

A Tool for Generating Individual Driving Cycles - IDCB

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ABSTRACT

Standardized driving cycles, such as the New European Driving Cycle (NEDC) in Europe or the Federal Test Procedure 75 (FTP-75) in the U.S. are an important tool to certify new vehicle models. They are used to estimate real world fuel consumption as well as real world emissions. The latter has recently become more important with the stronger focus on green driving, resulting in much stricter emission regulations, while fuel consumption still remains one of the most important aspects in terms of economy and long term costs for the vehicle owner. However these cycles do not reflect the actual behaviour of the driver or regional influences (i.e. topography). Therefore, manufacturers have developed their own usage and test cycles and are able to extract data from the vehicle to analyse the individual driving behaviour and vehicle usage. Apart from that, Naturalistic Driving Observation (NDO) is interested in understanding the driver. Thus, methods are required to create individual driving cycles (or derive them from large sets of recorded data) that can be used to describe the behaviour of a single driver as well as a group. However, creating driving cycles “by hand” is time consuming and less effective due to the large amount of data. The paper presents the Individual Driving Cycle Builder (IDCB), a software tool that automatically creates an individual driving cycle based on individual driving data. The cycle construction process itself is based on the same method used to create the ARTEMIS driving cycles. To verify the IDCB method, 15 created cycles are compared against the original data as well as several standardised driving cycles.

CITATION: Grüner, J. and Marker, S., "A Tool for Generating Individual Driving Cycles - IDCB," *SAE Int. J. Commer. Veh.* 9(2):2016, doi:10.4271/2016-01-9019.

INTRODUCTION

Generally, a driving cycle can be described as a velocity-time series where additional instructions and conditions may be applied. Using such velocity-time profiles allows comparing different brands and models. However, not all brands and models are sold worldwide and different countries have different rules and emission regulations. Additionally, there are distinct driving cycles for different vehicle types as well as for different usage scenarios. Therefore, a big variety of driving cycles exists (see [1] for a list of example).

However, with the introduction of hybrid (HEV, PHEV) and fully electric vehicles (BEV) the comparison has become more complex. While the latter seems rather straight forward in terms of fuel consumption (kWh/100 km instead of l/ 100 km) and emissions (none in local driving), the story is far more complicated with vehicles that use fuel (gasoline, diesel, etc.) and electrical power. Given that most standardized driving cycles are rather short (< 1 hour, < 50 km, see Table 1) most hybrids are able to drive the whole test profile fully electric, thus burning no fuel / producing no local emissions. The main reason is that most driving cycles are rather antiquated (FTP-75: 1978; NEDC: 1990; 10-15 Mode: 1983) and were not designed for

these types of cars. In order to solve this problem the former test methods have been changed to accommodate the new situation accordingly, as well as the development of new driving cycles that could be used universally and globally (WLTP).

While standardized tests are a practical and “simple” solution to compare vehicles across different brands and allow legislature to implement laws and regulations on emissions the question remains: Is there a driving cycle that covers all types of real world usage? Regional aspects are likely to have a big influence as well [2, 3]. Vehicles used in mountainous and hot areas will feature a higher fuel consumption and emission level than the same vehicle used in a flat area with 20°C ambient temperature for multiple reasons:

- Higher air conditioning use
- Higher power / energy demand required to drive uphill

Yet, the individual driving style (velocity, engine revs, shifting points, acceleration ...) or driver's vehicle usage has not been taken into account here. For example, one driver could use the vehicle for city driving only, another mainly for trips on the motorway. Also the same

vehicle could be used for different purposes (e.g. a pickup could be used as a snowplow during the winter driving back and forth and therefore have a completely different using profile than during the summer where it might be used to transport goods on highways).

