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Development of a Trace-Based Driving Cycle for Doha Using Real-World Data

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Abstract. The rapid expansion of anthropogenic infrastructure has increased commuting distances and patterns, particularly in countries like Qatar where personal vehicles dominate transportation. This trend has contributed to traffic congestion. This study introduces a Doha Driving Cycle (DC) to facilitate a tool that can be used to analyze various aspects of vehicle performance, including tailpipe emissions. The DC is developed using real-world data collected from vehicles equipped with on-board diagnostics devices. This data was meticulously processed and filtered before employing the microtrip approach to construct the driving cycle. Two distinct driving cycles were created to reflect seasonal variations in Doha's driving patterns: one for the summer, characterized by greater variability in speed and acceleration, and one for the winter, marked by speeds with low variance. The resulting driving cycles reveal significant deviations from the Worldwide Harmonized Light Vehicles Test Cycle (WLTC), underscoring the necessity of creating site-specific driving cycles for accurate environmental and performance assessments in Doha.

Keywords. Driving Cycle, microtrip, vehicle driving pattern

1. Introduction

Driving cycles (DCs) consist of a series of speed-time data points that concisely represent driving behavior in a specific geographical area. This representation is crucial for traffic management and emissions analysis. Notable examples include the New European Driving Cycle (NEDC), Japan's 10-15 mode (JP1015) and JC08 cycle, as well as the USA's US06 and the World Harmonized Light Vehicle Test (WLTP) [1–6].

DCs vary depending on factors such as driving patterns, road conditions, and congestion levels, leading to differences across countries, states, and cities. Consequently, many DCs have been developed for specific geographical locations. Cities like Athens, Bangalore, Beijing, Edinburgh, Hamburg, Hong Kong, Los Angeles, Singapore, and Tehran have created their own DCs, and countries such as Kuwait and Abu Dhabi have developed national DCs [7–14]. Although some DCs might show similar trends under high-traffic conditions, others can differ significantly. For example, DCs from Kuwait and Athens differ considerably, with Kuwait exhibiting an average speed 2.2 times higher than Athens (47.5 km/h vs. 21.2 km/h).

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In addition to localized approaches, a Worldwide Harmonized Light Duty Test Cycle (WLTC) has been developed to integrate real-life data from the European Union (EU), USA, Korea, Japan, and India [15,16]. While these models are often studied individually, several studies have compared multiple driving cycles. For instance, one study comparing over 30 DCs found that local and standard driving cycles could exhibit deviations of 12.5% and 28.6%, respectively, compared to the USA's FTP-75 and the WLTC-3, highlighting the importance of developing localized DCs that reflect specific conditions [7].

There are various methods for generating a driving cycle, with the microtrip-based approach and the Markov analysis method being the most common [17,18]. The Markov method employs stochastic modeling, while the microtrip approach relies on real-world driving data collected via onboard measurements. The Markov approach allows for the generation of multiple scenarios and diverse driving cycles, whereas the microtrip approach captures realistic driving patterns and accounts for factors such as congestion and road diversions due to construction or repairs [19].

Besides traffic control applications, DCs are also used to estimate a vehicle's driving range, fuel economy, and emissions. Estimating emissions is particularly significant given the countries' emission reduction goals (e.g Qatar's 3.6 Mt CO_2eq by 2030), and developing driving cycles can aid in decision-making processes [20]. This is especially relevant for nations with a high reliance on personal vehicles, which account for up to 65% of the modal split in transportation compared to just 9% for public transport [21].

Considering the variability of DCs and the deviations of standard driving cycles (SDCs), this study aims to develop Doha's first driving cycle using the microtrip approach based on real-world measurements. This approach addresses a gap in the WLTC, as it does not include Middle Eastern conditions in its development. Additionally, the study will highlight seasonal variations in driving patterns by creating winter and summer DCs, demonstrating how driving patterns and vehicle congestion shift affect travel behavior modeling.

