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Development of real-world Driving Cycles for Battery Electric Vehicles

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Summary

Driving cycles are used in various aspects of vehicle development and for the homologation of new vehicles. The character and duration of a cycle have a huge impact on the energy consumption for longitudinal dynamics and comfort functions. Current driving cycles are widely criticised for their insufficient representation of real-world driving, especially for battery electric vehicles (BEV). Therefore we developed three driving cycles for BEV that are based on empiric data from a large-scale field operational test with electric vehicles (project CROME) for future application in research and policy making.

Keywords: BEV (battery electric vehicle), city traffic, commercial, fleet, passenger car

1 Introduction

Driving cycles are an important instrument in the development of new vehicles and for the evaluation of vehicle characteristics like energy consumption and emissions. In recent years, the discussion about the appropriate cycle has gained momentum in science [1], [2] and in the public domain [3] as the gap between real-world consumption and driving cycle consumption increased due to optimized adaption to the certification process. In [4] it is shown that maximum and average propulsion power differ for three vehicle classes between Urban Dynanometer Cycle and US06 Cycle by more than factor 2. For battery electric vehicles (BEV), the difference in energy consumption can reach more than factor 2 and even more than factor 5 in case of the maximum driving torque depending on the cycle [5]. This demonstrates that the choice of the appropriate driving cycle is absolutely crucial for a meaningful evaluation of vehicles. For that reason we decided to build up empirically based real-world driving cycles for electric vehicles for future application in research and policy making. This work is presented here an excerpt from the corresponding author's doctoral thesis [6].

2 Empiric foundation

The data, on which the driving cycles are built, has been gathered in the project CROME – Cross-border Mobility for Electric Vehicles [7], [8]. In this field operational test more than 100 BEV of 6 types have been employed in corporate fleets in France and Germany by average users. Almost 3 years of data collection in 80 vehicles have led to more than 125,000 trip records with a total length of about 600,000 km in binned data or continuous curve signals. The driving cycles presented here are founded on 16,690 trips, which consist of a total number of 88,431 driving sequences. They cover a driving distance of ca. 129.000 km and have been recorded with continuous curve signals at an acquisition rate of at least 1 Hz. Overall the data shows a ratio of 74 % urban trips and 26 % rural trips. Rural trips are defined as trips that exceed 70 km/h at least once and show a speed profile of at least 20 % of the driving time beyond 60 km/h. The data shows a focus on rather short trips with a mean value of 8.4 km and a median of 5.2 km. This results mainly from the locally focused mobility of the users, but – in parts – as well from the availability of alternative vehicles with combustion for longer trips. The BEV have in many cases been used as part of heterogeneous fleets in combination with other vehicles.

3 Methodology

The goal of the development of the driving cycles was to gain the best possible representation of the data basis in one representative trip per usage domain. The three domains, which have been defined as targets, are predominantly urban driving, predominantly rural driving and the mixed overall operation with a ratio of urban to rural segments as it is found in the data basis.

The first step to build up each driving cycle is a statistical analysis to define target vectors for the total length, the duration, the proportion of urban to rural driving and the number of driving sequences to gain the best possible representation of the driving data. The following procedure is based on the methodology that has been used in [9]. Hereby 13 further statistical parameters are derived from the data base to complete the target values for the driving cycle. The parameters are based on the evaluation of [9], [10] and [11]. The complete overview of the parameters employed is given in table 1.

Table1: Overview of parameters employed for driving cycles

No.	Parameter	Unit
1	Average speed	km/h
2	Average speed >0	km/h
3	Average longitudinal acceleration	m/s^2
4	Average longitudinal deceleration	m/s^2
5	Average duration of driving sequences	s
6	Proportion idling	%
7	Proportion cruising	%
8	Proportion creeping	%
9	Proportion acceleration	%
10	Proportion deceleration	%
11	Number of acceleration-deceleration changes	
12	Root mean square longitudinal acceleration	m/s^2
13	Normalised positive acceleration kinetic energy	m/s^2

The borders of speed and lateral acceleration for stop, cruising, creeping, acceleration and deceleration can be found in table 2.

Table 2: Definition of operating modes

Operating mode	Speed $\boldsymbol{v}$ in km/h	Longitudinal acceleration a_x in m/s^2
Stop	0	0
Cruising	> 5	$0,1 \leq \boldsymbol{a_x} \leq 0,1$
Creeping	$0 < \boldsymbol{v} \leq 5$	$-0,1 \leq \boldsymbol{a_x} \leq 0,1$
Acceleration	>0	>0,1
Deceleration	>0	<-0,1

After the statistical analysis, all trips of the database are divided into micro-trips, what results here in a total number of 88,431. A micro-trip is defined as the phase with a positive driving speed between two stops as shown for example in Figure 1 with 5 micro-trips. Every micro-trips keeps linked with the stop phase that occurred before it to have realistic idle phases in the cycle.

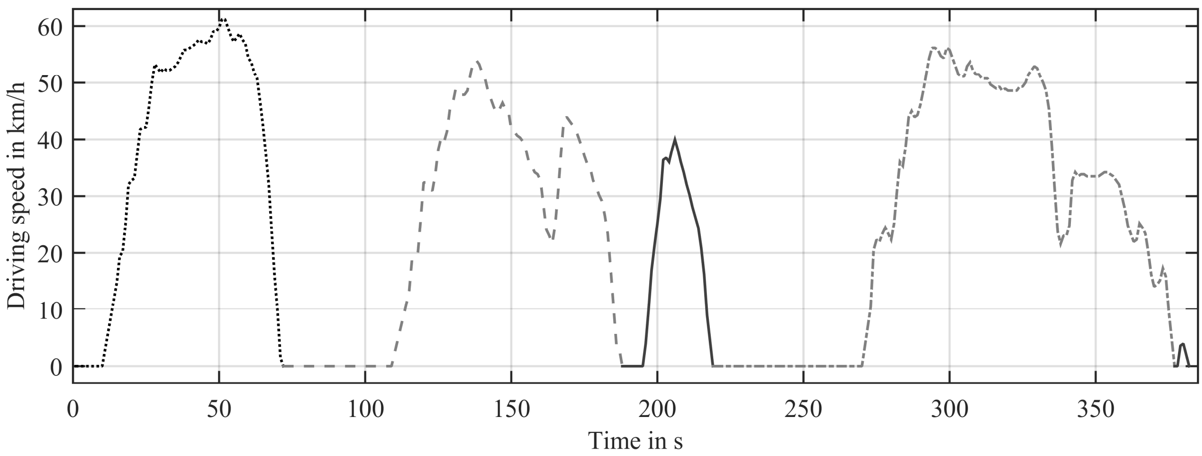

Figure 1: Driving sequence with 5 micro-trips

The micro-trip pool is in the next step cleaned to remove strong statistical outliers. Finally, random combinations of micro-trips with the statistically pre-defined total number of micro-trips are built-up and all parameters evaluated in comparison to the target vector. In total 100,000,000 combinations are evaluated and compared to find the driving cycle that represents the data best. This process is repeated for each of the three driving cycles with it specific target values.

4 Results

In total three driving cycles have been built up to represent the real-world usage of BEV in corporate fleets in central Europe.

4.1 Fleet-BEV-Cycle

The Fleet-BEV-Cycle (see Figure 2) for combined usage and the Fleet-BEV-Urban-Cycle and the Fleet-BEV-Rural-Cycle for urban and rural driving.

