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The estimation of a driving cycle for Celje and a comparison to other European cities

Matjaz Knez[a,*], Tariq Muneer[b], Borut Jereb[a], Kevin Cullinane[b]

[a] Faculty of Logistics, University of Maribor, Mariborska 7, 3000 Celje, Slovenia
[b] Transport Research Institute, Edinburgh Napier University, Merchiston Campus, Edinburgh EH10 5DT, UK

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ABSTRACT

Due to rapidly increasing numbers of vehicles, growing traffic congestion and the very limited use of emission control strategies, motor vehicles are emerging as the largest source of urban air pollution globally. The effectiveness of any control strategy depends on accurate emission models. This study is an attempt to estimate vehicular driving patterns in the Slovenian city of Celje. Using the TangoGPS program for measuring important driving parameters while a vehicle is in motion in traffic, the urban driving cycle of this small city is estimated and then compared with the driving cycles of other cities in Europe. As predicted and demonstrated in the present paper the average speed of vehicles in smaller cities is higher than in larger ones.

1. Introduction

As a result of rapidly increasing transport demand, traffic jams in city centres across the globe are continuously increasing despite the imposition of various measures to stem this growth. Such problems are only partly due to the increased use of motor vehicles. In many locations, the evolution and development of urban logistics over the past decade has only worsened the situation. Because of these problems, experts and decision makers around the world are striving to optimise transport frequency within city centres and if necessary restrain it. Solutions are sought not only in technology, but also in new laws and regulations. According to Portal (2003) and Knez (2008), city authorities can influence the choice of transport mode in three ways: imposing regulations and taxes; co-funding infrastructure development and environmentally friendly vehicles and; through a change of transport regime.

Measures for improving the environment are increasingly incorporated into spatial planning. Michaelis (1995) asserts that the level of CO_2 emissions in city transport can be reduced in three different ways: by using more efficient, environmentally friendly transport technologies; by altering the travel habits of the population and; by changing the transport policy of city authorities regarding city centre transport management. In order to reduce negative impacts on the environment, for example, different economic instruments have been implemented – such as environmental taxes, whereby the polluter pays. Another important instrument is providing subsidies to investments in environmental protection or taxing those deemed responsible for environmental damage. To this end, the environment can also be protected by appropriate transport policy and the application of laws that are defined by such policies. In all cases, however, the benefits which the use of a motor vehicle brings cannot be overlooked (see Table 1).

Traffic reduction policies, although necessary, can be highly controversial, since it is an aspect that affects either directly or indirectly the whole population. Reducing traffic and therefore pollution in congested areas such as city centres is not by itself an optimum solution. According to Pullin (2000), public transport journeys take, on average, three times as long as equivalent car journeys. This means that either policies are able to tackle public and private transport simultaneously or else face the consequent congestion caused by, for example, closing some main arteries of city centres, which will inevitably result in additional levels of pollution.

For the above reasons, there is an increasing need for developing sophisticated prediction tools to allow a clearer perspective on effective future scenarios regarding traffic management. The availability of emission models and the estimation of vehicle emissions in Europe have improved significantly (Esteves-Booth, Muneer, Kubie, & Kirby, 2002). However, there are still gaps that can affect the prediction of possible strategies. Most of these gaps are due to a lack of data on emission measurements for different vehicle types, vehicle operational modes (idle, acceleration, deceleration and cruise) and difficulties inherent in accurately predicting vehicle usage under real driving conditions (Zachariadis & Samaras, 1997). Due to the quantity of information required to determine the different parameters related to traffic emissions, direct measurement becomes impractical and expensive.

* Corresponding author.
E-mail address: matjaz.knez@fl.uni-mb.si (M. Knez).

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Table 1
Merits and demerits of automobiles.

Advantages	Disadvantages
Freedom of movement	Air pollution, major contributor towards climate change
Personal (driver/passenger) security	Road congestion
Large employment sector	Fossil fuel exhaustion
Personal or work space	Loss of building material
Ability to travel long distances	Space consumption on roads
Increased speed	Society stratification
Enjoining of communities	Accidents

Source: Muneer et al. (2011).

For all these reasons, there is an increasing need to measure driving cycles for a particular area of study rather than using standard cycles that will not accurately represent the reality (Jiang & Van-Gerpen, 1992). A driving cycle of any vibrant city environment is a 'dynamic' entity, which is continuously changing and evolving. Knowledge of the driving cycle, which describes the exact patterns of the city in question, is of paramount importance with reference to its understanding and the role it will play in accurately forecasting vehicular emissions.