The usage pattern is of special interest for many people and groups: On the one hand, manufacturers have a strong interest in knowing their customers and their behaviour in order to design their vehicles (space, engine (and battery) power requirements, etc.). Therefore, they have developed their own usage and test cycles and are able to extract data from the vehicle to analyse the individual driving behaviour and vehicle usage [4]. Apart from that, Naturalistic Driving Observation (NDO) is interested in understanding the driver. A NDO is best described as “study undertaken to provide insight into driver behaviour during everyday trips by recording details of the driver, the vehicle and the surroundings through unobtrusive data gathering equipment and without experimental control”.

Thus, methods are required to describe the individual driving procedure and, as a result, methods to create individual driving cycles (or derive them from large sets of recorded data) that can be used to describe the behaviour of a single driver as well as a group while factoring in different areas, thus allowing to compare them and understand the key-differences between them. However, creating driving cycles “by hand” is time consuming and less effective due to the large amount of data. Therefore, the ideal solution is to have a fully automated software tool that generates individual driving cycles. This allows for a quick comparison between different drivers instead of having to simulate hundreds of hours of recorded data.

The purpose of these individual driving cycles is not to replace existing regulatory cycles, as those have to consider other aspects and interests as well, but for identifying individual driving aspects.

EXISTING DRIVING CYCLES

Although there exist a vast number of driving cycles for different purposes and usage scenarios, not all of them are equally important. It stands to reason that cycles used for legislation have a bigger influence than purely academic cycles, or cycles that only apply to a very specific type of vehicle. Hence this paper will only cover the two most widely used driving cycles (NEDC for the EU, FTP-75 for the USA) while the third (ARTEMIS) is the result of more recent (2004 [5]) research and development. The designated successor of the NEDC, the WLTP will be presented as well. The methods used there are also applied for the Individual Driving Cycle Builder (IDCB).

For a better understanding of the characteristics the following Table 1 gives a quick overview of the cycles as described in the following sections. Generally, single cycles longer than 1500 seconds seem to be the exception (see [1]).

Table 1. Short comparison of different driving cycles [1], 13

	NEDC	FTP-75	ARTEMIS (Urban / Rural)	ARTEMIS (Motorway / Motorway 130)	WLTP Class 3
Duration [s]	1180	1874	993 / 1082	1068 / 1068	1800
Length [km]	11.02	17.79	4.87 / 17.28	29.55 / 28.73	23.27
Average speed (trip) [km/h]	33.6	34.2	17.7 / 57.5	99.6 / 96.9	46.50
Average driving speed [km/h]	42.24	39.21	22.29 / 58.34	100.35 / 97.6	53.48
Maximum speed [km/h]	120.09	91.09	57.32 / 111.09	150.37 / 131.43	131,30
Average positive acceleration [m/s ²]	0.528	0.420	0.531 / 0.359	0.271 / 0.273	0,41
Average negative acceleration [m/s ²]	-0.719	-0.457	-0.571 / - 0.371	-0.344 / -0.345	-0,45
Number of stops [-]	14	16	14 / 5	3 / 3	9
Stops per km [1/km]	1.27	0.9	2.87 / 0.29	0.1 / 0.1	0,39
% of time driving [%]	79.58	87.14	79.25 / 98.52	99.25 / 99.25	87,4
% of time cruising [%]	38.81	20.06	9.57 / 21.63	27.81 / 26.03	3,6
% of time accelerating [%]	23.56	36.45	35.95 / 39.74	39.70 / 40.64	43,8
% of time decelerating [%]	17.29	30.63	33.74 / 37.15	31.74 / 32.58	39,9
% of time standing [%]	20.42	12.86	20.75 / 1.48	0.75 / 0.75	12,6

New European Driving Cycle (NEDC)

The test protocol for the NEDC (Figure 1) is described in the policy 93/116/EG and is used for fuel and emission certification in the EU. The NEDC consists of two separate driving cycles, the urban driving cycle (also known as ECE-15) which is repeated four times (avg. velocity: 18.4 km/h) and the extra urban driving cycle (EUDC, avg. velocity: 62.6 km/h) [6].