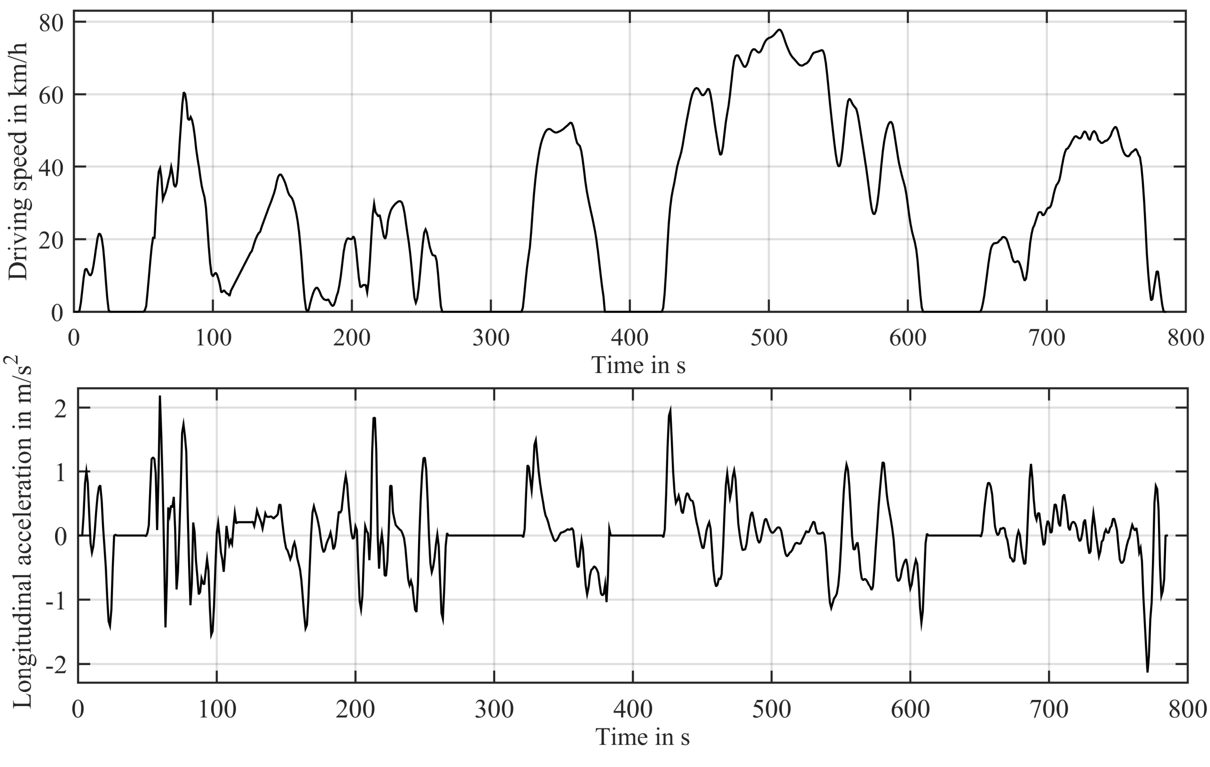

Figure 2: Speed and acceleration profile of the Fleet-BEV-Cycle

The Fleet-BEV-Cycle shows an average deviation of the target values of 2.8 % and a maximum deviation of 8 %. It is intended to represent the overall usage of the BEV and therefore consists of four of urban as well as one rural micro-trip. As it is found in the data base, the driving cycle reflects predominant urban operation. In sum 13.7 % of the actual driving time without idle phases shows a speed of 60 km/h or more. The Fleet-BEV-Cycle has phases with a speed limit of 50 km/h and with 30 km/h as well as an initial sequence of 27 s with a top speed of 21 km/h as it occurs when a large parking lot has to be left. Key characteristics of the three cycles can be found in Table 3 and the corresponding speed values are found in Appendix A.

The longitudinal characteristic of the cycles can be visualised with the speed acceleration probability distribution (SAPD). The Fleet-BEV-Cycle has the core of the usage in classes of constant driving to soft acceleration at urban speed classes (see Figure 3). But there is also a significant share in the class between 70 km/h and 80 km/h resulting from the rural driving sequence. Accelerations and decelerations range to ca. +/- 2.2 m/s^2.

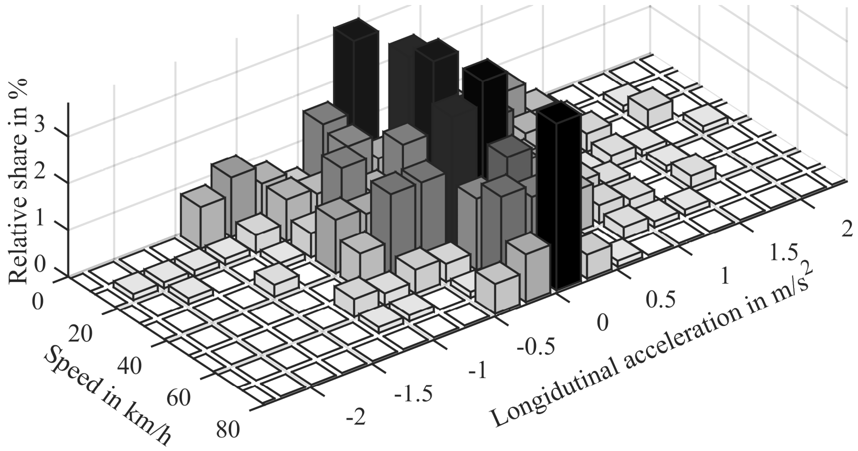

Figure 3: Speed Acceleration Probability Distribution Matrix of Fleet-BEV-Cycle without idle time

4.2 Fleet-BEV-Urban-Cycle

The Fleet-BEV-Urban Cycle (Figure 4) represents a purely urban trip. In comparison to the Fleet-BEV-Cycle and the Fleet-BEV-Rural-Cycle it is shorter in distance and time, has a lower average speed and a higher proportion of idle-time. At the same time it consists of seven micro-trips, which is the highest number of the three cycles as urban micro-trips are usually shorter than rural micro-trips. The average deviation of the target values is 4.3 % and the maximum is 9.9 %.