2. Driving cycles

Emissions from vehicles are affected by the driving patterns that mainly depend on traffic conditions. "Driving Cycles" have been developed to provide a speed–time profile that is representative of urban driving (Lyons, Kenworthy, Austin, & Newman, 1986). A number of studies show that the European driving cycle ECE and the US FTP (driving cycles used as the basis of most European and American legislation and in emission models) do not accurately characterize real driving behaviour. The models underpinning these standard driving cycles statistically smooth the effect of the vehicle's modal operations (acceleration, deceleration, idle and cruising). Since most pollution is generated in changing between these modes, the output of these types of models is dramatically compromised (Ergeneman, 1997).

As a consequence, there is an increasing need to build driving cycles for a particular area of study, rather than using standard cycles that will not accurately represent real driving behaviour within that location. A driving cycle is, therefore, a representative plot of driving behaviour within a given city or a region and is characterized by speed and acceleration. A driving cycle is based on typical driving conditions for a particular geographical area and time period and, according to Andre (1996) encompasses a sequence of several vehicle operating conditions that comprise the four main operational modes: idle, acceleration, cruise and deceleration.

Kamble, Mathew, & Sharma (2009) emphasise that driving patterns vary from city to city and from region to region. As such, an empirically measured driving cycle can be considered as a signature of driving characteristics of the city or region where the measurements are taken. Since driving patterns vary from city to city and from area to area, the available drive cycles obtained for certain cities or countries are not usually applicable to other locations. Therefore, a lot of research work has been undertaken which targets the development of driving cycles using recorded real world driving tests (complex transient), as well as steady state (cruise) conditions encountered in road driving.

City authorities in Slovenia are confronted with severe transportation problems relating to pollution, accidents and congestion. In order to reduce the damage inflicted on city environments, a change in the behaviour of people and companies is needed in order that different modes of transportation are selected. Alternatively, there may be a need to force people and companies to choose other means of transport. In order to inform the development of the appropriate policies, it is vitally important to understand the nature of real-world driving cycles within Slovenian cities. However, driving cycles have not yet been developed for any of the towns in Slovenia. This provides an important justification for undertaking the detailed study reported herein on the driving patterns in the town of Celje (the third largest city in the nation) and comparing these measured driving cycles to those obtained in other EU cities.

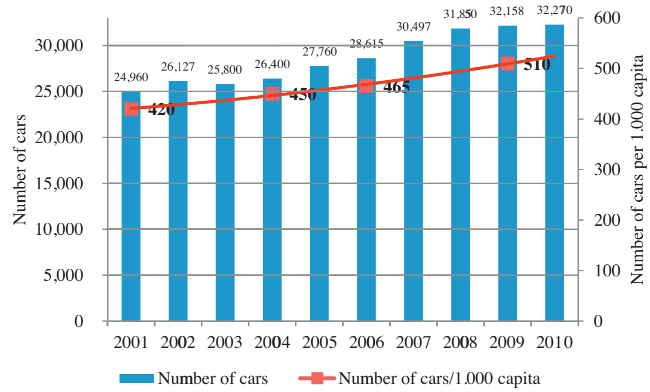

Fig. 1. Number of vehicles registered in Celje from 2001 to 2010.

3. Driving cycle measurements in Celje using TangoGPS

Celje is a typical Central European town and the third largest city in Slovenia, with around 40,000 inhabitants. The city centre is very accessible by many roads. Some important road links run through the town, which further increases pressures on the environment. In 2010, Celje had 32,214 registered road vehicles (SURS, 2010 and SURS, 2011). Fig. 1 shows that the number of vehicles has been increasing year-on-year, which means that individual passenger traffic is growing and, in all probability, also the level of GHG emissions. More and more people (70%) use the car as their only means of transport.

Measurements of the driving cycle were taken in November 2011, on a daily basis (in the morning at 7 am, afternoon at 4 pm and evening at 6 pm). The data obtained in this study were taken from actual traffic conditions and not based upon models. To measure the driving patterns experienced in the city of Celje, data loggers were installed into a test car, in this case a Peugeot 5008 model. Measurements of elements such as distance travelled, speed, rate of acceleration, rate of deceleration, and difference in altitude to determine incline rates and time for journey were recorded. Additional notes were taken, such as weather conditions and starting and ending times of each journey taken. Data were recorded every second.

The program TangoGPS was used for data recording. It is a mapping application running on Linux, especially suited to small computers. TangoGPS defaults to using maps based on OSM (Open Street Maps). If connected to a GPS device, a track can be logged and processed later for addition to OSM (Wiki, 2012). TangoGPS writes data in the Log file (text file) on average every second (Jereb & Skok, 2011), like shown in Table 2.