2. Motivation

Qatar, a small country with an area of 11,637 km^2, is divided into eight municipalities, with Doha, the capital, being the most densely populated. Doha houses approximately 42% of the nation's population, totaling around 2.9 million people [22,23]. The country relies heavily on personal vehicles, which account for about 65% of transportation preferences [21]. Doha's urban area spans approximately 50 km in length and 40 km in width. The city is well-connected by numerous highways and ring roads, ensuring efficient traffic flow and short travel times. However, traffic patterns in Doha vary both spatially and temporally, influenced by factors such as the seasonal departure of expatriates during school breaks. Despite these variations, there is currently no driving cycle that accurately represents Doha's unique characteristics. Therefore, this study aims to develop a driving cycle specifically for Doha to capture and illustrate the city's distinct driving patterns.

3. Methodology

3.1. Data Gathering and Processing

To develop this study, four years of data is used—comprising of odometer speed and distance traveled—collected from seven vehicles equipped with high-resolution GPS. These vehicles were driven by regular volunteers during their routine activities. Detailed information about the data collection process can be found in [24]. The data was gathered remotely using on-board diagnostics (OBD) devices connected via cellular networks (see Figure 1). The devices transmitted data every 3 minutes when the car was stationary and every 10-20 seconds while moving, as detected by the accelerometer, allowing for the capture of trips. For this study, we primarily used data from one year because traffic patterns from 2020 to 2022 were atypical due to intermittent lockdowns related to the global pandemic and the FIFA Football World Cup.

After data gathering and preprocessing, trips are filtered by combining consecutive trips with a time gap of less than 2 minutes into a single trip and discarding those with a travel distance of less than 2 km. Additionally, because the OBD devices do not transmit speed at fixed intervals but only when changes exceed a specified tolerance, interpolation is performed between 5-second timestamps. Subsequently, a Savitzky-Golay smoothing filter is applied to the interpolated data. Finally, the trips are segmented into a sequence of microtrips, which are defined as the intervals between consecutive idle points.

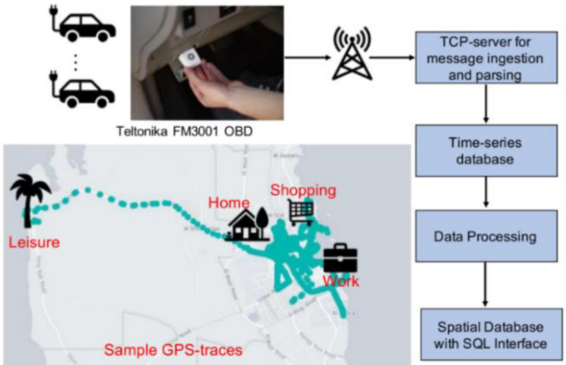

Figure 1. Data acquisition overview [24]

Additionally, once the smoothing filter is applied, downstream tasks such as clustering are performed. To facilitate this, features listed in Table 1 are extracted from the microtrips.

Table 1. Features extracted from microtrips

Feature	Description
Trip-duration	Microtrip duration calculated in seconds
Avg-acc	Average acceleration
Max-acc	Maximum acceleration
Min-acc	Minimum acceleration
Std-acc	Acceleration's standard deviation
Std-speed	Speed's standard deviation
Trip-distance	Distance travelled in the microtrip
Number_of_peaks	Number of peaks in the microtrip

Spd_100_plus	Duration in seconds where the car has been above 100 km/h
Spd_80_plus	Duration in seconds where the car has been above 80 km/h
Spd_60_plus	Duration in seconds where the car has been between 50 and 70 km/h.
Median_speed_cruise	Duration in seconds where the car is within ±10 km/h of the trip's median speed.
Active_time	Amount of time the car has been moving
Idle_time	Amount of time the car has been idle
Relative positive acceleration	This is the integral of vehicle speed multiplied by the time interval and positive acceleration divided by total distance.