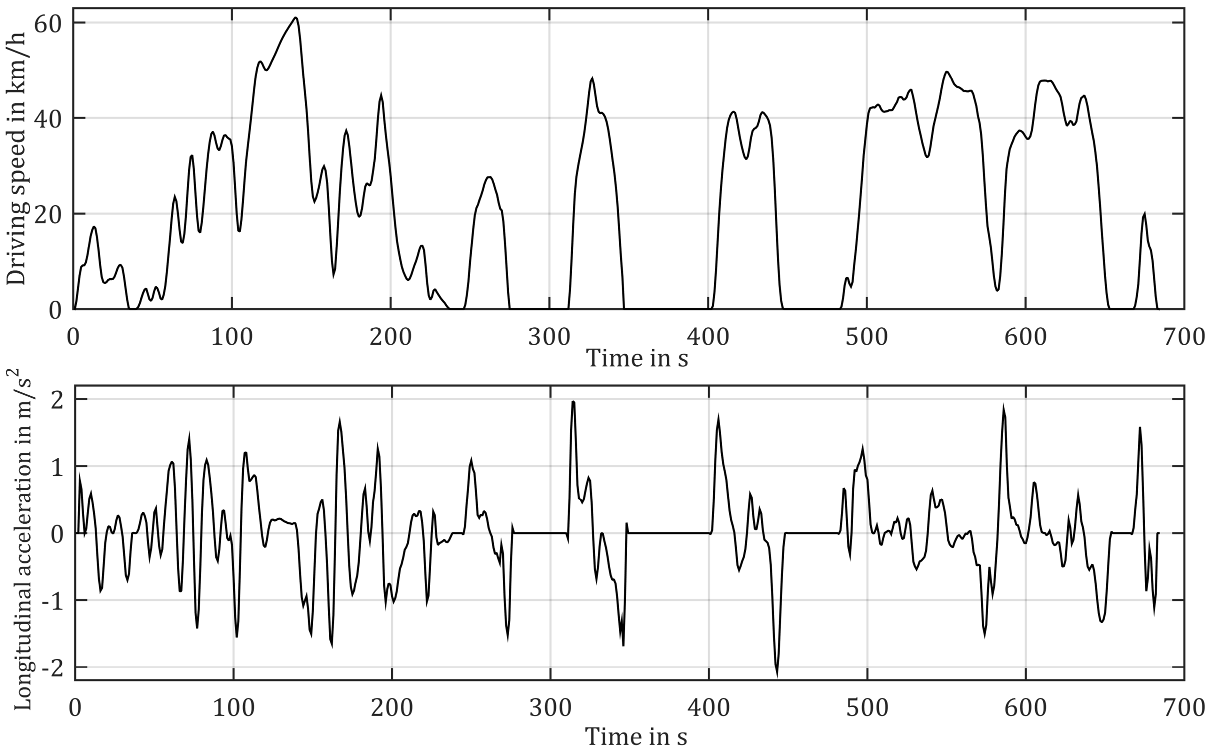

Figure 4: Speed and acceleration profile of the Fleet-BEV-Urban-Cycle

Being built-up with real-world sequences, it also contains a short period of speeding with a top speed of 61 km/h despite the urban limit of 50 km/h. In result approx. 4 % of the cycle time are driven above 50 km/h. Here as well, the SAPD-Matrix is used for the visualisation of the longitudinal dynamics (Figure 5).

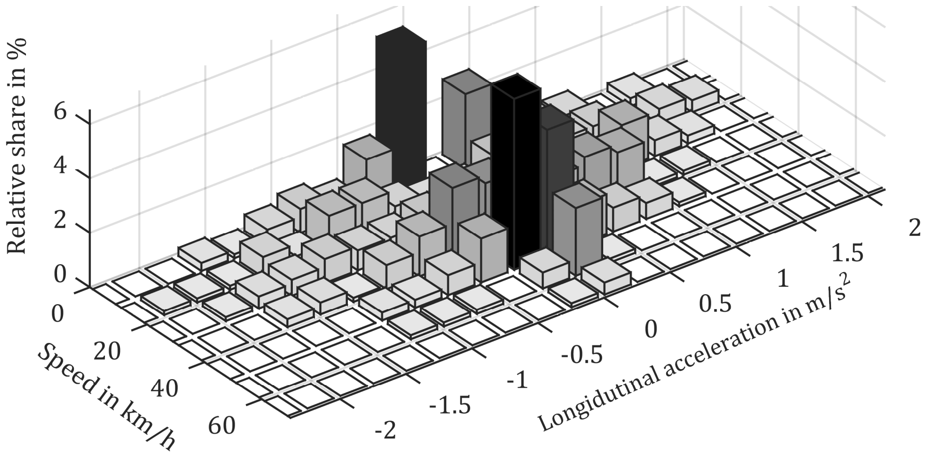

Figure 5: Speed Acceleration Probability Distribution Matrix of Fleet-BEV-Urban-Cycle without idle time

It can be seen that the main area of usage is in the class between 40 km/h and 50 km/h. The longitudinal acceleration ranges between -2.1 m/s^2 and 2 m/s^2. Higher values occur mostly at comparably low speed. Overall the proportion of constant driving is low in comparison to the other cycles. Including idle time, which is responsible for 23.3 % of the total cycle time, only 52.5 % of the cycle are driven with a longitudinal acceleration between -0.5 m/s^2 und 0.5 m/s^2. During the rest of the time, the vehicle is accelerated or decelerated at higher values what reflects the volatility of the speed signal in urban driving and reveals a high potential for the recuperation of brake-energy. The corresponding speed values are found in Appendix B.

4.3 Fleet-BEV-Rural-Cycle

Figure 6 shows the Fleet-BEV-Rural-Cycle which is intended to represent a typical rural trip with a fleet BEV. It matches the target values with an average deviation of 2.1 % and a maximum deviation of 5 %.

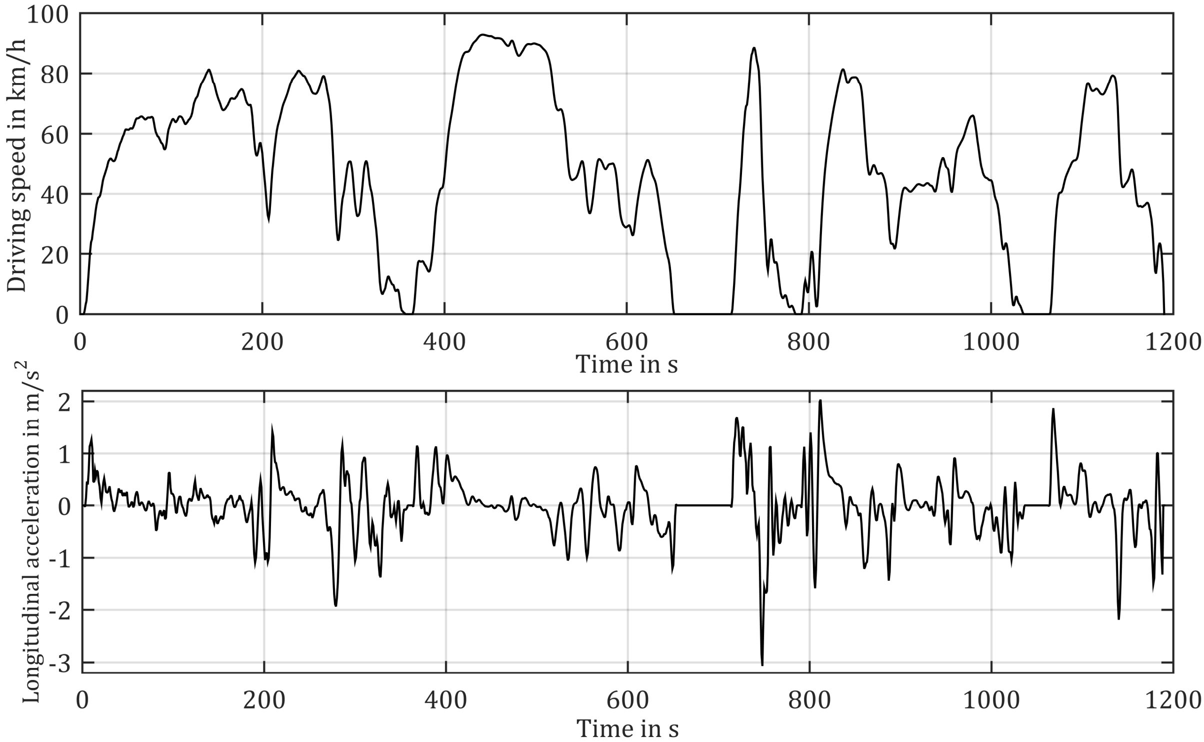

Figure 6: Speed and acceleration profile of the Fleet-BEV-Rural-Cycle

This cycle is by far the longest among the three with a total length of 15,393 m and a duration of 1,190 s. Its average speed of 46.6 km/h is comparably close to the average speed without idling of 51.4 km/h as the car stands still for only 9.4 % of the time. The Fleet-BEV-Rural-Cycle consists of 5 micro-trips with an average driving time of 216 s and a maximum of 353 s. There are several phases in the cycle with a maximum speed of 50 km/h that result from passing through towns and villages. During the study the usage of motorways (Autobahn) has been rare and driving on rural roads has been the dominant form of non-urban operation. The speed values of the cycle are found in Appendix C.

