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Paper title: **A typical Adelaide drive: How should it be derived?**

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Abstract (200 words):

Drive cycles are stereotypical vehicle journeys representing typical motor vehicle trips in a given study area. This paper will concentrate on the derivation of drive cycles that will represent typical driving for Adelaide. In this way allowing accurate and reliable emissions models to be developed for studies of air quality and greenhouse gases.

Highly detailed analysis of driving in Adelaide was performed using second by second time, position and speed data collected from GPS receivers in the vehicles. This allows for a very detailed statistical analysis of what a typical drive is. Further more the level of detail of the data allowed the typical drive to be disaggregated further into peak period driving and inter peak driving. The results showed quantifiable differences between the stop start nature of peak period driving and the more free flowing nature of interpeak driving. These factors have large influence on total vehicle emissions, hence a much better understanding of the contribution of traffic emissions throughout the day can be considered.

Introduction

Transport contributes some 17% of greenhouse gas emissions in Australia, as indicated in the 1996 National Greenhouse Gas Inventory from the Australian Greenhouse Office (AGO). It is projected that this figure will increase if nothing is done to alleviate the problem. There has been a push by government to look at ways of reducing greenhouse emissions from all sectors. In the transport sector one of the means of reducing greenhouse gas emissions is to make more efficient use of existing road infrastructure. Globally this initiative has been given the title Intelligent Transport Systems (ITS). One of the objectives of ITS is to reduce travel times and decrease overall vehicle travel which in turn should reduce greenhouse gas emissions and improve air quality.

One question this initiative raises is how to assess the effectiveness of ITS or any schemes aimed at reducing greenhouse emissions and or increasing air quality. The most common assessments at the moment are Greenhouse Gas Inventories and National Pollutant Inventories performed by authorities such as the Australian Greenhouse Office (AGO) and the Environmental Protection Agency respectively. The methodologies used as a part of these inventories use broad brush and aggregated techniques to determine total emission quantities and don't necessarily assess impacts or policy options. The techniques often involve the use of total fuel sale statistics along with total kilometres of travel and emission factors for a limited number of vehicle categories to provide the emission levels (AGO Work Book for Transport, Mobile Sources 3.1, 1998) and EPA(2000). The Bureau of Transport and Regional Economics (BTRE) Report 94, (BTRE 1996), describes studies using similar approaches.

The modelling of traffic behaviour has seen many developments in recent years. One approach is to use a hierarchy of models designed to deal with different transport policy scenarios. At the top level are the most aggregated and broad-brush models as described above. Then there are the link-based models that can be used to identify changes on a link-by-link basis in the network. The final and most detailed levels are the micro simulation models that are used to assess the effect of various schemes on traffic performance. These micro models are highly detailed and allow for flexibility in the specification of the network and fleet characteristics. There is no point in using these sophisticated models in the evaluation of greenhouse gas and air quality performance of various schemes if only broad brush aggregated emission data is available such as those used in the AGO, EPA and BTE models. These aggregated factors do not have enough sensitivity to be able to reflect the various changes in policy that road agencies such as Transport SA are likely to deal with. Obtaining representative drive cycles, then determining their emissions outputs for representative vehicles, is one way of obtaining emissions models that are sensitive to these types of policy scenarios. The Transport Systems Centre (TSC) of the University of South Australia and the Environment Policy Unit of the Transport Planning agency, are jointly using this research project to provide the data necessary to calculate these emissions models for use in micro simulation modelling. This will permit a high level of accuracy and reliability when modelling the outcomes of various traffic schemes and policy implications.

The use of drive cycles

Drive cycles are typical vehicle journeys representing trips in a given study area. Drive cycles were developed in the 1980's for cities such as Sydney, Melbourne, Brisbane and Perth. Adelaide as yet does not have its own driving cycle, and as is the case with most driving cycles, a standard American based driving cycle is used as a substitute (Australian Design Rules 37/00 based on the American Federal Test Program cycle). However these types of drive cycles have been developed for the regulation of emissions from vehicles rather than the modelling of emissions.

This issue highlights the traditional dual use of drive cycles, on the one hand being used as a regulatory tool, while on the other being used to derive emission factors for various vehicles types under various driving conditions. The actual requirements of the drive cycle under for the two uses are quite different. In the modelling context the drive cycle must be representative of actual on road driving conditions, hence on road data collection techniques must be used in order to derive such drive cycles. Whereas in a regulatory context the actual nature of the drive is not important, but ensuring that the total emissions produced at the end of the drive are below the regulated value is paramount to passing the regulation.

A good example of this is the new European vehicle emissions standards that are now being introduced into Australia. The new Euro 2 cycles are essentially a repeat of a specific set of accelerations, cruise speed and decelerations, it is unlikely that the emissions results derived from these cycles are going to be useful in an emissions modelling / emissions inventory (i.e. the National Greenhouse Gas Inventory (NGGI) and the National Pollutant Inventory) context.

Internationally however both the US and the European Union have inventory methodologies that have emission rates that are dependent on the average speed of travel. In the US, Mobile 5 and later version of the Mobile software, have published these emission speed relationships in the context of speed corrections factors (SCF), see Figure 1. In Europe the European Emissions Inventory also have these types of relationships. Figure 2 shows the relationship between fuel consumption (FC) and average speed from the European Emissions Inventory Guidebook, for various passenger vehicle classes. It must be noted that in the US and European inventory methodologies these relationships are known for a wide range of vehicle and fuel types.