3.2. Driving Cycle Construction

The driving cycle is constructed using the microtrip approach, a widely used method in the literature for constructing driving cycles. The approach can be summarized as follows:

- Obtain trip data from the real dataset--this step processes the raw data into distinct trips.
- Identify idle points--determine instances of no movement throughout the trip.
- Extract microtrips--define regions of movement between consecutive idle points, known as microtrips.
- Extract features from microtrips--analyze the microtrips to derive relevant features. The features are listed in Table 1.
- Cluster the features--perform clustering on the extracted features and plot the inertia of the clusters. The K-means algorithm is used for this purpose.
- Determine the ideal number of clusters- Use the elbow method to identify the optimal number of clusters.
- Select representative microtrips--for each cluster, extract the microtrip closest to the cluster center.
- Repeat the microtrips--repeat each microtrip according to the pattern defined by Equation (1), where N_{rc} represents the number of repetitions for each cluster pattern.

$$\mathbb{N}_{rc} = \frac{(phase\ duration - average\ idling\ duration)}{(average\ short\ trip\ duration + average\ idling\ duration)} \tag{1}$$

4. Results and Discussion

4.1. Doha's Winter Driving Cycle

For the winter driving cycle, data from September 1st to January 1st is analyzed. This time range is chosen to reflect periods of increased congestion in Doha, primarily due to the academic year and a noticeable drop in temperature.

During this period, elevated speeds are relatively uncommon. As shown in Figure 2, speed density is higher at lower speeds, particularly within the 10 to 30 km/h range, indicating that traffic congestion limits higher speeds.

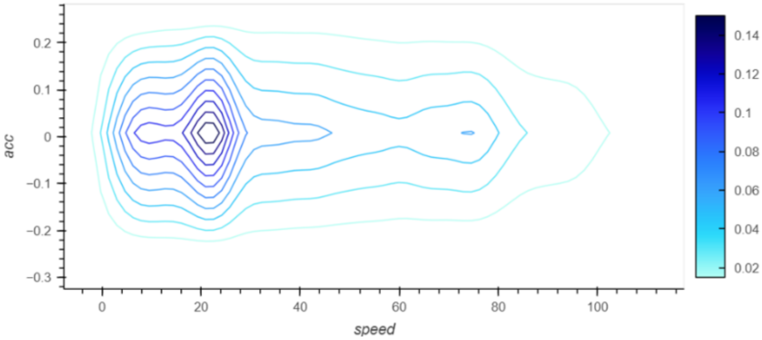

Figure 2. Doha's winter speed-acceleration density plot

To develop the driving cycle, three phases are identified through visual analysis of the clusters: low (0–20 km/h), medium (21–60 km/h), and high speed (>60 km/h). Figure 3 illustrates Doha's winter driving cycle, where it is evident that medium speed sections are the most prevalent, accounting for approximately 55% of the cycle, while low speed sections make up the smallest proportion at 16%.

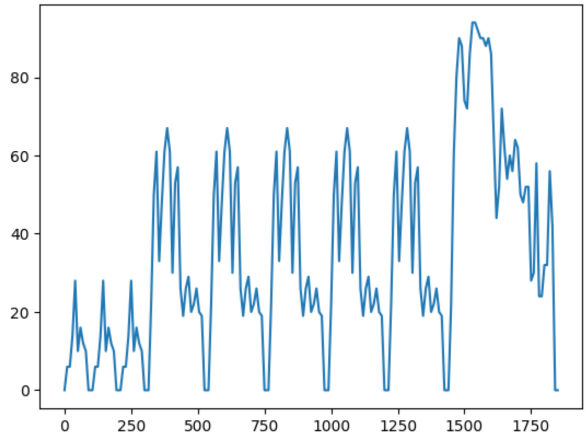

Figure 3. Doha's winter Driving Cycle

4.2. Doha's Summer Driving Cycle

The summer driving cycle is developed using data from June to August. Unlike winter, this period experiences less traffic congestion due to a decrease in population and school vacations. Figure 4 shows that the acceleration/speed density is more distributed compared to winter, indicating an increase in both acceleration and speed. This behavior aligns with the reduced traffic congestion during this season.