The overall length of about 20 min is short compared to other cycles (see Table 1), but more convenient for testing as more tests can be done in the same time span. One point of criticism is the actual driving profile with its constant accelerations / decelerations [7] hardly mirroring real world driving: For instance the 0 - 50 km/h acceleration takes 25 seconds for the ECE-15, hardly relevant or even realistic for any kind of city driving as other studies have shown (see [5, 6]).

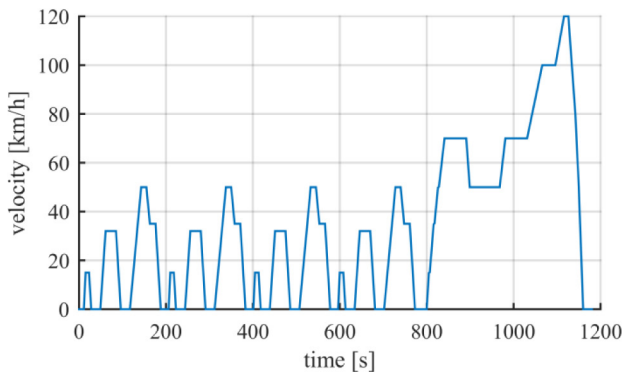


Figure 1. NEDC driving cycle

Federal Test Procedure (FTP-75)

The US-American FTP-75 (Figure 2) is based on real driving data, recorded during rush-hour in Los Angeles [8]. Compared to its European counterpart the FTP-75 features more dynamic acceleration and deceleration phases even though the overall average velocity is very similar (see Table 1). The American cycle is a derivative of the older FTP-72, of which the initial part (about 500 s) is repeated again at the end [8].

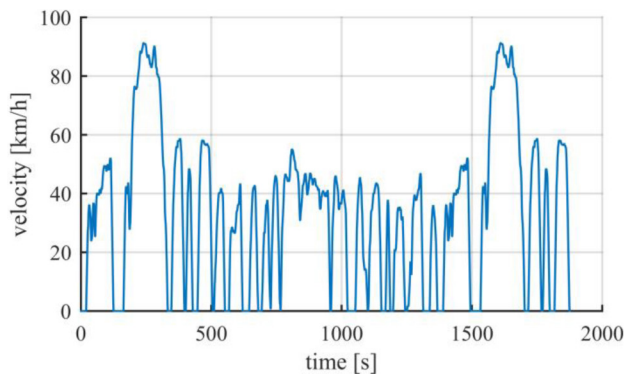


Figure 2. FTP-75 driving cycle

Compared to the NEDC there is no specific distinction between urban, rural or motorway; the cycle is viewed as a whole. NEDC and FTP-75 use a defined shift schedule, while for the latter the manufacturer may declare a different schedule [9].

ARTEMIS (CADC)

The Common ARTEMIS Driving Cycle (CADC)¹ is the result of the ARTEMIS Project, which had the goal to unify different methods of emission measurement and to generate a driving cycle that would contain many different driving situations like congested city driving or motorway [10]. As a result a 52 minute long cycle was generated that consists of three different sub-cycles (urban, rural and motorway) [5].

The ARTEMIS urban cycle (Figure 3) describes a common trip in a European city with a duration of 16.5 minutes and covers a distance of about 4.9 km. It features a continuous change between idle and dynamic driving states of different duration. The dynamic can be seen when comparing the percentage spent cruising (9.57 %) with other cycles like the FTP-75 (20 %) [1].

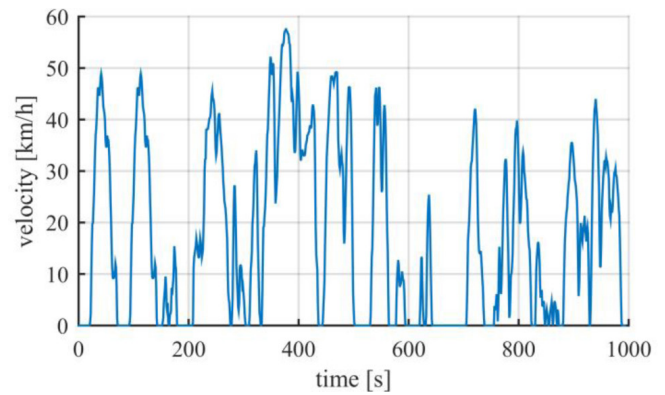


Figure 3. ARTEMIS urban driving cycle

The ARTEMIS rural cycle, as displayed in Figure 4, covers approximately 17 km in about 18 minutes. Compared to the urban cycle it features a higher average velocity (57.5 km/h) and a total idle phase of only 16 seconds. The cycle contains a higher percentage of cruising, i.e. more time is spent driving at a relatively constant velocity.