Here again, the SAPD matrix is used to visualize the longitudinal acceleration per speed class (see Figure 6).

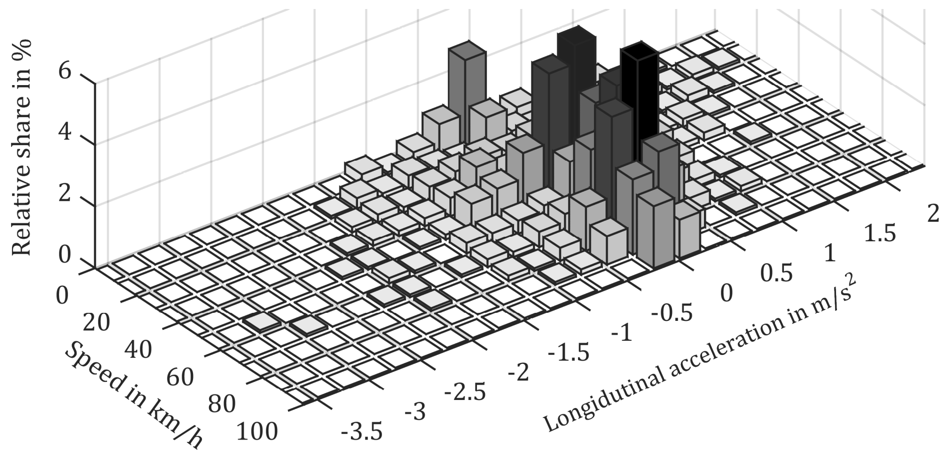

Figure 6: Speed Acceleration Probability Distribution Matrix of Fleet-BEV-Rural-Cycle without idle time

The profile is now comparably narrow, resulting from a higher proportion of constant or nearly constant driving. The main proportion of driving happens beyond urban speed limits but the share of urban driving is still noteworthy. Rural driving shows decelerations around 2 m/s^2 at speed levels above 60 km/h and there is even one strong deceleration with in peak approx. 3 m/s^2.

Table 3 gives an overview of key characteristics of the three cycles.

Table 3: Selected Characteristics of Driving Cycles

	Length (m)	Duration (s)	Av. speed (km/h)	Max. speed (km/h)	Idle (%)
Fleet-BEV-Cycle	5828	783	26.7	78	22.6
Fleet-BEV-Urban-Cycle	4021	684	21.2	61	23.3
Fleet-BEV-Rural-Cycle	15393	1190	46.6	92.9	9.3

4.4 Comparison to other Driving Cycles

The comparison of the Fleet-BEV-Cycle with the synthetically built New European Driving Cycle (NEDC) [12] revels a shorter total distance (5828 m vs. 11013 m), a shorter duration (783 s vs. 1220 s), a slower maximum speed (78 km/h vs. 120 km/h) and a slower average speed (26.7 km/h vs. 33.4 km/h). This reflects the fact that the major domain for BEV is the urban environment. It makes the Fleet-BEV-Cycle significantly more dynamic than the NEDC with more positive kinetic energy used for a higher number of accelerations. Where the NEDC has a large share of constant driving with a total number of only 14 acceleration-deceleration-changes in ca. 11 km the Fleet-BEV-Cycle as a real-world cycle shows 6.2 changes per km. The volatility of the speed signal rises with the proportion of urban driving with 8.2 acceleration-deceleration-changes per km in the Fleet-BEV-Urban-Cycle and only 3.4 changes per km in the Fleet-BEV-Rural-Cycle.

The comparison with the Worldwide harmonized Light duty driving Test Cycle (WLTC) [13] for class 3 vehicles reveals the biggest differences in the maximum speed (120 km/h), the distance (23 km) and the duration (30 min). This brings the WLTC far away from representative for the observed BEV usage as only 3.5 % of the observed trips are 23 km long or more. Especially for the representation of all processes that tend towards a thermo-dynamic equilibrium like the tyre temperature, that largely influences rolling resistance [14], or the climatisation of the interior, it is absolutely crucial to have realistic driving time, distance and speed profiles.

The volatility of the three driving cycles, as they are found in all real-world speed profiles might turn out as difficulty for the adaption of the cycle for bench tests. Therefore a series of test drives with trained drivers should be conducted to evaluate the deviation of driving speed in set-actual comparison. Maybe, for this purpose it will turn out necessary to smooth the speed profile. But that process should lead to a revaluation of energy consumption of the adapted cycle towards the original cycle in a simulation environment. The potential drawback of driveability influences only bench tests with human drivers but does not affect the usage in simulation models. Being combined from real-world micro trips that are connected with idle phases the general driveability of the cycle is guaranteed.

5 Conclusion

In this paper we presented three driving cycles for electric passenger cars that have been built up on a large empiric basis from real-world driving of BEV in corporate fleets. The comparison with NEDC and WLTP reveals major differences in distance, duration and longitudinal dynamics that account for unrealistic consumption and an insufficient representation of everyday usage in those cycles. Therefore we recommend the family of the here presented Fleet-BEV-Cycles for the future research on battery electric passenger cars. The usage on test benches with human drivers might need slight adaption for enhanced drivability. To determine this, we recommend a test campaign for the cycles with trained drivers. For the usage in simulation models, the cycles are suitable right away with the values found in Appendix A to C. They can be employed for the evaluation, development or enhancement of components, full vehicles or the integration of BEV in traffic or energy research models.

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References

[1] K. Rhode-Brandenburger, *Verbrauch in Fahrzyklen und im Realverkehr*, in Energiemanagement im Kraftfahrzeug, ISBN 978-3-658-04450-3, Wiesbaden, Springer Vieweg, 2014

[2] U. Tietge et. al., *From Laboratory to Road*, White Paper, Berlin, International Council on Clean Transportation Europe, 2015

[3] C. M. Schwarzer, *3,8 Liter? Nie im Leben!*, Hamburg, Zeit Online 2014, http://www.zeit.de/mobilitaet/2014-09/auto-benzinverbrauch-abweichung, accessed on 2015-10-27

[4] H. Wallentowitz, A. Freialdenhoven, *Strategien zur Elektrifizierung des Antriebsstranges,* ISBN 978-3-8348-1412-8, Wiesbaden, Vieweg + Teubner, 2011

[5] H. Neudorfer et. al., *Analyse von unterschiedlichen Fahrzyklen für den Einsatz von Elektrofahrzeugen*, e & i Elektrotechnik und Informationstechnik, ISSN 1613-7620, 2006, 123(7-8), 352-360

[6] M. Pfriem, *Analyse der Realnutzung von Elektrofahrzeugen in kommerziellen Flotten zur Definition einer bedarfsgerechten Fahrzeugauslegung*, ISBN: 978-3-7315- 0489-4, Karlsruhe, KIT Scientific Publishing, 2016

[7] CROME Project Homepage, http://crome-project.eu/, accessed on 2015-10-27

[8] J. Schäuble et. al. (Eds.), *Cross-border Mobility for Electric Vehicles*, ISBN: 978-3-7315-0492-4, Karlsruhe, KIT Scientific Publishing, 2016

[9] W.T. Hung et. al., *Development of a practical driving cycle construction methodology: A case study in Hong Kong*, Transportation Research Part D, ISSN 1361-9209, 12 (2007) 115–128

[10] T.J. BARLOW et. al., *A reference book of driving cycles for use in the measurement of road vehicle emissions. Version 3.* Bracknell: IHS, 2009. Published project report. PPR354. ISBN 9781846088162.