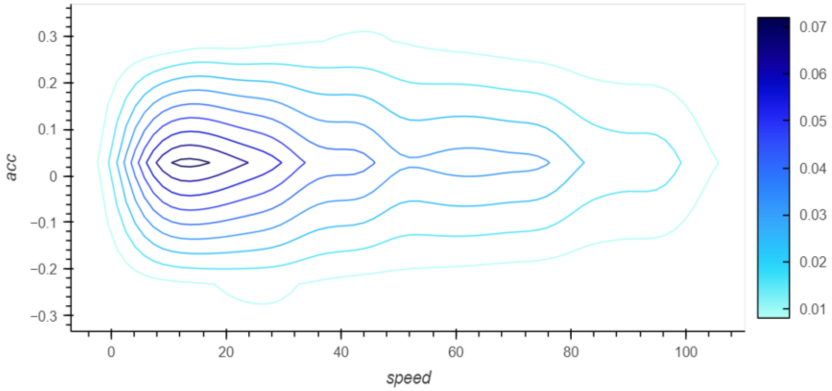

Figure 4. Doha's summer speed-acceleration density plot

The same clustering approach used for the winter driving cycle was applied to create the summer driving cycle, as illustrated in Figure 5. In the summer cycle, low speed sections account for 17% of the cycle, while medium speed sections decrease to 51%. Additionally, there is a longer duration of higher speeds, reflecting the reduced traffic congestion during this period.

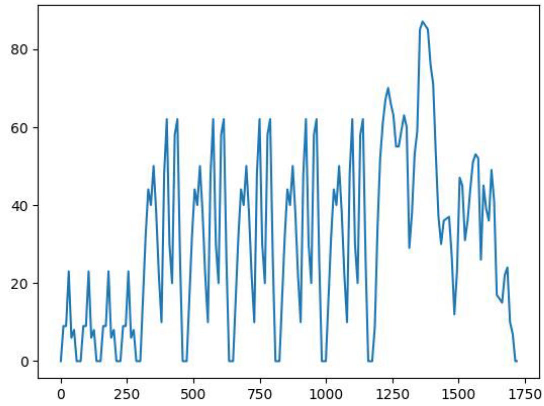

Figure 5. Doha's Summer Driving Cycle

4.3. Driving Cycles Comparison

In greater detail, various parameters are compared between the winter and summer driving cycles, as shown in Table 2. The results reveal noticeable differences in the speed-acceleration distribution graphs for each season. Specifically, the relative positive acceleration (rpa) value for the winter cycle is higher than that of the summer cycle, while acceleration and speed standard deviation show slightly more variation in the summer cycle. These findings underscore the importance of developing seasonal driving cycles to accurately reflect the changes in driving behavior between winter and summer.

Table 2. Parameter comparison between Doha winter and summer DC

Parameters	Winter Driving Cycle	Summer Driving Cycle
Negative Acceleration (m/s^2)	-0.19	-0.22
Acceleration-std	0.23	0.27
Positive Acceleration (m/s^2)	0.21	0.23
Speed-std	0.23	0.27
Average speed (km/h)	34	31
Max speed (km/h)	94	87
Relative positive acceleration	15%	13.7%

4.4. Driving Cycles Comparison with WLTC

Standardized driving cycles offer an aggregated estimate of driving parameters across different countries and throughout the year. However, because they account for many trends to create a generalized profile, they often lose specificity, which can lead to discrepancies with actual driving behavior. This loss of precision is significant, as these driving cycles are used for purposes such as emission calculations, where any inaccuracies can result in either underestimations or overestimations.