In order for Australia to reach the same standard, drive cycles must be derived that represent various average speeds of travel. Then these cycles must then be tested by a large number of representative vehicles in order to obtain emissions rates for each average speed cycle. These results would then be aggregated to form a single emission rate versus mean speed of travel for each vehicle category required. This would then be comparable to the emissions inventories used in the US and Europe for these classes of vehicles. The incorporation of these new emission factors would make Australian Inventories methodologies harmonised, more accurate and reliable and fall into line with International best practice. The current National In Service Emissions study (NISE2) gives Australia the opportunity for the first time to have emissions models that have the ability to account for different levels of average speeds between Australian cities as well as within city variations. For example occurrences of recurrent congestions i.e. peak hours and non-recurrent congestion i.e. incidents all cause large fluctuations in average speeds. It is only with the adoption of these new average speed emission models that these situations can be accurately and reliably modelled for inventory or other transport planning policy-setting options. These types of models will allow transport agencies to make informed decisions on policy options

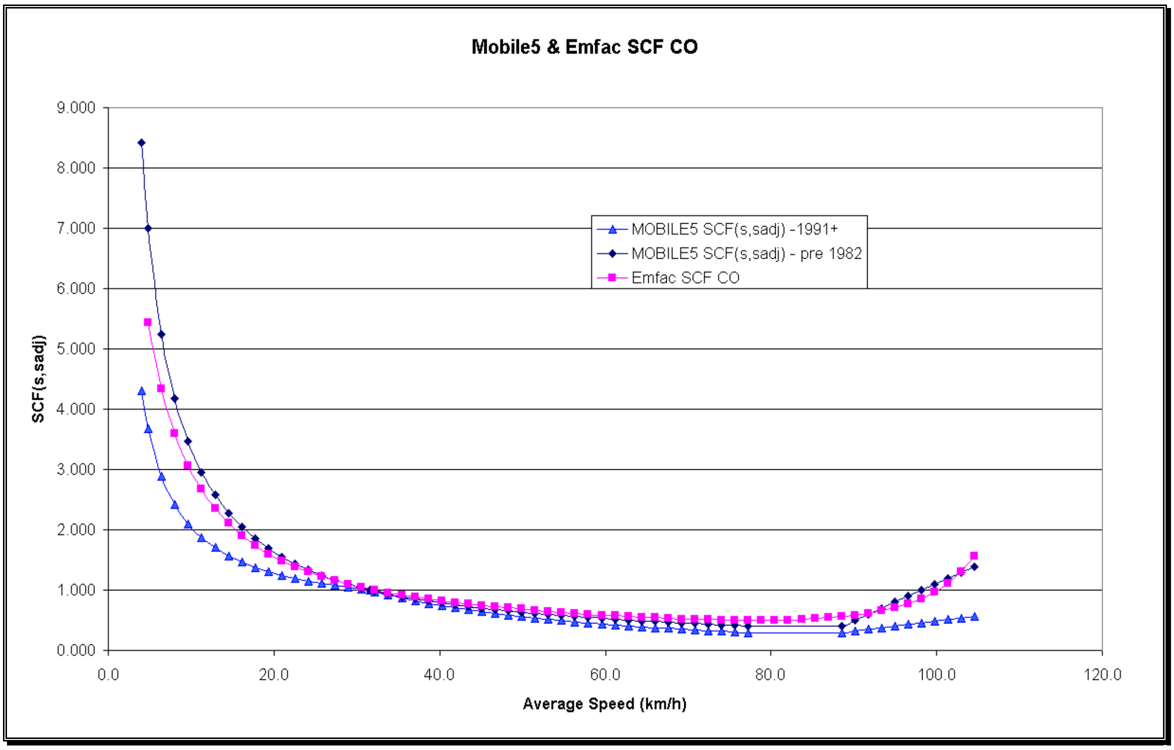

Figure 1 Mobile 5 Speed Correction Factors for CO

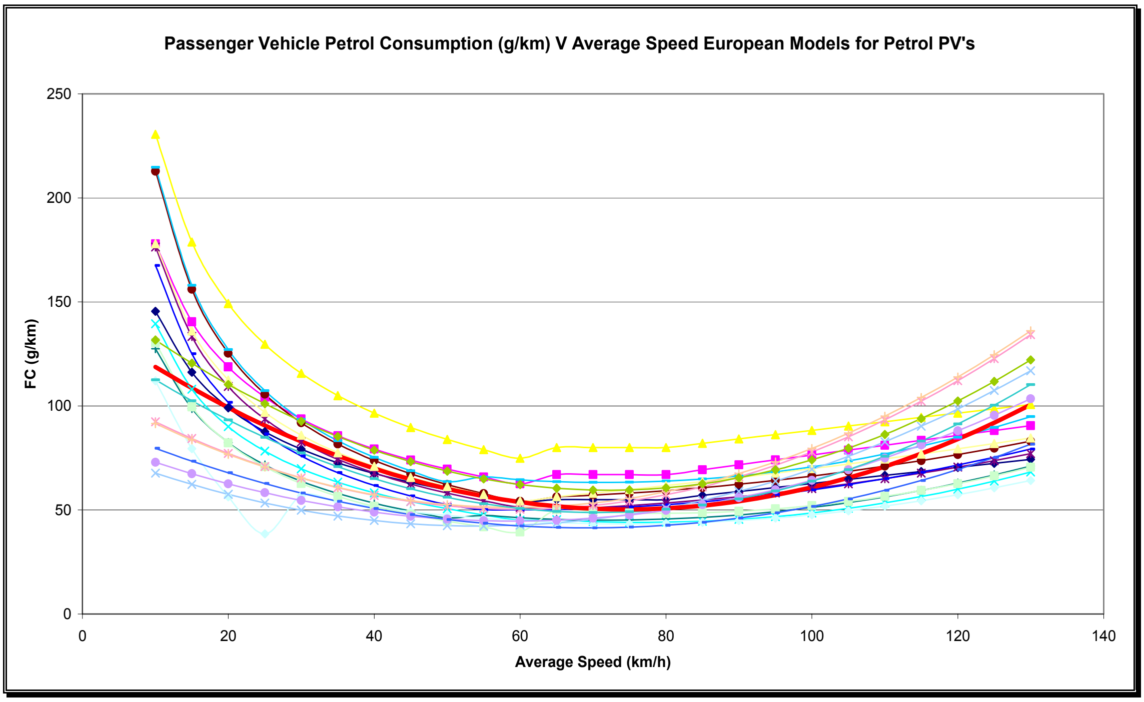

Figure 2 European Emissions inventory - Fuel Consumption V Average Speed

Drive cycles for different cities

All cities are different, from the way the road network has been designed, climate variations, locations of the different socio economic groups etc all have a significant effect on the travel patterns within the city. Adelaide driving conditions differ from those of the other states, in terms of its semi arid climate, lower traffic volumes, older population and a regular planned road network. Adelaide motorists driving to the city can expect a shorter travel time than those of Sydney or Melbourne. Hence the proportion of the trip spent with an engine running under “cold start” conditions will have a greater influence on the total amount of emissions for that journey in Adelaide than Melbourne or Sydney. There have been numerous studies showing that “cold starts” increase fuel consumption significantly. For example, Waters (1992) showed that 160% more fuel is required to drive a distance of 5km if the engine is initially cold. The Australian Standard AS 2077 - 1982 suggests that at 80 km/h every 6°C drop in engine temperature results in a fuel consumption increase of 2%. There is therefore a need to develop a unique driving cycle that will encompass characteristics that are specific to Adelaide.

The development of driving cycles is a complex science and requires a great deal of engineering knowledge and technical expertise. There are many issues that can be easily overlooked by those who have not studied the literature in detail. Some of the more relevant drive cycle literature includes the following:

- development of the Melbourne peak cycle by Watson, Milkins and Braunsteins (1982).
- development of the Sydney driving cycle by Kent, Allen and Rule (1978).
- development of a driving cycle for Perth by Kenworthy and Newman (1982).
- development of the unified cycle for California by Sierra Research (eg. Effa and Larsen 1993; Austin *et al*. 1992).
- development of a protocol for creating representative facility-type driving cycles (eg. Young *et al*. 1997)

Driving cycles are dependent on many factors. A driving cycle must be created from a large database of real-world driving data collected from a representative fleet of vehicles driven on typical road types under the full range of expected traffic conditions.

A study of the available literature and hands-on experience has revealed several fundamental reasons for the inherent difficulty in the development of driving cycles. These include the following issues:

1. Microscopic variability is a function of facility-specific attributes and traffic mix as well as macroscopic traffic conditions (i.e. driving cycles depend on facility configuration and heavy-duty vehicle mix as well as average traffic volumes and speeds);
