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Comparison of Melbourne driving characteristics with the NEDC and WLTC

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Abstract

In Australia, all new motorised road vehicles sold must undergo test procedures to measure the fuel consumption and emissions. Currently, the New European Driving Cycle (NEDC) is used. Regulations might change, like they have in other countries, to abandon the NEDC in favour of the Worldwide Harmonized Light Vehicles Test Cycles (WLTC). Evidence from many countries, including Australia, suggests that the NEDC underestimates fuel consumption and emissions. Evidence also suggests that the WLTC can provide more-accurate estimates when used with the appropriate procedures but that it could also provide underestimates `when driving characteristics are not representative. The aim of the present study is to determine the representativeness of the NEDC and WLTC for car driving in Australia. Primary data of Melbourne driving is collected and analysed using statistical tests. The results show evidence for many driving-cycle characteristics being different for Melbourne than for the NEDC and WLTC, but more data are required to increase certainty.

1. Introduction

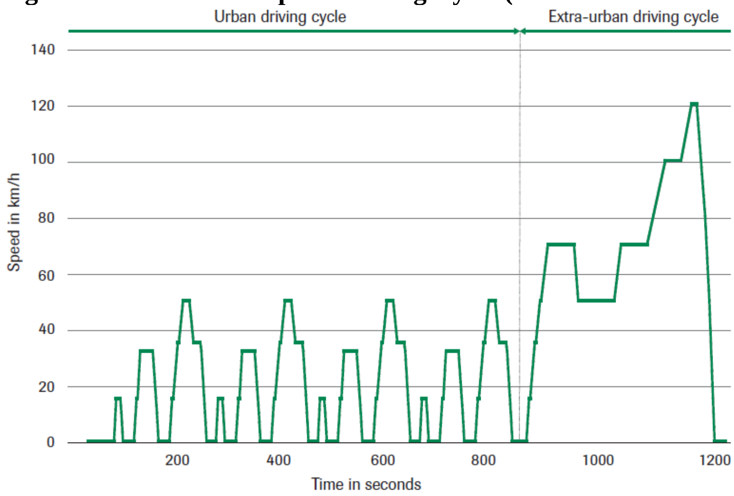
In Australia and many other countries, all new motorised road vehicles sold must undergo test procedures to measure the fuel consumption and emissions. The results allow governments to manage emission targets and allow consumers to predict fuel costs for purchasing decisions. A component of these procedures is the driving cycle, a profile of vehicle speed designed to simulate real, on-road driving conditions.

Many driving cycles are used in testing (Barlow et al. 2009) and many country-specific driving cycles are being developed (Pathak et al. 2016). For cars sold in Australia, the test procedures are specified in Australian Design Rule 81/02 – Fuel Consumption Labelling for Light Vehicles 2008 (ADR 81/02), which are based on the procedures of United Nations Economic Commission for Europe Regulation No. 101 (Office of Legislative Drafting and Publishing 2012).

1.1 New European Driving Cycle

ADR 81/02 requires tests to use the New European Driving Cycle (NEDC), which has been used in many countries since the early 1980s and in Australia since 1997. Figure 1 shows that the NEDC driving profile comprises an ‘urban’ and an ‘extra-urban’ cycle.

Figure 1: The New European Driving Cycle (Verband der Automobilindustrie 2014)



During the test (Franco et al. 2013), the vehicle is driven on a chassis dynamometer, which includes a controllable roller on which the wheels are placed, allowing the vehicle to remain stationary on a test cell in a controlled laboratory. The roller imposes resistive forces that are intended to simulate the road loads that the vehicle would experience across the NEDC speed profile. The exhaust gas flow rate is continuously monitored. Exhaust gases are analysed for emissions, either during the driving procedure by chemical analysers or after being collected in sample bags. The fuel consumption is calculated from the measurements of carbon dioxide (CO_2), hydrocarbons (HC), and carbon monoxide (CO) emissions; and from the carbon mass balance.