These data were then transferred to computer for analysis and the development of driving patterns along the main commuter routes into the city centre. The data collected were then used as the basis for deriving the driving cycle in this work. One primary route (the green line in Fig. 2) was determined for the study. This route ran as follows: Ljubljanska Road – the Square of Celje Counts – Gosposka Street – Savinjsko Quay – the Street of the XIVth division – Askerceva Street – Levstikova Street – Gregorciceva Street – Kersnikova Street – Deckova Road – Mariborska Road – the Street

Table 2
The example of TangoGPS written data.

	A	B	C	D	E	F	G	H
Example:	46.226502	15.266948	249.8	0.1	0.0	1.0	2010-11-05	T06:02:43Z

The software writes information about: A: Latitude (geographic) width (x); B: Latitude (geographical) length (y); C: Elevation (geographical) level (z); D: speed; E: direction; F: signal strength; G: date (d); H: time (t).

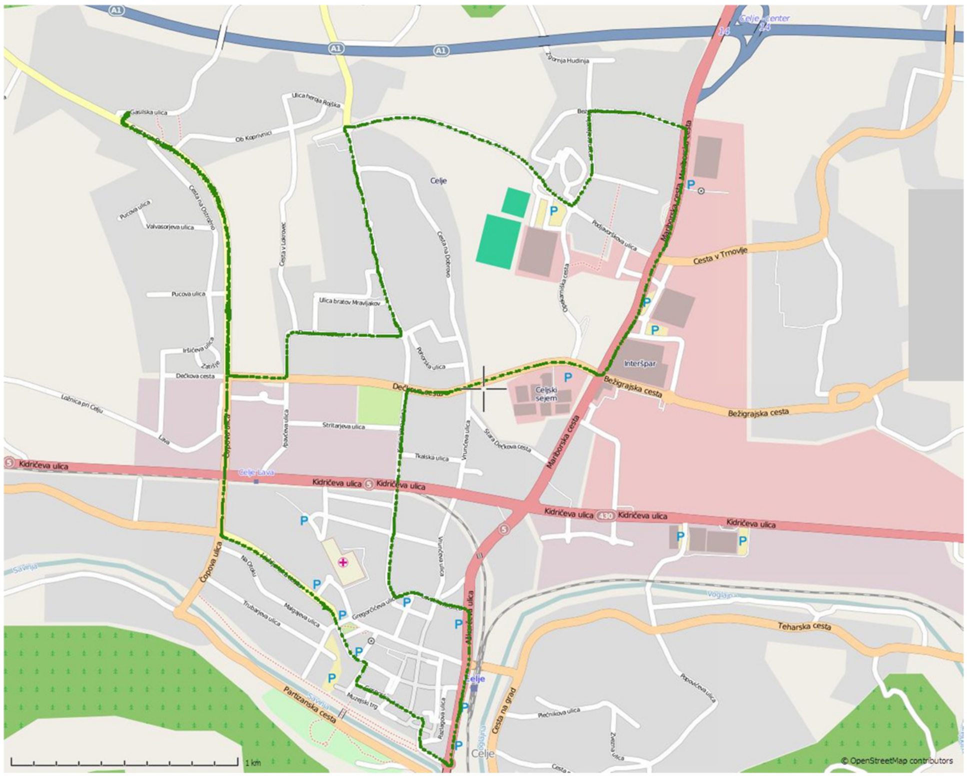

Fig. 2. The route where the measurements were taken.

of Frankolovo Victims – Prijateljeva Street – North State Road – the Street of the City of Grevenbroich – Drapsinova Street – Deckova Road – Road to Ostrozno – /turn/ – Road to Ostrozno – Copova Street – Ljubljanska Road.

This route through the city, which starts and ends at Ljubljanska Road, has a total length of 12.9 km. It was selected because it is one of the main arteries into and out of the city and also represents a standard route that an average commuter might take on a daily basis. The participant driving the test vehicle along the selected route used the car following technique to help ensure that their driving style would not affect the measurements being taken and would more accurately represent the flow of traffic in the city of Celje.

4. Results and discussion

Table 3 shows that, when compared to each other, the figures measured at 7.00 am and 4.00 pm are very similar. This is as expected since these two measured periods of the day are the city rush hours, when people are usually driving to their place of employment or returning back to home. The figures measured in the late afternoon (6.00 pm) indicate that the road is less burdened with traffic. This is reflected in a higher average speed which naturally implies a reduction in the overall time for the completion of the journey; this is more than 5 min shorter compared to the first two measured driving cycles.