2. Microscopic activity is sensitive to high levels of congestion, which can be caused by both recurrent and non-recurrent events;
3. There are intra- and inter-regional differences in facility configurations, and therefore the notion of a 'typical' or 'representative' cycle requires a highly aggregated view of driving, which may or may not truly represent typical driving on a given facility or in a given region.

Drive cycle data collection

Obtaining the data to calculate the driving cycle at TSC has been based around the use of Global Positioning System (GPS) receivers to record the time position and speed data at update rates of once per second in conjunction with the instrumentation in the TSC car. The TSC has a wealth of experience in using GPS for travel time studies and congestion analysis (eg Zito and Taylor (1994), Zito, D'Este and Taylor (1995), D'Este Zito and Taylor (1999), Taylor, Woolley and Zito (2000)). The TSC already has a number of GPS receivers that can be used to obtain the positional data together linked to a notebook computer that can be used to store the data. The data that will be collected on a second by second basis will therefore include:

Time (secs)	Throttle position
Distance (m)	Latitude
Speed (km/h)	Longitude
Fuel (ml)	Hydrocarbons (g/s)
Engine RPM	oxygen (g/s)
Manifold pressure	$C0_2$ (g/s)
A/C (on/off)	CO (g/s)
Gear	N0x (g/s)
Power/Economy mode	
Engine Temp	

To obtain representative driving cycle data various regions throughout the Adelaide metropolitan area will need to be sampled. Kenworthy and Newman (1982) suggested a method for determining different socio-economic regions within a metropolitan area. They used this method to collect travel time and fuel consumption data in Perth in seven different areas using various driving techniques including the chase car and floating car methods. This data was then used to derive a typical drive cycle for Perth. The data collected for the Adelaide study is based around the Austroad's routes used for the collection of national network performance indicators for each state. TSC and TPA have been collecting this data as a part of a collaborative Australian Research Council grant. The advantages of this partnership between TSC and Transport SA for this research project is that travel time data is already collected by Transport SA on a regular basis as a part of their Austroads requirements. Normally the data collected by Transport SA constitutes the travel time of various links along a prescribed route in the morning and afternoon peak periods as well as during interpeak periods. This data is not detailed enough to provide any useful information for drive cycle determination. However since the conception of this research project Transport SA have moved to using GPS to obtain second by second time, location and speed data along the routes. This can provide the acceleration, cruise and deceleration profiles of the traffic stream along the routes. This is exactly the type of data that is required for the derivation of a drive cycle. The routes surveyed by Transport SA cover most of the Adelaide metropolitan area.

Once the GPS and other data had been collected it was imported into a Geographical Information System (GIS) where it can be displayed and analysed spatially as well as analytically. The TSC already has the Adelaide metropolitan street centre line data that will be added as a layer to the GIS so that the exact route, speed profile and time data can be determined on a link-by-link basis. This data will then be used as the basis for deriving the standard driving cycle.

A combination of chase car and floating car techniques was used to collect on-road data and hence obtain speed time profiles. This involves using the TSC instrumented vehicle or Transport SA contracted vehicle (fitted with GPS as a part of this research project) travelling behind a targeted vehicle or blending in with the traffic stream. As Figure 3 shows this will enable a detailed picture of time, speed and position to be obtained at update rates of up to once per second. Therefore not only will a detailed picture of speed profile and time information be obtained but also when imported into a GIS, a spatial distribution of where these speeds occurred can be obtained. The other advantage of using a GIS is that spatial and numerical analysis of the data can be performed.