[11] H.Y. Tong et. al., *Development of a driving cycle for Hong Kong*. Atmospheric Environment 33, pp. 2323—2335, DOI: 10.1016/S1352-2310(99)00074-6,Elsevier, 1999

[12] *Richtlinie des Rates vom 26. Juni 1991 zur Änderung der Richtlinie 70/220/EWG zur Angleichung der Rechtsvorschriften der Mitgliedstaaten über Maßnahmen gegen die Verunreinigung der Luft durch Emissionen von Kraftfahrzeugen*, Amtsblatt der Europäischen Gemeinschaften, 991/441/EWG, 1991

[13] M. Tutuianu et. al., *Development of a Worldwide harmonized Light duty driving Test Cycle (WLTC)*, UN/ECE/WP.29/GRPE/WLTP-IG., WLTP DHC CHAIR (Ed.), 2013

Authors

Matthias Pfriem has been working as research assistant at the Institute of Vehicle System Technology at KIT from 2010 to 2015 to prepare his doctoral thesis. During this time he has organised and conducted the scientific analysis of data from three field operational tests with hybrid and full electric vehicles. The main focus of his work were the analysis of the real-world usage of those vehicles with regard to user acceptance and as a basis for demand-based vehicle specifications as well as the associated development of new methods of data logging.
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Frank Gauterin is Director of the Institute of Vehicle System Technology. He is full professor and holder of the Chair of Vehicle Technology at KIT. His main areas of research are interaction of vehicle, user, infrastructure and traffic, concepts of conventional, hybrid and electric vehicles, driving and operation strategies, driver assistance, noise, vibration and harshness, ride and handling, suspension and tire technology, tire road interaction.

Appendix A

Fleet-BEV-Cycle at 1 Hz acquisition rate with separator ",":

0.00, 0.00, 0.00, 0.31, 2.48, 5.87, 9.30, 11.51, 11.79, 10.99, 10.17, 9.94, 10.66, 12.46, 14.93, 17.74, 20.30, 21.54, 21.37, 20.28, 17.70, 13.44, 8.42, 3.69, 0.47, 0.00, 0.41, 1.54, 5.45, 9.69, 14.09, 18.03, 20.61, 20.19, 27.72, 34.25, 38.54, 39.53, 36.84, 30.99, 32.07, 33.03, 34.42, 36.22, 37.63, 39.93, 37.92, 34.97, 34.35, 35.42, 39.67, 46.22, 51.74, 57.22, 60.55, 60.09, 57.74, 53.27, 52.90, 53.75, 52.92, 51.09, 48.38, 44.79, 42.21, 39.77, 36.94, 34.53, 32.95, 31.52, 28.66, 23.61, 18.03, 13.29, 10.37, 9.69, 10.27, 10.70, 10.13, 8.93, 7.44, 5.33, 5.54, 5.88, 5.44, 5.02, 4.86, 4.36, 5.79, 6.54, 7.26, 8.00, 8.74, 9.48, 10.22, 10.96, 11.70, 12.44, 13.18, 13.92, 14.66, 15.40, 16.14, 16.61, 17.96, 19.21, 20.25, 21.09, 21.71, 22.06, 23.29, 24.36, 25.40, 26.44, 27.48, 28.55, 29.51, 30.47, 31.58, 32.67, 34.05, 35.95, 37.23, 37.78, 37.77, 37.20, 36.41, 35.52, 34.30, 33.02, 32.16, 31.71, 31.22, 30.22, 28.75, 27.09, 24.89, 21.99, 17.93, 13.19, 7.82, 3.53, 0.76, 0.05, 0.72, 2.33, 3.77, 4.99, 5.93, 6.49, 6.62, 6.12, 5.34, 4.37, 3.81, 3.40, 3.26, 3.20, 3.41, 2.72, 2.06, 1.60, 1.83, 2.83, 4.30, 5.39, 7.29, 9.75, 12.95, 16.18, 18.49, 19.71, 20.28, 20.15, 20.04, 20.04, 20.80, 20.12, 17.17, 13.16, 9.30, 6.79, 6.86, 7.32, 7.32, 7.32, 5.38, 8.29, 14.10, 20.88, 26.73, 29.71, 27.44, 26.88, 26.28, 26.68, 24.91, 22.67, 20.72, 20.12, 21.57, 25.07, 26.73, 27.92, 28.64, 29.15, 29.64, 29.97, 30.29, 30.46, 30.43, 30.07, 28.93, 26.93, 24.19, 21.51, 19.00, 15.75, 11.91, 7.60, 3.83, 2.49, 3.60, 6.31, 10.35, 14.72, 18.85, 21.80, 22.69, 21.80, 19.89, 17.97, 16.48, 15.55, 15.41, 15.31, 13.91, 10.34, 5.67, 1.60, 0.00, 1.14, 4.62, 8.57, 12.12, 14.92, 17.61, 22.05, 27.43, 32.41, 36.40, 39.74, 42.41, 44.65, 46.37, 47.64, 48.66, 49.54, 50.09, 50.39, 50.46, 50.35, 50.03, 49.75, 49.54, 49.48, 49.57, 49.75, 49.91, 50.16, 50.40, 50.75, 51.07, 51.40, 51.75, 52.15, 52.16, 51.35, 49.88, 48.05, 46.63, 46.16, 45.80, 44.49, 42.15, 39.02, 35.80, 33.26, 31.24, 29.36, 27.55, 25.88, 23.98, 22.06, 19.70, 16.66, 13.31, 10.01, 6.86, 4.27, 0.00, 1.14, 4.98, 10.85, 18.00, 24.33, 28.68, 31.69, 33.76, 35.55, 37.75, 39.88, 41.54, 42.73, 44.16, 46.05, 48.39, 50.74, 52.97, 54.92, 56.92, 58.74, 60.11, 60.96, 61.53, 61.72, 61.54, 61.01, 60.28, 59.74, 59.78, 60.19, 60.81, 61.49, 61.36, 59.98, 57.73, 55.03, 52.14, 49.64, 47.31, 44.86, 43.33, 43.64, 45.66, 48.99, 52.26, 54.64, 56.79, 59.79, 63.29, 66.85, 69.38, 70.59, 70.83, 70.73, 69.98, 69.22, 68.43, 67.78, 67.63, 68.10, 69.02, 70.34, 71.49, 72.21, 72.49, 72.42, 72.05, 71.69, 71.56, 71.86, 72.54, 73.49, 74.33, 74.94, 75.32, 75.54, 75.69, 75.87, 76.15, 76.53, 76.98, 77.42, 77.77, 77.82, 77.38, 76.55, 75.43, 74.29, 73.27, 72.36, 71.49, 70.81, 70.28, 69.87, 69.44, 69.01, 68.54, 68.18, 68.04, 68.00, 68.19, 68.44, 68.57, 68.91, 69.40, 70.07, 70.86, 71.43, 71.58, 71.73, 71.81, 71.95, 72.07, 72.24, 72.02, 70.94, 68.69, 65.36, 61.36, 57.40, 53.78, 50.31, 46.95, 43.88, 41.47, 40.07, 40.20, 41.94, 44.95, 48.70, 52.66, 55.90, 58.17, 58.78, 58.31, 57.47, 56.86, 56.42, 55.89, 54.36, 52.17, 49.69, 47.25, 44.84, 42.33, 39.69, 36.89, 33.98, 30.89, 28.40, 27.08, 26.89, 27.78, 29.81, 32.69, 36.45, 40.68, 44.35, 47.09, 49.11, 50.61, 51.71, 52.32, 52.39, 51.72, 49.86, 47.39, 44.92, 42.45, 40.35, 38.63, 37.07, 35.74, 34.31, 32.23, 29.43, 26.49, 24.07, 22.14, 20.62, 19.24, 17.23, 13.97, 9.33, 4.64, 1.21, 0.00, 0.69, 2.31, 4.48, 7.39, 10.28, 13.21, 15.69, 17.71, 18.48, 18.89, 18.91, 18.99, 19.20, 19.71, 19.95, 20.54, 20.62, 20.47, 20.04, 19.01, 17.69, 16.46, 14.85, 13.85, 13.56, 13.66, 13.89, 13.58, 12.58, 11.30, 9.58, 8.54, 9.03, 11.40, 15.10, 18.98, 21.39, 23.09, 23.85, 25.01, 26.23, 27.31, 27.46, 27.39, 26.59, 26.74, 27.36, 28.22, 28.65, 28.68, 29.26, 30.69, 32.50, 33.96, 34.97, 35.43, 36.26, 38.07, 40.44, 42.51, 44.01, 44.93, 45.07, 45.65, 46.29, 47.11, 47.74, 48.34, 48.48, 48.22, 47.95, 47.85, 48.26, 49.18, 49.80, 49.59, 48.84, 47.79, 47.42, 48.67, 49.53, 49.92, 49.49, 48.75, 47.40, 47.07, 46.63, 46.63, 46.87, 47.19, 47.23, 47.57, 48.05, 48.69, 49.78, 50.45, 51.02, 50.90, 49.94, 48.39, 46.97, 45.43, 44.31, 43.54, 43.15, 42.96, 42.99, 43.51, 44.04, 44.30, 44.64, 44.97, 44.35, 43.32, 42.70, 40.15, 35.98, 30.46, 23.45, 15.69, 10.28, 6.10, 3.14, 3.51, 6.21, 8.68, 11.05, 10.99, 8.01, 4.78, 1.97, 0.14, 0.00