From the results shown in Figs. 3 and 4, it is clear that the test vehicle was idle for almost one-third of the entire journey duration. A vehicle carries out most of its work when accelerating and expends a lot of energy in doing so. From the driving cycle figures, acceleration periods also make up almost one-third of the entire journey time of the driving cycle (note acceleration and deceleration periods are nearly of equal length).

The Celje driving cycle was also compared to measured driving cycles for both Istanbul and Edinburgh (Muneer, Celikb, & Caliskan, 2011). This comparison is detailed in Table 4 below. The two cities were chosen for comparison because Istanbul is a good example of a large city and Edinburgh is a medium-sized city. This table, where

Table 3
Celje driving cycle.

	7.00 am	4.00 pm	6.00 pm	Average
Duration of cycle (s)	2578	2542	2238	2453
Duration of idle phases (s)	660	550	600	603
Average speed (km/h)	24.6	23.5	28.5	25.53
Average acceleration (m/s^2)	0.73	0.76	0.89	0.79
Average deceleration (m/s^2)	−0.78	−0.82	−0.93	−0.84
Distance travelled (km)	12.99	12.99	12.99	12.99

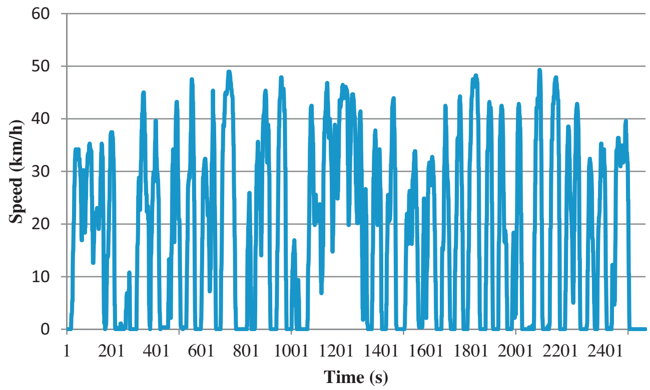

Fig. 3. Measured driving cycle for Celje.

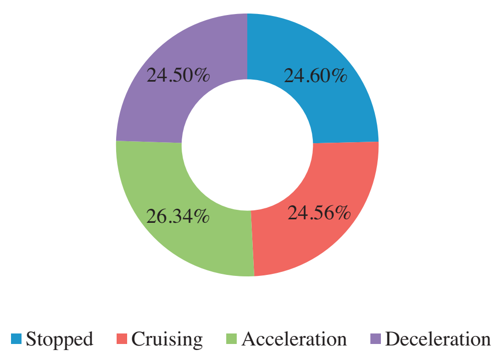

Fig. 4. Driving cycle characteristics for Celje.

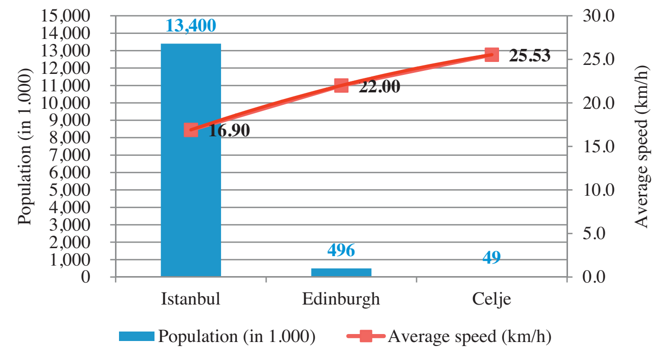

Fig. 5. Comparison of average speed relative to population size.

Table 4
Comparison of driving cycles.

	Istanbul Ref. X1	Edinburgh Ref. X2	Celje
Population (in 1000)	13,400	496	49
Duration of cycle (s)	228	974	2453
Duration of idle phases (s)	39	262	603
Average speed (km/h)	16.90	22.00	25.53
Average acceleration (m/s^2)	0.66	0.59	0.79
Average deceleration (m/s^2)	−0.59	−53.00	−0.84
Distance travelled (km)	1.07	5.90	12.99

we compare large, medium-sized and small cities, demonstrates the differences which exist between the characteristics of the city's respective driving cycles.

As was expected for a larger and more populated city, the average travel speed is lower. Table 4 shows, for example, that in Istanbul the average travel speed is almost 34 percent lower compared to the rates in Celje. This relationship between size of city and average speeds is graphically illustrated in Fig. 5.

As shown in Table 5, another comparison of the Celje driving cycle was then made to both the Edinburgh and the standard European driving cycle (Walsh, Muneer, & Celik Ali, 2011).