The advantages of using GPS and GIS include:

- The ability to obtain second by second speed profile data
- The spatial display and analysis of data in a GIS
- The ease of transferability of GPS equipment from vehicle to vehicle
- Greater GPS accuracy due to the deliberate spoofing being turned off in May 2000 (Selective Availability)

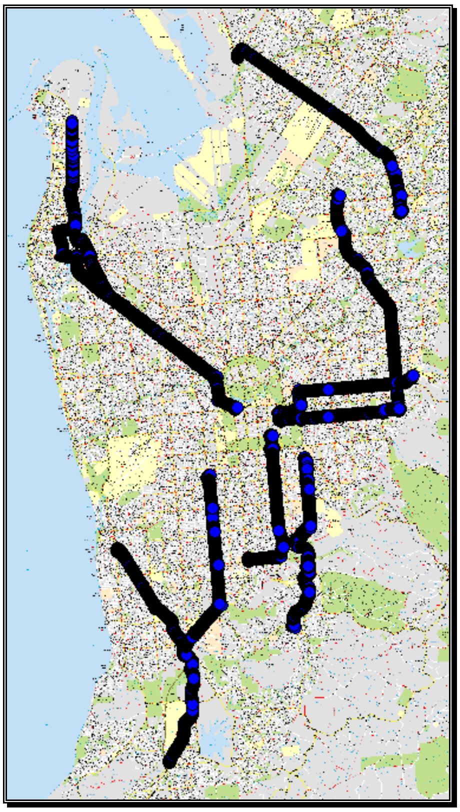

Figure 3 Map of Adelaide showing roads where GPS data were collected

The TSC already uses micro simulation modelling for the assessment of various traffic schemes. The Paramics micro simulation modelling package was chosen to perform these assessments since it has advanced visual representation capabilities that allow the user to determine if the model is working effectively. The Paramics website http://www.paramics-online.com/projects/ shows some examples of how TSC has used the model for the evaluation of a roundabout. It also shows how others have used this modelling software for the evaluations of different applications including Speed Controls and Vehicle Emissions for the M25 motorway in the UK. It is envisaged that the emission factors calculated for individual vehicle categories and the various drive cycle categories calculated as a part of the family of drive cycles, derived as a part of this research project will then be used as inputs to Paramics for the evaluation of environmental impacts of traffic schemes. Other modelling packages will also be assessed to evaluate the appropriateness of inputting the results of the drive cycles.

Traffic schemes to be modelled will be selected by the research team and Transport SA to reflect the current policy commitments of the road authority. The schemes are likely to be based around the implementation of ITS technologies and various other strategies.

Once all the data has been collected it will then be a matter of compiling each route it into a number of different categories. The aim of this research project to determine a family of drive cycles for different purposes. One of the outputs of this research project will be a drive cycle that is typical of all driving in the Adelaide region. This drive cycle will require no disaggregation and will simply use all the data collected. All the speed time data will be broken up into the various components of travel that make up the journey namely acceleration, cruise and deceleration. Akcelik and Biggs (1985) derived a set of mathematical criteria to determine from a speed time profile what phases are acceleration, cruise and deceleration. The data to come from this process will be the acceleration and deceleration rates and how long each rate occurs for, together with the different cruise speeds and how long each cruise was maintained for. It will then be a matter of aggregating the data into various acceleration rate, declaration rate and cruise speed bins and determining the distribution of each as well as the distribution of times for each phase. It is these phase and time distributions that will be used to derive the total drive cycle. Since the total drive cycle will have phases and timings correlating to those found for the entire set of driving data.

Other drive cycles can be obtained by selecting only various routes that satisfy the required criteria and then disaggregating them into their acceleration, cruise and declaration phases as described above. Some of the criteria used on the data could include all routes that have an average speed within a certain range. Hence drive cycles could be derived for routes that have average speeds between 45-50 km/h and more congested routes with average speeds of 25-30km/h. Other aggregations that could be investigated include only interpeak journeys or only peak period journeys. A better understanding of what criteria must be used to aggregate the different journeys will be obtained once all of the data has been collected. The above are just a few suggestions that are likely to be used as a starting point in this research project.

Drive cycle case study TSC instrumented vehicle data

1807 km of data was collected by the TSC car and was used to develop this drive cycle case study. The driving was performed while the vehicle was being used as a pool car at the TSC, as well as for a major investigation of Adelaide Southern Expressway, one of only a few fully reversible freeways in the world. Hence out of the total of over 127000 data records over 65000 were located either on the Southern Expressway or South Road a parallel arterial road also serving the Southern Suburbs of Adelaide, see Figure 4.

As described in the previous section the data obtained from the instrumented vehicle is quite extensive and cover vehicle operating parameters as well as GPS positional information. For this case study however only the time speed data will be used to derive a typical drive cycle based on this data.

The speed time data was divided into six different phase types based on the mathematical definition of the phases presented in (Biggs and Akcelic 1985), namely:

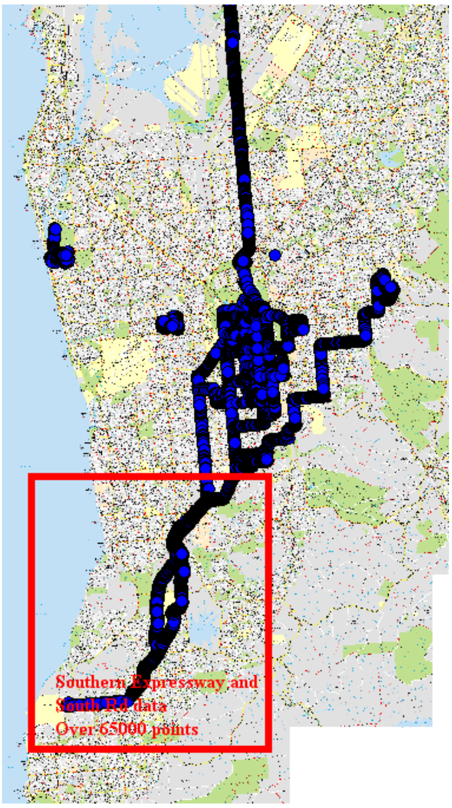

Figure 4 GPS data collected by TSC instrumented vehicle data

- Idle,
- Acceleration from idle;
- Deceleration to idle;
- Acceleration from other speeds;
- Deceleration to other speeds; and
- Cruise.