Appendix B

Fleet-BEV-Urban-Cycle at 1 Hz acquisition rate with separator ",":

0.00, 1.65, 4.30, 6.99, 8.80, 9.14, 9.14, 9.79, 11.29, 13.38, 15.35, 16.60, 17.33, 16.94, 15.06, 12.28, 9.12, 6.67, 5.63, 5.46, 5.66, 6.09, 6.26, 6.25, 6.29, 6.74, 7.60, 8.54, 9.16, 9.21, 8.64, 6.80, 4.36, 1.99, 0.25, 0.00, 0.00, 0.00, 0.00, 0.11, 0.47, 1.26, 2.35, 3.36, 4.09, 4.30, 3.20, 2.09, 1.74, 2.35, 3.74, 4.66, 4.36, 3.46, 2.26, 1.99, 2.98, 4.78, 7.71, 11.29, 14.95, 18.84, 22.08, 23.46, 22.56, 19.96, 16.69, 14.20, 13.90, 15.73, 19.42, 24.34, 28.98, 31.86, 32.24, 29.22, 24.30, 19.56, 16.46, 16.04, 18.15, 21.43, 25.28, 29.10, 32.46, 34.97, 36.66, 37.13, 36.32, 34.82, 33.61, 33.24, 34.11, 35.38, 36.33, 36.40, 35.97, 35.69, 35.48, 34.07, 30.62, 25.38, 20.01, 16.48, 16.28, 18.82, 22.78, 27.15, 31.18, 34.11, 36.96, 39.90, 42.97, 46.07, 48.83, 50.59, 51.66, 51.91, 51.49, 50.73, 50.13, 50.04, 50.45, 51.10, 51.84, 52.53, 53.21, 53.95, 54.72, 55.49, 56.21, 56.87, 57.48, 58.07, 58.59, 59.13, 59.62, 60.13, 60.66, 61.08, 60.80, 59.28, 56.41, 52.62, 48.81, 45.32, 41.78, 37.09, 31.65, 26.68, 23.51, 22.51, 23.20, 24.34, 25.80, 27.59, 29.18, 29.82, 28.92, 26.38, 21.35, 15.49, 10.06, 7.26, 8.37, 13.07, 18.78, 24.62, 29.46, 33.52, 36.32, 37.33, 36.41, 33.99, 30.86, 27.59, 24.75, 22.31, 20.30, 19.32, 19.63, 21.15, 23.59, 25.61, 26.30, 26.01, 25.83, 26.82, 28.98, 31.48, 35.62, 40.07, 43.43, 44.70, 43.29, 39.57, 36.33, 33.50, 30.84, 27.76, 24.11, 20.52, 17.16, 14.33, 12.22, 10.45, 8.90, 7.82, 7.04, 6.35, 6.06, 6.37, 7.16, 8.18, 9.18, 10.03, 11.11, 12.32, 13.26, 13.35, 12.28, 9.18, 5.45, 2.84, 1.98, 2.54, 3.87, 4.17, 3.59, 3.05, 2.55, 2.08, 1.69, 1.32, 0.79, 0.39, 0.06, 0.00, 0.00, 0.00, 0.00, 0.00, 0.00, 0.00, 0.00, 0.00, 0.89, 2.93, 5.78, 9.84, 13.35, 16.75, 19.61, 21.14, 21.84, 22.89, 23.78, 24.82, 26.06, 26.93, 27.53, 27.53, 27.57, 27.07, 26.11, 24.94, 23.93, 22.30, 21.02, 20.66, 18.34, 14.01, 8.76, 3.50, 0.00, 0.10, 4.17, 10.57, 17.79, 24.02, 27.60, 29.63, 31.55, 33.26, 34.94, 36.96, 39.46, 42.26, 45.25, 47.58, 48.27, 47.04, 44.76, 42.50, 41.30, 40.97, 41.08, 40.81, 40.24, 39.24, 37.73, 35.64, 33.27, 30.72, 28.26, 25.20, 21.42, 16.50, 11.18, 6.74, 0.00, 0.68, 3.58, 8.33, 14.29, 20.10, 24.86, 28.91, 32.37, 35.53, 38.01, 39.60, 40.52, 41.08, 41.30, 41.05, 39.73, 37.81, 35.92, 34.32, 32.94, 31.84, 31.38, 31.96, 33.67, 35.85, 37.27, 37.73, 37.91, 38.29, 39.29, 40.62, 41.21, 41.05, 40.63, 40.20, 39.53, 38.40, 35.89, 31.42, 25.05, 17.71, 10.56, 5.07, 1.76, 0.23, 0.00, 0.51, 2.28, 4.97, 6.46, 6.51, 5.33, 4.71, 5.69, 9.18, 12.21, 15.86, 19.42, 23.49, 27.60, 32.25, 35.43, 38.59, 40.99, 42.03, 42.14, 42.24, 42.15, 42.53, 42.81, 42.53, 41.81, 41.38, 41.28, 41.37, 41.40, 41.61, 41.61, 41.62, 42.15, 42.77, 43.32, 44.25, 44.35, 44.30, 43.83, 43.89, 44.28, 45.22, 45.74, 45.93, 44.62, 43.06, 41.13, 39.29, 37.65, 36.22, 34.71, 33.48, 32.25, 31.75, 32.19, 33.89, 36.10, 38.28, 39.72, 41.13, 42.53, 44.13, 46.03, 47.67, 48.94, 49.73, 49.65, 49.10, 48.48, 47.71, 47.06, 46.71, 46.44, 46.39, 46.18, 45.94, 45.62, 45.62, 45.55, 45.55, 45.67, 45.67, 44.98, 43.73, 42.41, 40.39, 38.98, 36.55, 32.40, 26.93, 21.89, 17.40, 15.41, 13.23, 10.19, 6.97, 4.73, 3.81, 4.14, 6.86, 11.39, 17.45, 24.12, 29.28, 31.58, 33.45, 34.37, 35.18, 36.05, 36.60, 36.99, 37.39, 37.27, 37.06, 36.62, 36.07, 35.62, 35.66, 36.19, 37.47, 39.91, 42.70, 45.07, 46.77, 47.55, 47.74, 47.78, 47.79, 47.78, 47.62, 47.71, 47.74, 47.35, 46.77, 46.11, 45.57, 45.09, 44.42, 42.91, 41.04, 39.50, 38.35, 38.74, 39.36, 39.22, 38.50, 38.67, 39.26, 41.21, 43.03, 44.13, 44.40, 44.69, 43.89, 42.45, 40.44, 38.62, 36.82, 35.16, 32.74, 29.76, 25.65, 21.26, 16.32, 11.76, 7.11, 3.41, 0.93, 0.00, 0.00, 0.00, 0.00, 0.00, 0.00, 0.00, 0.00, 0.00, 0.00, 0.00, 0.00, 0.00, 0.00, 0.00, 0.00, 0.73, 2.54, 5.18, 10.30, 15.81, 19.23, 19.90, 17.65, 14.43, 13.10, 12.23, 10.07, 6.33, 2.57, 0.15, 0.00