For the Celje driving cycle the deceleration phase takes up about 25% of the journey, which is far greater than that found for the European driving cycle and a little bit lower than that found by the Edinburgh driving cycle. Something similar has been found for the acceleration rates. Steady state cruising is found to account for 25% of the driving cycle, which is comparable to that found for the European driving cycle. For the Edinburgh driving cycle, however, steady state cruising accounts for quite a low figure of only 4% of the overall journey. This is mainly due to the hilly nature of the city.

When idle periods are removed and only the periods of acceleration, cruise, and deceleration are reviewed for all cycles, it shows that for the Celje driving cycle 34% of the journey is spent accelerating, 33% decelerating and 33% of the journey is in cruise mode. These are not that different from the figures for the standard European driving cycle, where the cruise mode is a little higher. Similar calculations for the Edinburgh driving cycle reveal that 47% of the journey is spent accelerating, 47% decelerating and only 6% of the journey is in cruise mode. This is illustrated in Table 6.

The results for Edinburgh show clearly that the topography of a city has an important impact upon the amount of work that is carried out by a vehicle during a driving cycle. When a vehicle is travelling up a gradient, the internal combustion engine has to do more work to move the vehicle and its passengers uphill. It is also true, however, that when a vehicle is travelling down a gradient, the vehicle's internal combustion engine does not need to work as hard and so less fuel is consumed (Clarke, Muneer, & Cullinane, 2010; Walsh et al., 2011) which results in lower CO_2 emissions. The net impact on emissions, however, can still be reasonable accurately assessed on the basis of a measured driving cycle, since this captures the required data on the operational status of the vehicle.

The rates of acceleration and deceleration are an important part of the driving cycle. It was found that the average deceleration rate for the Celje driving cycle route was 0.79 m/s^2, which was higher

Table 5
Celje compared to the standard European and Edinburgh driving cycles.

Driving phases	European driving cycle		Edinburgh driving cycle		Celje driving cycle	
	Time (s)	Status (%)	Time (s)	Status (%)	Time (s)	Status (%)
At idle	284	36	273	28	603	25
Acceleration	152	19	328	34	646	26
Deceleration	108	14	333	34	601	25
Steady state speed	236	30	41	4	602	25
Additional information						
Average speed	19 km/h		18.7 km/h		25.5 km/h	
Running time	780 s		975 s		2453 s	
Distance covered	4.0 km		5.8 km		12.9	

Table 6
Driving cycle comparison excluding idle periods.

Driving phases	European driving cycle		Edinburgh driving cycle		Celje driving cycle	
	Time (s)	Status (%)	Time (s)	Status (%)	Time (s)	Status (%)
Acceleration	152	31	328	47	646	34
Deceleration	108	22	333	47	601	33
Steady state speed	236	47	41	6	602	33
Additional information						
Running time	496 s		702 s		1849 s	
Distance covered	4.0 km		5.8 km		12.9	

than the average acceleration rate for the European and Edinburgh driving cycles, which were around 0.59 m/s^2.

5. Conclusion

This paper presents a study which involves measuring driving patterns in the small Slovenian city of Celje, using the TangoGPS program for extracting real-world driving data. The empirically derived driving cycle of Celje is compared with the existing driving cycles and in certain characteristics exhibits distinctly different patterns. A comparison confirms that smaller cities have higher average travel speeds; as the smallest of the specific cities compared, Celje had the highest average speed. For example, the average speed in London is 18.9 km/h (Forbes, 2008), Paris 19.0 km/h (Massot, Armoogum, Bonnel, & Caubel, 2004) and Madrid 20.0 km/h (The economist, 2006) which compared to Celje are all big cities. This again confirms that the largest cities usually have lower average travelling speeds. The study would be more representative if data from a longer period of time were considered in the analysis, e.g. from January to December. Given that measurements were conducted for a period of one month, i.e. November, we may conclude that the data are representative of a typical autumn month of the year.

The results of this sort of empirical study of driving cycles can constitute important information for city authorities in the development of their policies for urban traffic management. It has been argued (Esteves-Booth et al., 2002) that driving cycles should be measured for a particular area rather than using a standard cycle that will not accurately represent reality. A driving cycle of any vibrant city environment is a dynamic entity which is continuously changing and evolving. Knowledge of the driving cycle, which describes the exact driving patterns of the city in question, is of paramount importance to the formulation of traffic management policies and in forecasting vehicular emissions. The use of standard driving cycles in this context cannot provide a true representation of actual traffic conditions and, as such, it is not reasonable to expect that emissions calculations that are built on these cycles to yield accurate estimates of emissions. Since this is likely to be the case for any given city (though the extent of deviation will of course vary), there is a need to understand, therefore, how the driving cycle differs from city to city and for various modes of traffic.

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