For each of these phase types, statistics such as mean, standard deviation, minimum and maximum values were collected for:

- Speed;
- Acceleration;
- Fuel consumption; and
- Emission of CO_2, CO, NOx, HC and N_2.

Other generalised information about each phase also includes time, distance duration, and beta coefficient. The graph in Figure 5 shows the amount of data collected for each phase type from the TSC research vehicle.

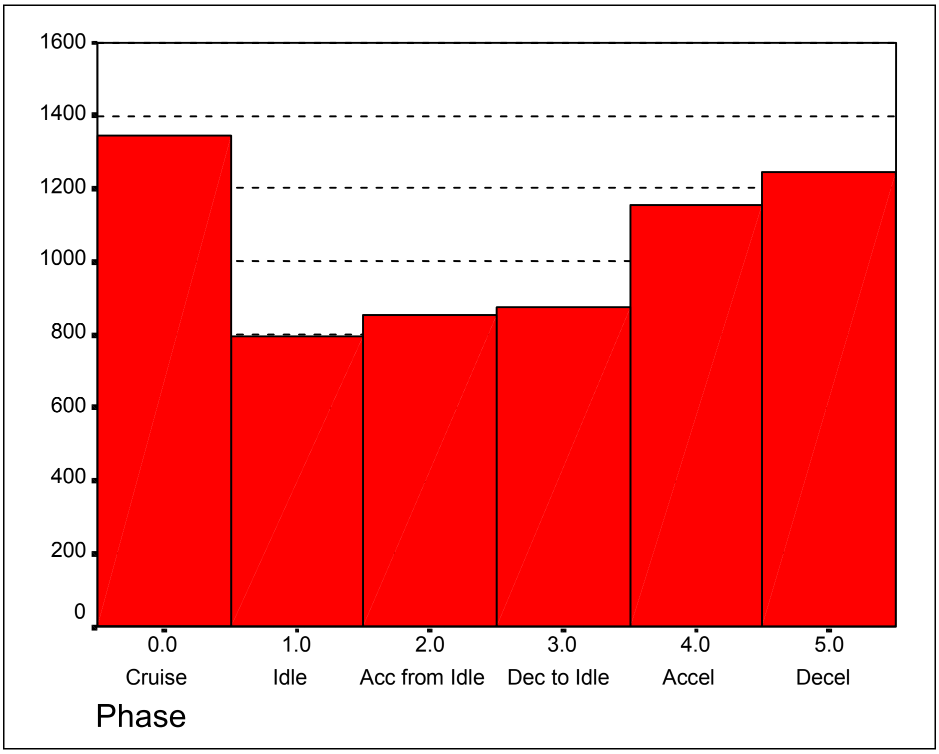

Figure 5 Number of phases collected from the TSC instrumented vehicle within each phase type.

The graph in Figure 6 shows the amount of data available for cruise phases by mean cruise speed. The categories represent the midpoint of each range. For example the 40 km/h category represents the mean cruise speed range from 35 km/h to less than 45km/h. As is expected there are two peaks in the distributions one around 60 km/h which was then the default urban road speed limit. With the other peak occurring at around 80 km/h which is dominated by driving along the Southern Expressway and parts of South Road that have speed limits at these higher speeds.

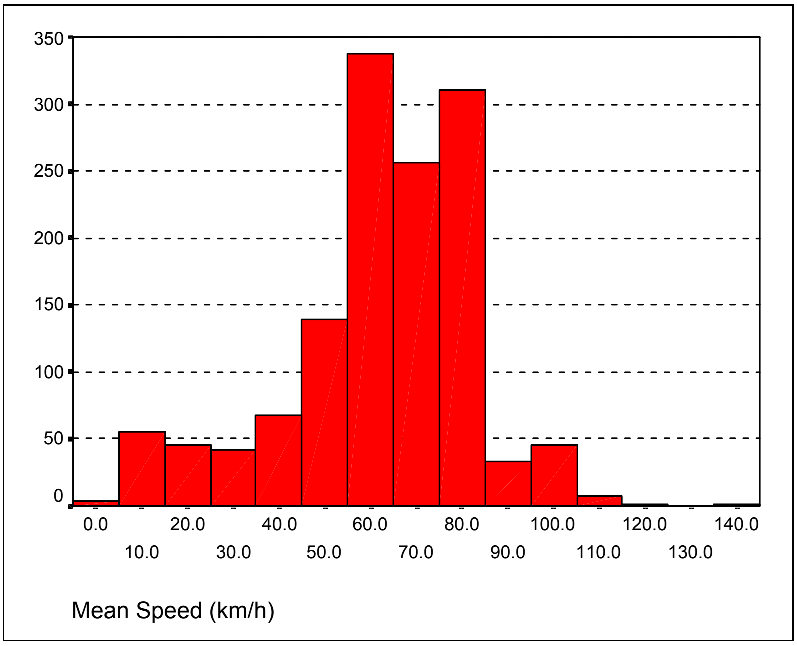

Figure 6. Number of cruise phases categorised by mean speed.