Appendix C

Fleet-BEV-Rural-Cycle at 1 Hz acquisition rate with separator ",":

0.00, 0.00, 0.00, 0.00, 1.20, 3.05, 4.41, 8.02, 12.21, 16.53, 21.03, 24.00, 24.93, 27.51, 29.55, 31.80, 34.30, 36.29, 37.66, 38.85, 38.91, 39.51, 40.77, 42.57, 44.36, 45.53, 46.41, 47.40, 48.32, 49.66, 50.83, 51.38, 51.81, 51.82, 51.38, 51.07, 50.97, 51.17, 51.81, 52.80, 54.05, 54.81, 55.92, 56.86, 57.46, 58.32, 59.18, 59.76, 60.79, 61.47, 61.35, 61.35, 61.29, 61.44, 61.75, 61.83, 61.61, 61.97, 62.69, 63.62, 64.56, 65.06, 65.07, 65.13, 65.33, 65.59, 65.71, 65.69, 65.42, 65.11, 64.73, 64.71, 64.97, 65.30, 65.35, 65.37, 65.28, 65.54, 65.54, 65.21, 63.75, 61.99, 60.62, 59.90, 59.19, 58.99, 58.39, 57.74, 57.03, 56.79, 56.21, 55.08, 54.77, 55.37, 57.05, 59.57, 61.34, 62.18, 63.10, 63.86, 64.59, 64.94, 64.59, 64.06, 63.74, 64.17, 64.63, 65.40, 65.73, 65.73, 65.59, 65.28, 64.66, 64.01, 63.27, 63.17, 63.58, 63.96, 64.54, 64.80, 65.25, 65.85, 66.86, 68.52, 70.06, 70.85, 71.64, 72.00, 72.53, 73.65, 74.81, 75.67, 76.49, 77.02, 77.57, 78.14, 78.75, 79.53, 80.18, 80.68, 81.33, 81.18, 80.35, 79.45, 78.31, 77.13, 76.58, 75.57, 74.28, 73.13, 72.14, 71.26, 70.53, 69.72, 68.73, 68.02, 67.77, 67.85, 68.11, 68.50, 69.02, 69.43, 70.13, 70.75, 71.47, 71.67, 71.71, 71.52, 71.52, 71.59, 72.05, 72.33, 72.98, 73.66, 74.07, 74.43, 74.76, 74.62, 74.19, 73.32, 72.17, 71.04, 70.25, 69.74, 69.43, 69.41, 69.67, 68.38, 65.79, 61.95, 58.23, 55.01, 53.25, 52.68, 53.50, 54.96, 56.73, 57.12, 55.53, 53.59, 49.97, 46.42, 43.30, 39.75, 35.81, 32.90, 31.75, 33.79, 38.40, 43.42, 47.66, 50.69, 53.78, 56.54, 58.99, 61.15, 62.66, 63.75, 64.85, 66.10, 67.34, 68.67, 69.69, 70.47, 71.23, 72.02, 72.86, 73.77, 74.76, 75.74, 76.66, 77.31, 78.03, 78.39, 78.81, 79.25, 79.78, 80.21, 80.79, 80.93, 80.74, 80.31, 79.90, 79.53, 79.17, 79.20, 78.81, 78.21, 77.59, 76.90, 76.23, 75.79, 74.97, 74.16, 73.59, 73.30, 73.25, 73.15, 73.18, 73.49, 74.07, 74.85, 75.71, 76.59, 77.68, 78.72, 79.19, 78.98, 77.93, 76.37, 74.54, 73.06, 71.52, 69.69, 66.82, 62.97, 57.36, 50.90, 43.90, 37.18, 31.30, 26.81, 24.57, 24.93, 27.79, 31.80, 35.69, 38.33, 39.72, 41.31, 43.75, 46.01, 48.21, 50.06, 50.74, 50.88, 50.83, 49.27, 46.92, 43.30, 39.57, 36.36, 34.20, 32.66, 32.67, 33.03, 33.98, 36.57, 39.62, 42.79, 46.20, 49.03, 50.50, 51.12, 50.43, 48.45, 45.55, 43.06, 41.55, 40.44, 38.55, 36.05, 33.15, 30.63, 28.22, 24.82, 20.19, 15.46, 10.70, 8.13, 6.99, 6.57, 7.29, 7.90, 8.66, 10.25, 11.54, 12.57, 12.38, 11.38, 10.78, 10.08, 9.79, 9.65, 8.57, 7.75, 7.63, 8.13, 8.09, 7.00, 4.80, 2.41, 1.25, 0.97, 0.60, 0.36, 0.05, 0.00, 0.00, 0.00, 0.00, 0.00, 0.00, 0.00, 0.02, 1.26, 3.70, 7.47, 11.64, 15.14, 17.17, 17.68, 17.50, 17.37, 17.44, 17.61, 17.22, 16.56, 16.13, 15.56, 14.90, 14.31, 14.02, 14.58, 16.12, 18.23, 21.06, 24.63, 28.69, 32.55, 35.51, 37.34, 38.76, 40.06, 41.19, 41.72, 41.85, 42.19, 43.60, 46.24, 49.60, 53.10, 56.36, 59.21, 61.56, 63.52, 65.22, 66.94, 68.81, 70.83, 72.84, 74.79, 76.61, 78.35, 79.97, 81.42, 82.69, 83.83, 84.88, 85.75, 86.40, 86.84, 87.08, 87.15, 87.19, 87.25, 87.50, 87.97, 88.60, 89.25, 89.80, 90.23, 90.52, 90.80, 91.13, 91.54, 91.95, 92.32, 92.58, 92.76, 92.85, 92.89, 92.84, 92.78, 92.71, 92.62, 92.53, 92.46, 92.41, 92.39, 92.40, 92.29, 92.12, 91.93, 91.78, 91.68, 91.72, 91.74, 91.72, 91.70, 91.63, 91.52, 91.36, 91.07, 90.68, 90.26, 89.84, 89.49, 89.22, 89.13, 89.37, 90.01, 90.66, 90.96, 90.69, 89.92, 88.90, 87.95, 87.06, 86.32, 85.89, 85.87, 86.14, 86.60, 87.12, 87.60, 88.15, 88.69, 89.14, 89.49, 89.72, 89.75, 89.76, 89.71, 89.69, 89.79, 89.90, 89.96, 89.95, 89.86, 89.75, 89.65, 89.54, 89.46, 89.28, 89.00, 88.67, 88.33, 88.03, 87.73, 87.36, 86.87, 86.13, 85.26, 84.25, 82.85, 80.95, 78.63, 75.84, 73.20, 71.07, 69.46, 68.40, 67.86, 67.67, 67.83, 68.06, 68.08, 67.59, 66.53, 64.91, 62.74, 59.77, 56.15, 52.38, 49.06, 46.69, 45.38, 44.79, 44.58, 44.66, 44.81, 45.01, 