Studies conclude that, for most vehicle categories, the NEDC and other test procedures underestimate the fuel consumption and emissions of on-road driving (Degraeuwe & Weiss 2017; Fontaras et al. 2017; Pathak et al. 2016; Pavlovic, Marotta & Ciuffo 2016; Tsokolis et al. 2016). This discrepancy arises because the controlled conditions, although enabling fair comparison between vehicles, lead to a systematic bias. On-road driving is different because drivers might travel with additional passengers and cargo mass, use the air conditioner and other auxiliary systems, use realistic gear shifting, have cold starts and hot starts, travel in cold and hot weather conditions, and travel on unfamiliar routes; and because environmental conditions—such as inclined roads, side winds, and rain—cause additional resistance (Fontaras, Biagio & Ciuffo 2017; Fontaras et al. 2017; Pelkmans and Debal 2006; Tietge et al. 2015; Tsokolis et al. 2016). The NEDC itself comprises relatively few periods of mild acceleration, mild deceleration, and stable cruising over a narrow operating range of the engine; whereas on-road driving is more-dynamic due to driver and vehicle responses to conditions and events (Demuynck et al. 2012; Fontaras, Biagio & Ciuffo 2017; Fontaras et al. 2017; Pathak et al. 2016; Tsokolis et al. 2016; Tutuianu et al. 2015).

Notable differences between the control conditions and Australian driving conditions include that air temperatures in Australia frequently exceed the 20-30°C control range, relatively few Australian roads have speed limits above 100 km/h, and that the urban average speed in Australia is 25-50 km/h but only 15-30 km/h in Europe (ABMARC 2017). A study of vehicles driven in Melbourne shows that on-road fuel consumption is an average of 23% higher than estimated using the NEDC (ABMARC 2017).

In many countries, the gap between the reported and on-road CO_2 emissions is increasing, having grown from 10-20% in the mid 2000s to 20-40% in the late 2010s (Fontaras, Biagio &

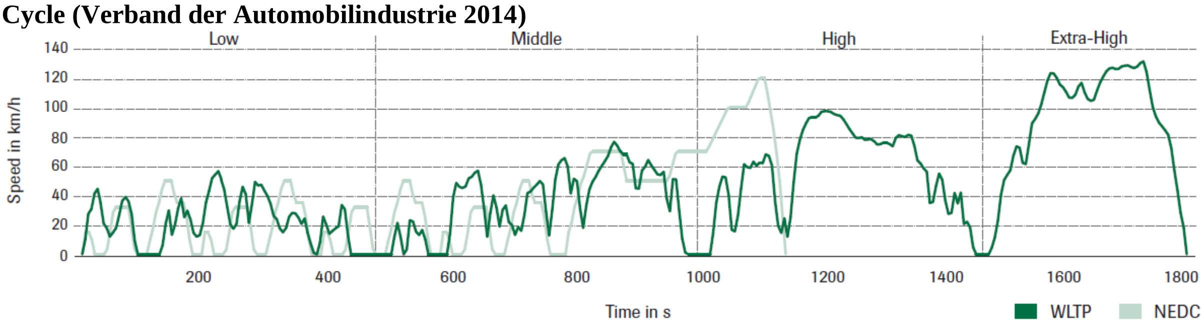
Ciuffo 2017; Fontaras et al. 2017; Tietge et al. 2015; Tietge et al. 2017). Evidence shows that this divergence is occurring for a few reasons. Manufacturers are better-optimising vehicle tests by exploiting the margins of flexibility and tolerances in the test procedures (Fontaras, Biagio & Ciuffo 2017; Tietge et al. 2015). Stop-start systems, hybrid powertrains, and some other fuel-efficiency technologies are typically more effective during laboratory testing (Tietge et al. 2015). Vehicles are equipped with larger air-conditioning systems, more on-board entertainment systems, and auxiliary systems, which are switched off during testing (Tietge et al. 2015). Driving style, which can have a large impact, seems to have remained relatively stable (Tietge et al. 2015).