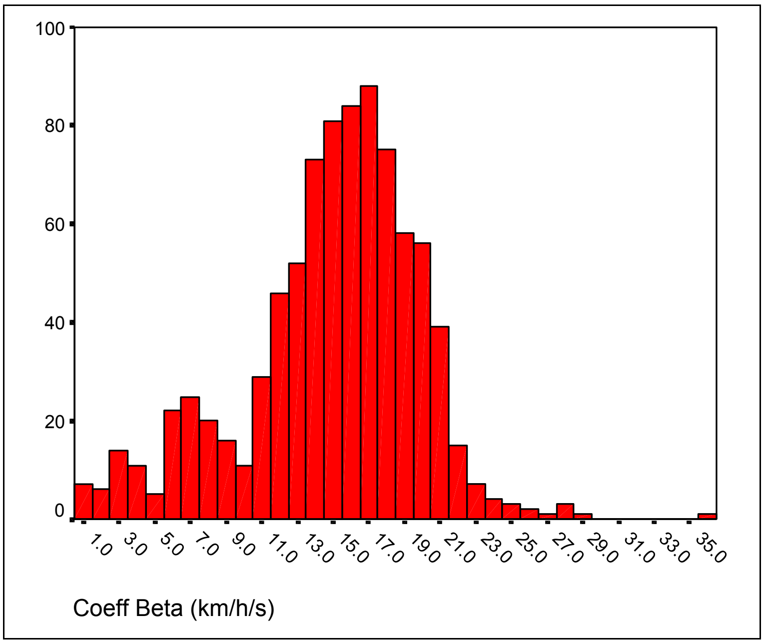

Figure 7. Number of Idle-to-Acceleration phases categorised by beta coefficients.

Figure 7 shows the amount of data available for the acceleration from idle phases categorised by beta coefficient ranges. The beta coefficient is a term used as a proxy for mean acceleration rate however it has been shown, Zito and Taylor (2001) that is a more robust acceleration parameter than mean acceleration.

The histogram in Figure 8 shows the amount of data available for the deceleration to idle phases for each acceleration category range.

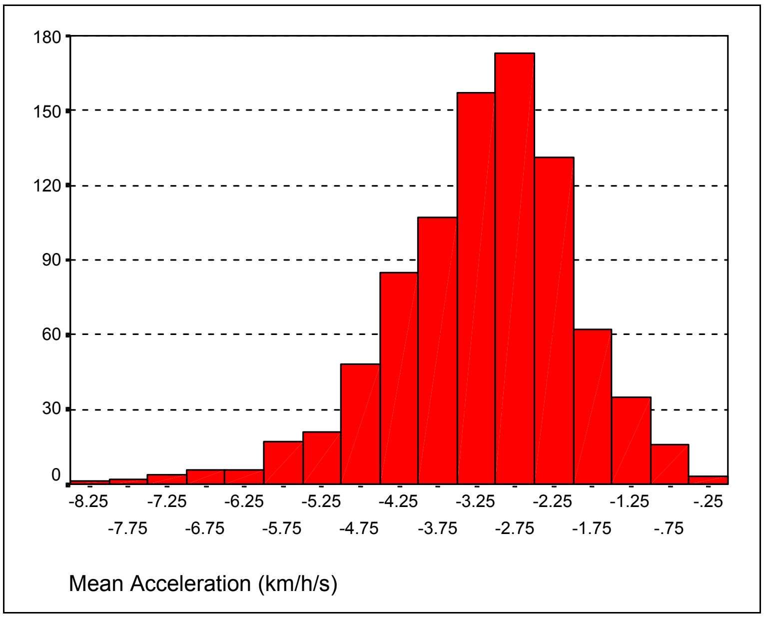

Figure 8. Number of Deceleration-to-Idle phases categorised by acceleration.

Table 1 gives the summary statistics for all of the data described above. The first set of results have the units of time in seconds and represent the average time the TSC vehicle spent in each phase. The table shows that the idle and cruise phase are typically longer than the other four phase types. The final five parameters show the average magnitudes of the phases; again as expected the deceleration rates are slightly higher than the acceleration rates. The average cruise speed does seem high at over 62 km/h, however this is a result of over half of the data being collected along roads that have higher speed limits. The distribution of the mean cruise speed shown in Figure 6 verifies this.

Table 1 Comparison of Drive Cycles

	TSC Vehicle Data	Units
Idle	27	secs
Acc From Idle	19	secs
Dec to Idle	17	secs
Int Acc	15	secs
Int Dec	13	secs
Cruise	37	secs
Mag Acc From Idle	14.9	beta
Mag Dec to Idle	-3.18	km/h/s
Mag Int Acc	1.82	km/h/s
Mag Int Dec	-2.50	km/h/s
Mean Cruise Speed	62.07	km/h

Now that all the data have been collected disaggregated into its six phases / modes of operation and the distribution plotted and verified as being representative of the actual driving that did occur. The next step in the process is to find a 30 minute (approximately) segment of data within the whole dataset that is most correlated to the 11 parameters given in Table 1. Since the aim of a drive cycle is to be stereotypical of the driving data that has been collected, the 11 parameters given in Table 1 give a very comprehensive description of what type of driving is occurring. Hence a strong correlation with a 30-minute subset of the data will provide a statistical measure of how stereotypical the subset is. Another advantage of this technique is that actual driving data is used for the final drive cycle, rather than having to mathematically derive a fictitious cycle.

Numerically this process occurred by listing all the phase data sequentially then producing summary statistics for 30 sequential phases i.e. the parameters in Table 1. The correlation coefficient was then determined between the parameters in Table 1 and the summary statistics of the first 30 phases and added to records. This process was then incremented by one phase and repeated for the whole phase data set. The correlation coefficients were than ranked in descending order. The highest correlation coefficient was fount to be 0.99901, however this collection of 30 phases was not chosen, as there was a time break within the phases i.e. the end of the run was merged with the beginning of the next run, where the runs occurred in different locations. Hence the second set was chosen that had a correlation coefficient of 0.99900, the second by second data that makes up the chosen 30 phases is shown in Figure 9.