Table 3 reflects differences between a standard WLTC and the Doha's winter DC. The latter's rpa is lower while the average speed and acceleration is also lower than that of the WLTC. Considering all the differences, it can be said that the WLTC is not representative for the city of Doha

For comparison purposes, we also include the parameters of a regional driving cycle [14]. The Abu Dhabi driving cycle for peak traffic period shows signs of similarity with Doha with all available parameters appearing similar. However, the Abu Dhabi study is limited in scale since the author only considered two roads with relatively small trips and at selected times. The methodology used for cycle construction is also different and we can also observe that not all parameters are available for comparison.

Table 3. Comparison between Doha's winter driving cycle, the WLTC and Abu Dhabi driving cycle

Parameters	Doha Driving Cycle Winter	WLTC	Abu Dhabi Driving Cycle
Average Speed (Km/h)	35	46.5	35.6
Average Running Speed (Km/h)	38	53.48	-
Max Speed (km/h)	94	131.3	-
Average Positive Acceleration (m/s^2)	0.2	0.62	0.21
Average Negative Acceleration (m/s^2)	0.19	−0.66	0.18
Max Acceleration (m/s^2)	0.7	1.66	-
Min Deceleration (m/s^2)	-0.62	−1.5	-

RPA	15%	23.8%	-
Trip Distance (km)	18	23.3	2.39

5. Conclusions

Doha is a rapidly evolving city characterized by constant expansion, and the constructed driving cycle reflects this growth. During the summer, high speeds, account for 10% of the driving cycle. Medium speeds, indicative of congestion or roads with low speed limits, cover 46% of the cycle. In winter, the driving cycle shows an increase in average speed and decrease in standard deviation indicating a relatively more consistent speed pointing towards increased congestion.

This study underscores the importance of developing city-specific driving cycles to accurately represent actual travel behavior. Specifically, Doha's driving cycle exhibits lower speeds compared to the WLTC. Additionally, analyzing seasonal driving patterns provides more detailed insights, which can be valuable for optimizing routing or developing road infrastructure based on the most congested scenarios.

References

[1] Wang Z, Zhang J, Liu P, Qu C, Li X. Driving Cycle Construction for Electric Vehicles Based on Markov Chain and Monte Carlo Method: A Case Study in Beijing. Energy Procedia 2019;158:2494–9. https://doi.org/10.1016/J.EGYPRO.2019.01.389.

[2] Hung WT, Tong HY, Lee CP, Ha K, Pao LY. Development of a practical driving cycle construction methodology: A case study in Hong Kong. Transp Res D Transp Environ 2007;12:115–28. https://doi.org/10.1016/J.TRD.2007.01.002.

[3] Institute for Environment and Sustainability. Regulated emissions of a Euro 5 passenger car measured over different driving cycles n.d.

[4] Bhatti AHU, Kazmi SAA, Tariq A, Ali G. Development and analysis of electric vehicle driving cycle for hilly urban areas. Transp Res D Transp Environ 2021;99:103025. https://doi.org/10.1016/J.TRD.2021.103025.

[5] Van Berkel K, Hofman T, Vroemen B, Steinbuch M. Optimal energy management for a flywheel-based hybrid vehicle. Proceedings of the American Control Conference 2011:5255–60. https://doi.org/10.1109/ACC.2011.5990820.

[6] US EPA. Dynamometer Drive Schedules n.d. https://www.epa.gov/vehicle-and-fuel-emissions-testing/dynamometer-drive-schedules (accessed July 18, 2024).

[7] De Andrade GMS, De Araújo FWC, De Novaes Santos MPM, Magnani FS. Standardized Comparison of 40 Local Driving Cycles: Energy and Kinematics. Energies 2020, Vol 13, Page 5434 2020;13:5434. https://doi.org/10.3390/EN13205434.