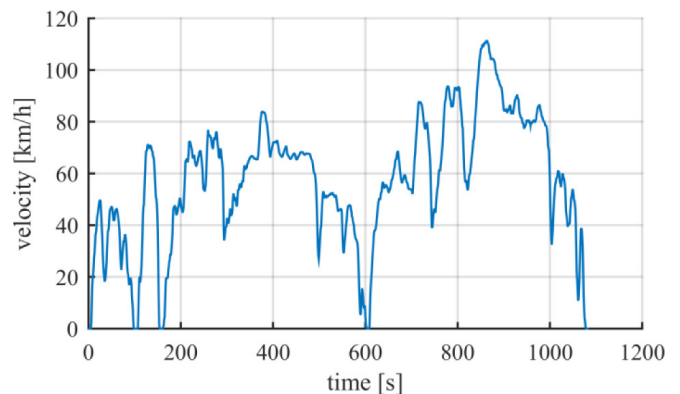


Figure 4. ARTEMIS rural driving cycle

There are two different cycles available for the motorway trips (Figure 5), since different kinds of car classes have different top speeds. For instance, vehicles mainly designed for city driving (microcars) have usually lower top speeds than average sized saloons. Therefore they would not reach the required speeds of the ARTEMIS motorway cycle. For those smaller powered cars the motorway 130 was designed [5] which, as the name implies, has a maximum velocity of 130 km/h instead of 150 km/h like the default motorway cycle.

Both cycles feature a similar duration as the rural cycle (18 minutes) but cover a greater distance due to the generally higher speeds (motorway 130: 28.7 km, motorway: 29.5 km) [1]. Generally, both cycles feature very similar characteristics (see Table 1).

Compared to the NEDC there is no fixed gear shift pattern, but rather an individual pattern based on several criteria such as gear ratios and engine power which is being defined up front to closely match real driving behaviour [5].

1. Assessment and Reliability of Transport Emission Models and Inventory Systems

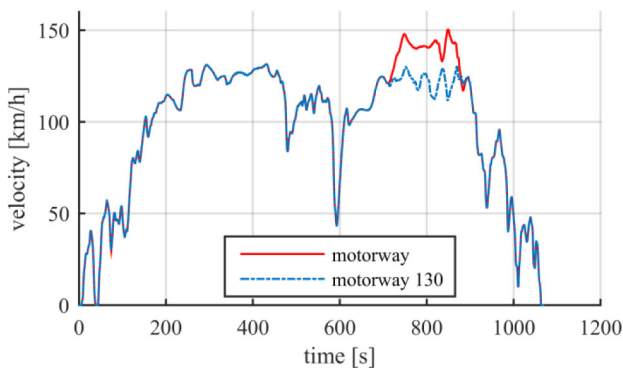


Figure 5. ARTEMIS motorway / motorway 130 driving cycle

Weighing of the ARTEMIS Cycles

As previously mentioned, all ARTEMIS cycles have about the same duration. The main reason for this is to create realistic emission behaviour, especially for motorway trips that can often continue for several hours at a stretch. Another reason originates from the construction method of the cycles itself, only allowing the use of complete kinematic sequences [10]. However, this equal length is not mirrored in the original recorded driving data [5] and thus a weighing of the cycles has to be applied as described in Table 2, putting a higher emphasis on the rural cycle.