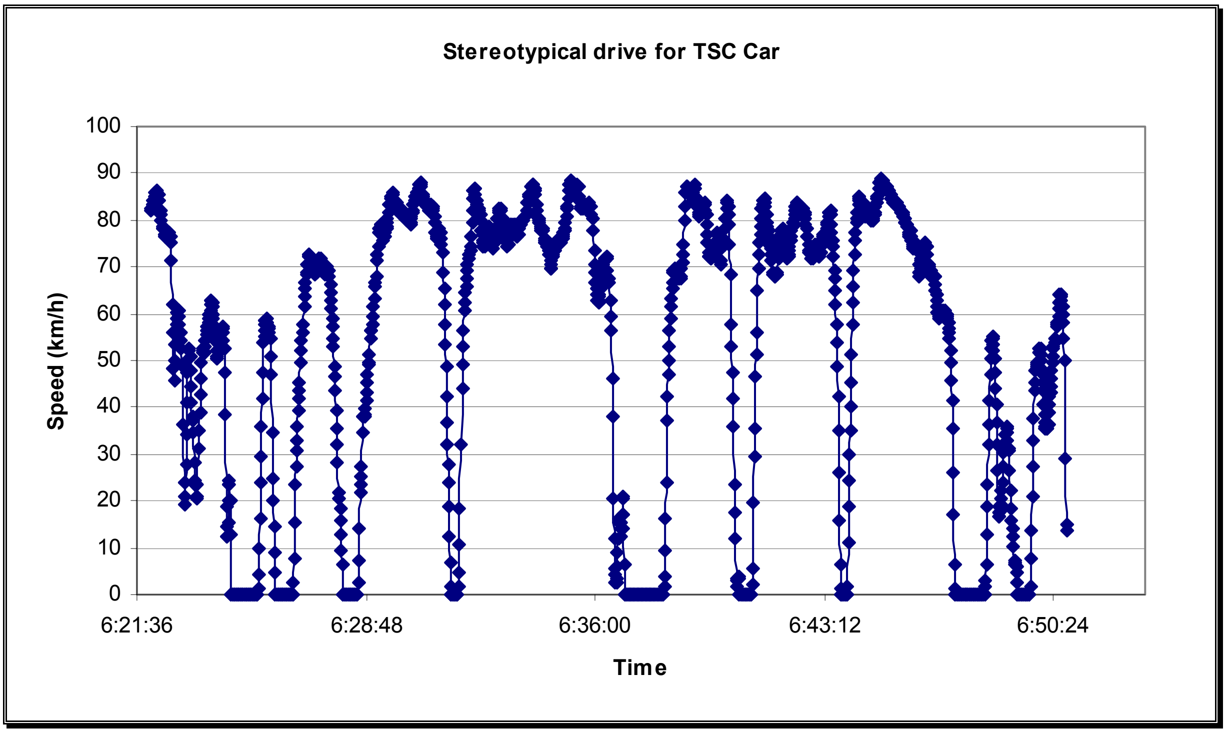

Figure 9 Stereotypical drive for TSC car

It has a duration of 28 minutes 48 seconds and was collected on the third December 1998 during the period 6:22:02 PM to 6:50:50 PM. Figure 10 shows the location of the drive from the GPS data. It has a limited amount of expressway driving and is dominated by driving along South Road. When considering how the data was gathered, and that more than half of the data was collected along these southern routes it should be expected that the stereotypical drive found is along the major arterial road in these southern suburbs.

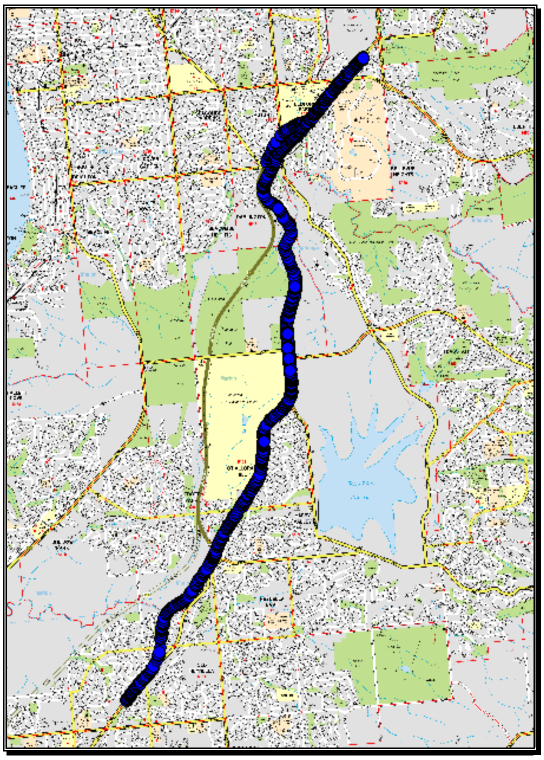

Figure 10 Location of stereotypical drive for TSC vehicle

Conclusions

In qualitative terms the advantages of this proposed drive cycle methodology are that new technologies like GPS and GIS can be used to collect and analyse the data obtained from the vehicles performing the travel time surveys. This allows for robust quality assurance since the precise route the vehicle has travelled as well as the timing of the journey can be verified in an independent way by GIS. This verification aspect is quite important and as such the Institute of Transport Studies, at the University of Sydney are incorporating GPS data collection into their household travel surveys they are performing in conjunction with the NSW Transport and Population Data Centre.

The most recent drive cycle data that has been collected in Australia is published in NEPC(1999). That methodology involved a data logger being fitted to volunteer vehicles and speed time data being collected from the odometer cable of the vehicle. The data was then disaggregated into micro trips i.e. from idle phase to idle phase and the average speed and proportion of idle time calculated for each micro trip. Then based on these two parameters the micro trip was categorised as a particular road type and level of congestion. All without knowing if the micro trip actually occurred on this particular road type. Given the data collection methodology used in this study this approach is likely to be an appropriate method of analysis. However this paper shows that GPS data collection combined with the data analysis method described allows a richer set of parameters to be derived, hence a more sound representation of a typical drive cycle. As well as providing for rigorous quality assurance of the data that is collected.