[8] Esteves-Booth A, Muneer T, Kirby H, Kubie J, Hunter J. The measurement of vehicular driving cycle within the city of Edinburgh. Transp Res D Transp Environ 2001;6:209–20. https://doi.org/10.1016/S1361-9209(00)00024-9.

[9] Zhao X, Zhao X, Yu Q, Ye Y, Yu M. Development of a representative urban driving cycle construction methodology for electric vehicles: A case study in Xi'an. Transp Res D Transp Environ 2020;81:102279. https://doi.org/10.1016/J.TRD.2020.102279.

[10] Hung WT, Tong HY, Lee CP, Ha K, Pao LY. Development of a practical driving cycle construction methodology: A case study in Hong Kong. Transp Res D Transp Environ 2007;12:115–28. https://doi.org/10.1016/J.TRD.2007.01.002.

[11] Ho SH, Wong YD, Chang VWC. Developing Singapore Driving Cycle for passenger cars to estimate fuel consumption and vehicular emissions. Atmos Environ 2014;97:353–62. https://doi.org/10.1016/J.ATMOSENV.2014.08.042.

[12] Mafi S, Kakaee A, Mashadi B, Moosavian A, Abdolmaleki S, Rezaei M. Developing local driving cycle for accurate vehicular CO2 monitoring: A case study of Tehran. J Clean Prod 2022;336:130176. https://doi.org/10.1016/J.JCLEPRO.2021.130176.
[13] Otkur M, Doust M. Kuwait Driving Cycle Generation Using Micro-Trip Combination Optimization Method Based on WLTC n.d.
[14] Al Zaidi A. Driving cycles as the tool to assess traffic demand management in Abu Dhabi. International Journal of Innovation and Knowledge Management in Middle East and North Africa 2013;2:157–72. https://doi.org/10.47556/J.IJIKMMENA.2.2.2013.3.
[15] Tutuianu M, Bonnel P, Ciuffo B, Haniu T, Ichikawa N, Marotta A, et al. Development of the World-wide harmonized Light duty Test Cycle (WLTC) and a possible pathway for its introduction in the European legislation. Transp Res D Transp Environ 2015;40:61–75. https://doi.org/10.1016/J.TRD.2015.07.011.
[16] Tutuianu M, Marotta A, Steven H, Ericsson E, Haniu T, Ichikawa N, et al. Development of a World-wide harmonized Light duty driving Test Cycle (WLTC) 2013.
[17] Peng J, Jiang J, Ding F, Tan H. Development of Driving Cycle Construction for Hybrid Electric Bus: A Case Study in Zhengzhou, China. Sustainability 2020, Vol 12, Page 7188 2020;12:7188. https://doi.org/10.3390/SU12177188.
[18] Wang L, Ma J, Zhao X, Li X. Development of a typical urban driving cycle for battery electric vehicles based on kernel principal component analysis and random forest. IEEE Access 2021;9:15053–65. https://doi.org/10.1109/ACCESS.2021.3052820.
[19] Nouri P, Morency C. Evaluating Microtrip Definitions for Developing Driving Cycles. Https://DoiOrg/103141/2627-10 2017;2627:86–92. https://doi.org/10.3141/2627-10.
[20] Ministry of Municipality and Environment. Qatar National Climate Change Action Plan - 2030. 2021.
[21] International Association of Public Transport (UITP). MENA Transport Report 2020/2021. 2021.
[22] National Planning Council. National Planning Council Home Page 2024. https://www.psa.gov.qa/en/Pages/default.aspx (accessed July 22, 2024).
[23] Planning and Statistics Authority. Qatar in Figures 38th Issue (2023). 2024.
[24] Zafar U, Bayram IS, Bayhan S, Jovanovic R. Analysis of GPS-based High Resolution Vehicle Mobility Data towards the Electrification of Transportation in Qatar. IECON Proceedings (Industrial Electronics Conference) 2022;2022-October. https://doi.org/10.1109/IECON49645.2022.9968586.