1.2 Worldwide Harmonized Light Vehicles Test Procedure

The limitations of the NEDC procedure and the increasing gap are being addressed by the development and implementation of the new Worldwide Harmonized Light Vehicles Test Procedure (WLTP) (Fontaras, Biagio & Ciuffo 2017). Countries transitioning to the WLTP to some extent during 2017-2021 include the European Union 28 countries, Japan, South Korea, India, and China.

In addition to modifying some components of the NEDC test procedure and introducing some new components (Pavlovic et al. 2018), the WLTP uses the Worldwide Harmonized Light Vehicles Test Cycles (WLTC). The WLTC, designed to suit driving in many countries, are developed using data from 815,000 km of driving, various vehicle categories, various road types, and various driving conditions across Europe, India, Japan, Korea, and the USA (Tutuianu et al. 2015). Figure 2 shows that the WLTC driving profile comprises a ‘low’, a ‘medium’, a ‘high’, and an ‘extra-urban’ cycle. The WLTC Class 3 driving cycle, for vehicles of power-to-mass ratio of 34 kW/ton or more, is relevant to most passenger cars.

Figure 2: The Worldwide Harmonized Light Vehicles Test Cycle (Class 3) and New European Driving Cycle (Verband der Automobilindustrie 2014)



Early experimental studies compare the NEDC to the WLTC. They generally show that the WLTC results in higher nitrogen oxides (NOx), particulate matter (PM), and particulate number (PN) emissions; lower total hydrocarbons (THC) and CO emissions; but the same fuel consumption and CO_2 emissions because the higher variability and diversity in speed and acceleration is offset by the higher average engine efficiency, the lower average engine speeds (because of the new gear-shifting profile), and fewer cold starts (Pavlovic, Marotta & Ciuffo 2016; Pavlovic et al. 2018).

Subsequent studies compare the NEDC procedure to the WLTP, accounting for other components. They generally show that the WLTP results in 15-25% higher CO_2 emissions, equivalent to about half of the gap between the NEDC and on-road CO_2 emissions (Fontaras, Biagio & Ciuffo 2017; Pavlovic, Marotta & Ciuffo 2016; Pavlovic et al. 2018), and even higher fuel consumption (Pavlovic, Marotta & Ciuffo 2016). Of this increase, the more-realistic road load contributes about half; the higher vehicle inertia contributes about one quarter; and the new driving profile, gear-shifting profile, and test temperature contribute about one quarter (Tsokolis et al. 2016). Some studies, however, show that the WLTP considerably underestimates emissions when average speed is low and acceleration is high (Pathak et al. 2016).

1.3 The present study

In Australia, the NEDC is used to measure the fuel consumption and emissions of new vehicles. Regulations might change, like they are in other countries, to abandon the NEDC in favour of the WLTC. Evidence from many countries, including Australia, suggests that the NEDC underestimates fuel consumption and emissions. Evidence also suggests that the WLTC can provide more-accurate estimates when used with the appropriate procedures but that it could also provide underestimates when driving characteristics are not representative. The aim of the present study is to determine the representativeness of the NEDC and WLTC for car driving in Australia by an analysis of driving characteristics.

The next section outlines the methods, tools, driving characteristics, and data of the study. The subsequent section presents and describes the results. The following section discusses the results in the context of the study aim and identifies actions to address the study limitations. The final section provides the study conclusions.

2. Methodology

This study is a pilot that demonstrates the procedure for a larger study that is expected to be conducted over several years. The study quantifies driving-cycle characteristics that allow direct comparison with published values for the NEDC (Steven 2013) and WLTC Class 3 Version 1 (Tutuianu et al. 2015). For this pilot, the targeted driving data are of passenger cars in metropolitan Melbourne.

2.1 Participants

Three volunteers were recruited by word of mouth to participate in the study in August-September 2017. Each participant has driving characteristics logged over a period of 2-4 days, and completes a questionnaire about personal characteristics and unusual driving experiences during the test period. Relevant ethics clearance for these procedures was obtained from the University Human Research Ethics Committee at RMIT University. Table 1 shows the details about the participants and cars.