Table 2. Weighing of the ARTEMIS Driving Cycles [5]

Driving Cycle	Type	Weight [%]
ARTEMIS Urban	Urban	29.2
ARTEMIS Rural	Rural	44.9
ARTEMIS Motorway / Motorway 130	Motorway	25.9

Worldwide Harmonized Light Vehicles Test Procedure (WLTP)

The WLTP is being developed by the UNECE (the United Nations Economic Commission for Europe) and will serve as a successor to the NEDC in the European Union. The ultimate goal during the development of the cycle was to create a driving cycle framework that can be used worldwide in order to harmonize testing and therefore reduce costs [13]. The WLTP is divided into three slightly different cycles depending on the power to mass ratio (PMR) of the vehicle, with Class 3 (Figure 6) being the relevant cycle for most of today's passenger cars ($PMR \geq 34$). This cycle combines 4 different phases of driving: low, medium, high and extra high.

With a duration of 30 minutes it is just slightly shorter than the FTP-75 while covering more than 5 kilometres more distance (see Table 1). Therefore the WLTP is considerably faster (average speed WLTP: 46.5 km/h, FTP-75: 34.2 km/h), despite featuring similar acceleration and deceleration averages. The WLTP features a very low cruising speed percentage (3.6%), especially when being compared to the NEDC (38.81%), while also spending less time standing still. The WLTP is most comparable to the ARTEMIS, in terms of dynamic and maximum speeds, but comes without the

necessity of driving three different cycles and weighing the results. Because of this, the WLTP is easier to use and faster to perform (22 minutes driving time alone).

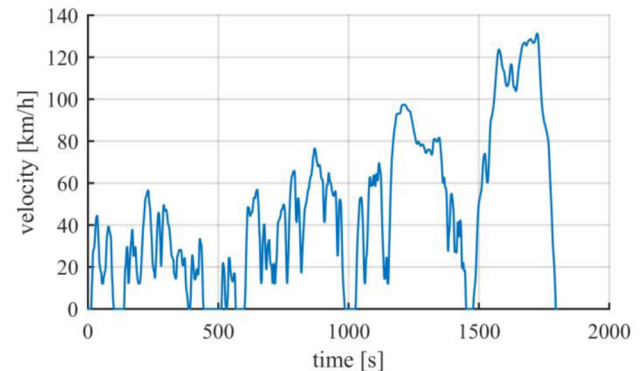


Figure 6. WLTP Class 3 driving cycle

CONSTRUCTION METHODS FOR DRIVING CYCLES

Generally all construction methods include the following steps [11, 5]: (1) Collection of real world data; (2) Segmentation of the driving data; (3) Construction of the cycles; (4) Evaluation and selection of the final driving cycle. For the cycle construction, [11] lists four different approaches using real world driving data which shall be explained briefly in the following section with a special focus on the method used in [5] which is also the method used for the ICDB.

Micro-Trip Based Cycle Construction

A micro-trip "is defined as a trip between adjacent stops, including the leading period of idle" [11]. The driving cycle itself is constructed by chaining several micro-trips together with the goal of closely matching the observed data. The micro-trips themselves are selected by either random selection, incremental search for a trip with specific characteristics or a combination of both. Micro-trip based cycles are assessed by different parameters such as speed or acceleration. One of the limitations is that micro-trips do not differentiate between different types of driving conditions, such as congested or free flowing traffic (Level of Service, LOS) [11] which in turn may make it difficult to recreate specific driving conditions [5].

Segment-Based Cycle Construction

This method is based on a strict differentiation between different LOS types and may start and end at any speed. Advantageous is the development of cycles for specific conditions. It also introduces the issue of connecting segments with different velocities and accelerations [11]. According to [11] the EPA (US Environmental Protection Agency) therefore only allows segments to be connected with a speed / acceleration difference $< 0.5 \text{ mph} / < 0.5 \text{ mph/s}^2$. The selection of the segments is a mix between random and best-incremental logic similar to micro-trips.

One of the downsides of this method is that the cycles are viewed and created from a transportation engineering perspective and are therefore less applicable for emission testing [11].