates, due to the inclusion of fuel consumption from non-individually owned vehicles. This result indicates that the calculation underestimates fuel consumption. There are three possible contributing factors:

- Values in the EPA dataset are based on fuel consumption tests performed in laboratory conditions, not real world driving, and are hence lower.
- New Zealand has a relatively old vehicle fleet and older vehicles are less efficient. Although the EPA dataset includes data on vehicles from 1984 onward, the current calculation considers engine size as the only variable, and thus underestimates fuel consumption.
- The correlations between engine size and fuel consumption developed from the EPA data may simply not apply to the New Zealand vehicle fleet.

6. Future Work

The LATEE calculation of personal travel by private vehicle and the estimate of the fuel used will be used as a basis for future projects. One of the first future projects is to use the LATEE calculation to improve upon the VAMIRE and VIPER fuel vulnerability analysis carried by Dodson and The LATEE calculation can be combined with Stats NZ data on household ownership, household population, age and income to look at demographic and economic relationships with personal transport energy. The next research project to be carried out by the AEMSLab at UC under the TOTUS programme will look to combine the results of LATEE and other calculation methods and to develop new metrics for urban land use and urban form. Ultimately, the research will aim to correlate investment in infrastructure and urban development to energy use, behaviour, and travel energy adaptive capacity.

7. Acknowledgements

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Glossary

METAA	Minimum Energy Transport Activity Assessment
LATEE	Local Area Transport Energy Evaluation for VKT
EFaGE	Essential Freight and Goods Energy
FTGU	From the Ground Up
LUTES	Land Use, Transport and Energy System
VKT	Vehicle kilometres travelled
WoF	Warrant of Fitness

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