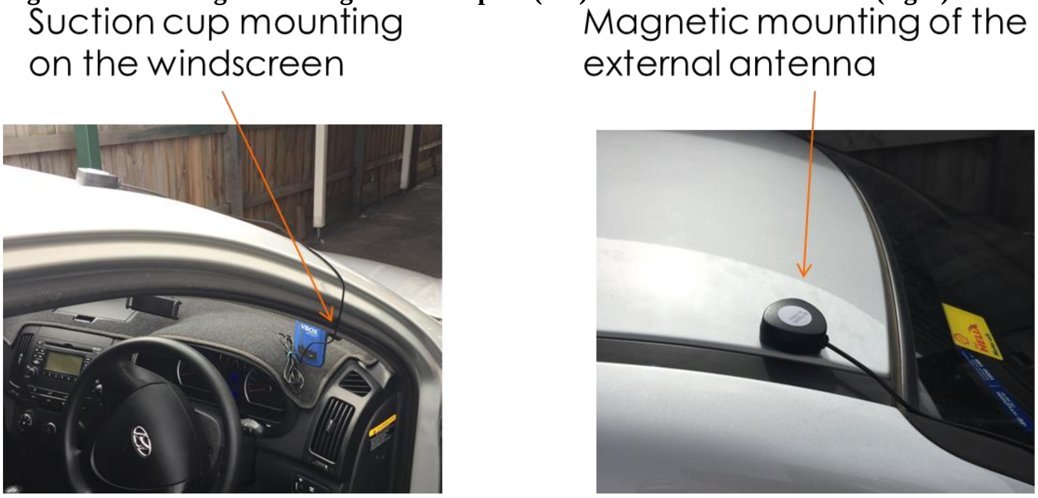
Table 1: Participants and cars in the study

Characteristic	Participant 1	Participant 2	Participant 3
Age	26-35 years old	26-35 years old	18-25 years old
Gender	Female	Male	Male
Car	2012 Holden Cruze	2012 Holden Cruze	2016 Kia Cerato
Routes driven	Typical	Typical	Atypical—rural
Weather conditions	Typical	Typical	Typical
Affected by illness, drugs, or otherwise	No	No	No

2.2 Data collection

Primary data of driving characteristics are collected using a Racelogic VBOX Sport, a professional global positioning system (GPS) data logger. A GPS logger, as used in other studies (ABMARC 2017; Pathak et al. 2016), is selected to avoid modification of the participants' cars. Figure 3 shows the suction-cup, windscreen mounting of the logger and the magnetic, rooftop mounting of the external antenna.

Figure 3: Mounting of Racelogic VBOX Sport (left) and its external antenna (right)



2.3 Data analysis

A 'journey' is the travel that is bound by the driver turning on the car and turning off the car (e.g., home to workplace). A 'short trip' is the travel bound by the driver accelerating from zero and returning to zero (e.g., between traffic lights). Each recorded journey is divided into a series of short trips. Each short trip is categorised by its maximum speed. The below categories are selected to align with the common speed limits in Melbourne and the WLTC.

- Low: up to 60 km/h
- Medium: 60-80 km/h
- High: 81-100 km/h
- Ex-high: above 100 km/h

Contiguous short trips are delimited by an increase above zero of the speed. As such, each short trip starts with a positive speed and ends with a zero-speed idle period. Because the logger's sensitivity enables it to detect movement caused by wind, the car is assumed to be stationary at all speeds less than 1 km/h.

Using Racelogic VBOXTools software, logged Melbourne data for the below 'journey characteristics' are extracted at 1-second intervals for each journey.