45.23, 45.64, 46.28, 47.23, 48.38, 49.59, 50.58, 51.09, 50.59, 48.90, 46.17, 42.76, 39.24, 36.37, 34.52, 33.55, 33.65, 34.72, 36.55, 38.80, 41.47, 44.08, 46.67, 48.96, 50.76, 51.56, 51.67, 51.45, 51.07, 50.49, 49.79, 48.94, 48.28, 48.13, 48.54, 49.26, 49.77, 49.98, 50.04, 50.09, 50.17, 50.24, 49.81, 48.78, 47.22, 44.98, 42.03, 38.97, 35.87, 33.29, 31.67, 30.56, 29.77, 29.41, 29.05, 28.88, 29.04, 29.29, 29.50, 29.62, 28.82, 27.53, 26.39, 26.27, 27.53, 30.09, 32.80, 35.42, 37.68, 39.64, 41.46, 43.16, 44.70, 46.04, 47.23, 48.29, 49.34, 50.35, 51.10, 51.44, 51.13, 50.30, 49.12, 47.78, 46.54, 45.73, 45.06, 44.35, 43.37, 41.85, 39.99, 38.08, 36.03, 33.84, 31.71, 29.55, 27.53, 25.61, 23.58, 21.88, 20.34, 19.00, 17.98, 16.27, 13.58, 9.62, 5.25, 1.77, 0.04, 0.00, 1.65, 6.00, 10.13, 15.77, 21.86, 27.82, 33.22, 37.71, 40.68, 44.85, 49.80, 55.38, 60.26, 63.57, 67.30, 69.10, 69.53, 72.03, 75.46, 79.49, 83.73, 86.13, 86.97, 88.25, 88.66, 87.70, 85.83, 83.97, 82.68, 80.79, 75.41, 66.81, 55.73, 45.77, 39.60, 33.75, 27.63, 21.75, 16.34, 14.47, 17.45, 21.53, 24.89, 24.96, 22.22, 18.82, 17.16, 16.97, 17.38, 16.56, 14.33, 11.79, 9.21, 7.03, 5.97, 5.33, 5.33, 6.00, 6.38, 5.98, 4.82, 3.34, 2.42, 2.30, 2.51, 2.86, 2.56, 1.85, 0.97, 0.15, 0.00, 0.00, 0.00, 0.00, 0.00, 0.00, 0.00, 2.06, 5.87, 9.54, 11.10, 9.75, 7.61, 7.06, 9.22, 13.72, 18.53, 21.03, 20.19, 16.31, 10.87, 5.53, 2.54, 2.60, 5.96, 12.17, 19.69, 26.44, 32.30, 37.29, 41.64, 45.51, 48.86, 51.81, 54.36, 56.60, 58.67, 60.68, 62.63, 64.55, 66.37, 68.07, 69.66, 71.21, 72.73, 74.20, 75.69, 77.10, 78.47, 79.77, 80.82, 81.38, 81.34, 80.56, 79.21, 77.84, 76.93, 76.76, 77.18, 77.85, 78.32, 78.59, 78.66, 78.71, 78.71, 78.73, 78.65, 78.36, 77.72, 77.00, 76.54, 75.69, 73.86, 70.84, 66.77, 62.38, 58.38, 54.42, 50.74, 47.98, 46.47, 46.33, 47.06, 48.09, 49.24, 49.75, 49.53, 48.71, 47.64, 46.78, 46.60, 46.63, 46.77, 46.88, 46.78, 46.33, 45.56, 44.64, 43.28, 41.35, 38.31, 33.68, 28.51, 25.01, 23.54, 23.42, 23.54, 22.70, 21.74, 22.29, 24.20, 26.82, 29.76, 32.49, 35.14, 37.58, 39.51, 40.94, 41.74, 42.05, 42.02, 41.80, 41.50, 41.18, 40.86, 40.72, 40.73, 40.96, 41.31, 41.68, 42.06, 42.43, 42.82, 43.08, 43.19, 43.22, 43.11, 42.94, 42.83, 42.74, 42.73, 42.94, 43.19, 43.48, 43.55, 43.49, 43.18, 42.83, 42.73, 42.61, 42.10, 41.43, 40.75, 40.83, 41.93, 43.75, 45.79, 47.65, 49.21, 50.57, 51.53, 52.13, 51.75, 50.67, 49.54, 48.86, 48.57, 47.95, 46.00, 43.20, 40.99, 40.47, 42.01, 44.94, 48.30, 51.23, 53.40, 54.78, 55.57, 56.12, 56.68, 57.26, 57.78, 58.42, 59.18, 60.08, 61.11, 62.09, 63.05, 63.94, 64.70, 65.31, 65.71, 65.85, 66.07, 65.61, 64.17, 62.29, 60.13, 57.69, 55.68, 53.50, 51.26, 49.49, 48.15, 46.93, 46.16, 45.66, 45.38, 45.28, 45.10, 44.82, 44.53, 44.51, 44.53, 44.01, 42.69, 40.95, 39.28, 38.25, 37.52, 36.43, 34.70, 32.51, 29.62, 26.25, 23.39, 21.80, 21.57, 22.66, 23.78, 23.34, 21.63, 18.85, 15.54, 12.44, 9.07, 5.29, 3.04, 2.85, 4.09, 5.68, 5.90, 4.67, 3.76, 3.24, 2.76, 2.06, 1.15, 0.30, 0.00, 0.44, 3.34, 8.42, 15.01, 21.47, 26.84, 31.44, 35.06, 37.78, 39.68, 40.35, 40.38, 40.50, 41.01, 42.01, 43.38, 44.60, 45.62, 46.43, 47.14, 47.85, 48.61, 49.36, 50.11, 50.68, 50.99, 51.21, 51.24, 51.35, 51.70, 52.56, 54.19, 56.66, 59.45, 62.45, 65.06, 67.44, 69.86, 72.31, 74.52, 76.12, 76.81, 76.66, 75.97, 75.15, 74.49, 74.14, 74.13, 74.28, 74.52, 74.81, 74.85, 74.57, 74.17, 73.66, 73.25, 73.04, 72.96, 72.99, 73.30, 73.78, 74.45, 75.12, 75.90, 76.64, 77.40, 78.21, 78.96, 79.31, 79.26, 79.06, 78.59, 77.22, 74.30, 68.99, 61.38, 53.82, 47.53, 43.69, 42.28, 42.22, 42.44, 43.05, 43.45, 43.87, 44.34, 45.04, 46.02, 47.17, 48.02, 48.07, 47.04, 45.03, 42.32, 39.43, 37.11, 36.04, 35.83, 35.93, 35.99, 35.75, 35.64, 35.85, 36.13, 36.31, 36.73, 37.02, 37.04, 36.42, 35.05, 33.29, 31.53, 28.52, 23.67, 18.28, 14.28, 13.44, 15.99, 19.91, 22.73, 23.77, 23.06, 20.54, 16.19, 10.53, 0.00