The GPS equipment used in data collection are highly portable, hence several different vehicles can be easily equipped to carry out the surveys, therefore adding to the richness of the data. The level of detailed data is equivalent but likely to be greater than previous methods of drive cycle data collection. The cost of this equipment is also reducing significantly, however we are still not at the stage where simple hand held GPS receivers can be used to perform this type of survey work. They often have limited memory (i.e. usually around 500 way points, and not second by second data). Hence small Original Equipment Manufacturer (OEM) receivers are preferred with onboard memory capabilities, while these are more expensive than the hand held receivers they do provide a good reliable solution for around the $1200 AUD (one off price, cheaper for bulk purchases).

Some of the limitation of GPS should also get a mention, the most relevant being the loss of GPS signal by tall buildings, for example in an urban canyon situation that is common in most central business districts (CBD). This loss of signal could mean that no position or speed information can be obtained in CBD areas, however if this is a problem in the study most GPS manufacturers have GPS receivers with in-built inertial navigation so that when GPS is not available a secondary system can fill in the data. Another limitation to the process is the amount of expertise required in data management and data analysis, both in a spatial and analytical context.

This paper describes a data collection and analysis methodology for drive cycle analysis that is relatively inexpensive easy to perform and has a high level of quality assurance. Due to this ease of implementation drive cycles can be developed more easily and quickly. Therefore in the future there is a possibility that a time series analysis of drive cycles can be undertaken and be used to show their changing characteristics over time. Currently Austroad publish the national network performance indicators for capital cities and have been doing so for several years. This information is related to the travel time and average speed data on various routes within these cities. With this new methodology there is now the potential to investigate the time series variations in drive cycles. Hence lead to a richer source of information that can not only be used for network performance indicators, but also emissions and fuel consumption performance.

References

Akcelik R and Biggs D C (1985) Further Work On Modelling Car Fuel Consumption, ARRB Internal Report 390-10. Australian Road Research Board, Victoria. February.

Austin T C, Carlson T R., DiGenova F J, Lee J M and Carlock M. (1992). An Analysis of Driving Patterns in Los Angeles During 1992, Presented at the Third Annual CRC-APRAC On-Road Vehicle Emissions Workshop, December 3, 1992.

Bureau of Transport and Regional Economics (1996) In Transport and Greenhouse: Costs and Options for Reducing Emissions, Report 94Bureau of Transport and Regional Economics, Canberra.

D'Este G M, Zito R and Taylor, MAP (1999). Using GPS to measure traffic system performance. Journal of Computer Aided Civil and Infrastructure Engineering 14, pp273-283.

Effa R C and Larsen L C (1993). Development of Real-World Driving Cycles for Estimating Facility-Specific Emissions from Light Duty Vehicles, Air and Waste Management Association Specialty Conference on The Emission Inventory - Perception and Reality, Pasadena, California, 18-20 October, 1993.

Environment Australia (2002). National Pollutant Inventory Emission Estimation Manual for Combustion Engines Version 2.2, Environment Australia

Kent, Allen and Rule (1982). A Driving Cycle for Sydney, Transportation Research, 12, pp. 147-152.

Kenworthy and Newman (1982). A Driving Cycle for Perth: Methodology and Preliminary Results, Proc. Joint SAE-A/ARRB Second Conference on Traffic, Energy and Emissions, Melbourne, Australia, May 19-21, 1982.

NEPC(1999) In-Service Emissions Performance Drive Cycles. Proposed Diesel Vehicle Emissions National Environment Protection Measure Preparatory Work. Vol 1, National Environment Protection Council, March 1999.

Oxlad L (1997) The temporal distribution of travel in Adelaide – a policy perspective, Proceedings of the 21st Australasian Transport Research Forum, Adelaide, South Australia, 21(2), pp917-934.

Taylor M A P and Young T M (1996). "Modelling Emissions and Fuel Consumption for Road Traffic Streams." In: Hensher, D.A., King, J. and Oum, T.H. (eds). World Transport Research - Volume 2, Modelling Transport Systems. (Pergamon-Elsevier: Oxford), pp. 271-286.

Taylor M A P, Bonsall P W and Young, W(2000). Understanding Traffic Systems : Data and Analysis.

Taylor MAP, Woolley JE and Zito R (2000). Integration of the Global Positioning System and Geographical Information Systems for Traffic Congestion Studies. Transportation Research C 8C

Watson H C, Milkins E E and Braunsteins J (1982). The Development of the Melbourne Peak Cycle, Proc. Joint SAE-A/ARRB Second Conference on Traffic, Energy and Emissions, Melbourne, Australia, May 19-21, 1982.

Young, T M (1992). "Analysis of Data Collected by Instrumented Vehicles." Proc. 14th Conference of Australian Institutes of Transport Research. Institute of Transport Studies, University of Sydney, New South Wales, Australia, 10-11 December, 1992.

Young T M and Taylor M A P (1993). "A macro for analysing fuel consumption and travel time data." Road and Transport Research, 2(3). pp. 62-69.

Young T M, Botha J L, Washington S P, and Sperling D (1997) Measurement of Modal Activity Under Varying Traffic Conditions on California Freeways: Preliminary Results. Paper No. 971052 presented at the 76th Annual Meeting of the Transportation Research Board, Washington, DC, 12-16 January, 1997.

Young T M, Washington S P, Botha J L, and Sperling D (1996) Modal Activity Under Varying Traffic Conditions on California Freeways: Experimental Design and Data Collection Procedures. Proc. TRB Transportation and Air Quality Committee Summer Conference, Irvine, CA, 10-12 July, 1996.

Zito R and Taylor, M A P (1995) The use of GPS in Travel Time Surveys. Traffic Engineering and Control. Vol 35 (12).

Zito R, Taylor M A P and D'Este G M (1995) GPS in the Time Domain: How Useful a tool for IVHS. Transportation Research C, 3C(4),pp 193-209

Zito R and Taylor M A P (2001). Modelling emissions from an instrumented car. Proc 8th World Congress on Intelligent Transport Systems, Sydney, October. (ITS Australia Inc: Canberra).