- Time stamp (s)
- Distance (m)
- Average speed (km/h)
- Acceleration (m/s^2)

The journey data are used to calculate the below 'short-trip characteristics' for each short trip. The characteristics are selected to allow direct comparison with published NEDC and WLTC values. They include various characteristics of speed (Brady and O'Mahony, 2016), acceleration (Ericsson 2001; Pathak et al. 2016), and idling (Tong et al., 2011), reported to most-strongly correlate with fuel consumption and emissions. Verification of data and analysis is by comparison of the average speed of the logged Melbourne data with the published average speed in metropolitan Melbourne—low-mid 30s km/h during peak times and low 40s km/h during off-peak times (VicRoads, 2014).

- Duration (s)
- Distance (m)
- Average speed (with stops) (km/h)
- Average speed (without stops) (km/h)
- Maximum speed (km/h)
- Idling ratio (%)
- Relative positive acceleration, RPA (m/s^2)
- Average positive acceleration (m/s^2)

The short trip data are used to calculate the below statistical parameters, enabling a subsequent one sample, two-tailed, Student's t-test of the logged Melbourne data against the published NEDC and WLTC values. The assumed significance level is 0.05. As such, p-value results of less than 0.05 suggest that the means of the Melbourne characteristics are different to the means of NEDC or WLTC characteristics.

- Mean
- Confidence interval
- P-value for the comparison to the NEDC
- P-value for the comparison to the WLTC

3. Results

Data of driving characteristics are logged for 192 short trips over a total distance of 296 km. Low-speed short trips comprise 76% of all short trips. The numbers of high-speed and extra-high-speed short trips are relatively small, leading to a statistically underpowered comparison of the logged Melbourne data with the NEDC and WLTC. Table 2 shows the details of the raw data, categorised by short trip.

Table 2: Details of the raw logged Melbourne data

Characteristic	Low	Medium	High	Extra-high	Total
Count	146	34	9	3	192
Duration (s)	16508	6578	8506	830	32422
Distance (m)	80570	62219	141096	12518	296403

Table 3 shows the results of the data analysis. The NEDC urban category is grouped with the Melbourne and WLTC low categories. The NEDC extra-urban category is grouped with the Melbourne and WLTC extra-high categories. The total average speed (with stops) of 37 km/h is consistent with the published average speed in metropolitan Melbourne, providing some evidence that the data collection and analysis procedures are valid.

The results show many p-values of less than 0.05. Therefore, there is evidence for many driving-cycle characteristics being different for the pilot Melbourne driving cycle than for the

NEDC and WLTC. In the extra-high category for the Melbourne driving cycle, the average speed is relatively low and the idle ratio is relatively high because two of the three trips seem to have been on urban freeways in which the driver surpassed the 100km/h limit only briefly.

Of the characteristics for which there is no evidence of a difference (p-value in blue), most are for the high and extra-high categories, but those outcomes might change given more samples. The few characteristics in the low and medium categories, for which there are sufficient samples, show that the average speed (with stops) is the same as the NEDC in the low category, the average speed (without stops) is the same as the WLTC in the medium category, the idle ratio is the same as the NEDC in the low category, and the RPA is the same as the WLTC in the medium category. Therefore, there is weak evidence for Melbourne driving to be represented by the NECD in the low and by the WLTC in the medium category.

Table 3: Comparison of the driving cycle characteristics of the logged Melbourne data with those of the published NEDC (Steven 2013) and WLTC (Tutuianu et al. 2015)

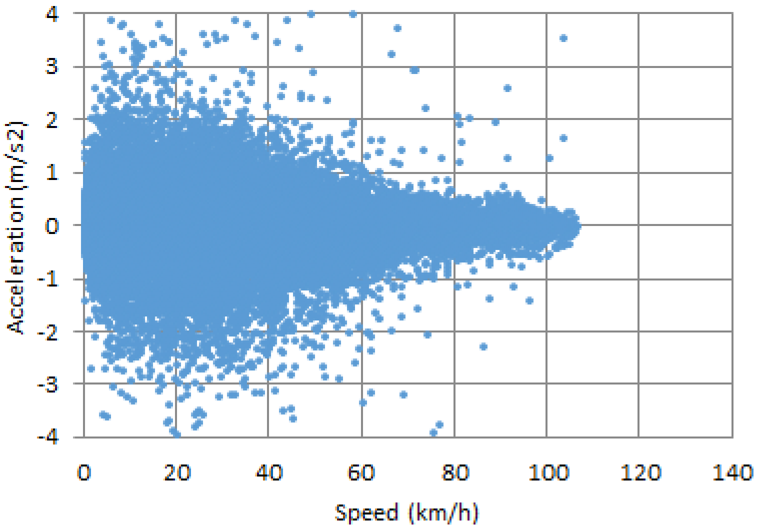
Characteristic		Low / Urban	Medium -	High -	Extra-high / Extra-urban	Total
Duration (s)	**Melbourne**	113 ± 13	193 ± 29	945 ± 192	277 ± 101	1528
	NEDC	780	-	-	400	1180
	P-value (NEDC)	<0.001	-	-	0.03	-
	WLTC	589	433	455	323	1800
	P-value (WLTC)	<0.001	<0.001	<0.001	**0.186**	-
Distance (m)	**Melbourne**	552 ± 86	1830 ± 292	15677 ± 3712	4173 ± 1779	22232
	NEDC	4058	-	-	6955	11017
	P-value (NEDC)	<0.001	-	-	0.021	-
	WLTC	3095	4756	7162	8254	23267
	P-value (WLTC)	<0.001	<0.001	<0.001	0.010	-
Av. speed (with stops) (km/h)	**Melbourne**	16.8 ± 1.9	33.1 ± 4.0	48.9 ± 16.0	43.8 ± 57.2	22.6
	NEDC	18.7	-	-	62.6	33.6
	P-value (NEDC)	**0.052**	-	-	**0.294**	-
	WLTC	18.9	39.2	56.7	92	46.5
	P-value (WLTC)	0.032	0.004	**0.203**	**0.068**	-
Av. speed (without stops) (km/h)	**Melbourne**	22.8 ± 2.0	42.0 ± 3.2	52.4 ± 15.2	61.2 ± 51.1	29.3
	NEDC	27.7	-	-	69.7	42.2
	P-value (NEDC)	<0.001	-	-	**0.550**	-
	WLTC	25.7	44.5	60.8	94.0	-
	P-value (WLTC)	0.004	**0.118**	**0.150**	**0.111**	-
Max. speed (km/h)	**Melbourne**	38.7 ± 3.6	64.2 ± 8.5	87.6 ± 14.1	105.4 ± 31.9	106.5
	NEDC	50.0	-	-	120.0	120.0

Characteristic		Low / Urban	Medium -	High -	Extra-high / Extra-urban	Total
	P-value (NEDC)	<0.001	-	-	**0.188**	-
	WLTC	56.5	76.6	97.4	131.3	-
	P-value (WLTC)	<0.001	0.006	**0.078**	**0.073**	-
Idle ratio (%)	**Melbourne**	32.8 ± 3.7	23.2 ± 6.7	12.4 ± 16.9	29.6 ±643.3	29.7
	NEDC	32.3	-	-	10.3	24.8
	P-value (NEDC)	**0.777**	-	-	**0.326**	
	WLTC	24.8	10.6	6.4	1.5	12.6
	P-value (WLTC)	<0.001	<0.001	**0.347**	**0.201**	
RPA (m/s^2)	**Melbourne**	0.29 ± 0.03	0.33 ± 0.19	0.28 ± 0.30	0.37 ± 0.59	0.30
	NEDC	0.14	-	-	0.09	0.11
	P-value (NEDC)	<0.001	-	-	**0.184**	
	WLTC	0.20	0.19	0.12	0.12	-
	P-value (WLTC)	<0.001	**0.134**	**0.179**	**0.219**	-
Av. +ve accel. (m/s^2)	**Melbourne**	0.59 ± 0.04	0.59 ± 0.09	0.36 ± 0.10	0.67 ± 0.92	0.58
	NEDC	0.64	-	-	0.35	0.53
	P-value (NEDC)	0.015	-	-	**0.274**	-
	WLTC	-	-	-	-	-
	P-value (WLTC)	-	-	-	-	-

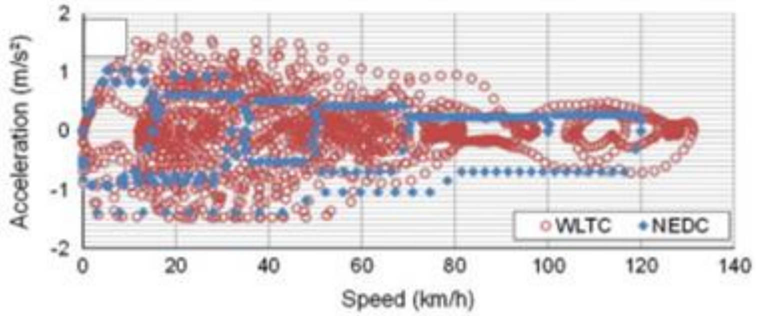
Figure 4 shows the acceleration as a function of speed. The chart for the pilot Melbourne driving cycle is trimmed vertically to exclude some outliers, which reach up to 20 m/s^2 and down to -27 m/s^2, largely at speeds of less than 40 km/h. These outliers are artifacts of the measurement device. The authors plan to experiment with data filtering to remove the outliers while retaining the characteristics of the driving cycle.

The ranges of the data differ. The Melbourne driving cycle suggests more-aggressive acceleration (and deceleration). Even if data filtering moves acceleration values closer to zero, the acceleration range is still likely to be wider than those of the NEDC and WLTC. The Melbourne driving cycle also shows lower maximum speed for the reasons stated above.

Figure 4: Acceleration as a function of speed for (a) the logged Melbourne data and (b) the published NEDC and WLTC (Tutuianu et al. 2015)



(a)



(b)

4. Discussion

The results, though preliminary, agree with the previous studies that suggest that the NEDC fails to accurately represent some characteristics of Melbourne driving, and likely underestimates the fuel consumption and emissions. RPA and average positive acceleration, the two characteristics most strongly correlated with emissions, are higher for most categories of the Melbourne driving cycle. These results warrant further investigation using more samples.

The results suggest that the WLTC might also fail to accurately represent some characteristics of Melbourne driving. With additional samples, however, there might arise an opportunity to identify a close match between driving in Melbourne and driving in Europe, India, Japan, Korea, or the USA. In such a case, the WLTC might represent Melbourne driving sufficiently.

The categorisation of short trips is only according to maximum speed; it is limited by the lack of known road speed limits. Therefore, without speed-limit data, a short trip might be miscategorised when the driver exceeds the speed limit (e.g., travels at 70 km/h in a 60-km/h zone) or drives slowly (e.g., travels at 40 km/h on a congested 100-km/h freeway).

Additional samples would help to address many study limitations. They would increase the statistical power of the comparisons, especially for the high-speed and extra-high-speed short-trip categories. Samples from wider range of participants would allow investigations into the differences in driving characteristics by age group and gender, and would average out any bias of young drivers, such as higher acceleration because of aggressive driving. Samples during other times of the year would help to address seasonal variation and average out any bias of winter driving, such as lower average speeds and higher idle times because of more private car use and congestion. Samples in other locations would help to address topographical, weather, climate, market, and cultural variations. The authors' immediate plans are to collect more samples in Melbourne from wider range of participants during other times of the year.

5. Conclusion

The representativeness of the NEDC and WLTC for driving in Australia is unknown. Therefore, the Australian Government must manage emission targets and consumers must predict fuel costs based on uncertain data. To increase certainty in that data, this pilot study collects and analyses primary data of car travel in Melbourne to determine the representativeness. The preliminary results show evidence for many driving-cycle characteristics being different for Melbourne than for the NEDC and WLTC. More data from a wider range of participants, other times of the year, and other locations are required to increase certainty.

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