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Definition of a Typical Driving Cycle of an electric taxi in an Andean city

Definición de un Ciclo Típico de Conducción de un taxi eléctrico en una ciudad Andina

Jairo Castillo-Calderón [1]*, Daniel Cordero-Moreno [2], Efrén Esteban Fernández-Palomeque [2], Byron Agustín Solórzano-Castillo [1], Pablo Rafael Jaramillo-Merino [1]

[1]eX-MoVeT, Grupo de Investigación, Facultad de la Energía, las Industrias y los Recursos Naturales no Renovables, Universidad Nacional de Loja. Avenida Pio Jaramillo Alvarado y Reinaldo Espinosa. C. P. 110103. Loja, Ecuador.
[2]ERGON, Centro de investigación y desarrollo en ingeniería automotriz, Facultad de Ciencia y Tecnología, Universidad del Azuay. Av. 24 de Mayo y Hernán Malo, C. P. 010204, Cuenca, Ecuador.

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ABSTRACT: This research aims to define a Typical Driving Cycle (TDC) of an electric taxi in Loja, Ecuador, an intermediate Andean city, considering the unit in service. In the first instance, the speed, taxi positions, current, and battery voltage are acquired in real time through the OBDII port of the KIA SOUL EV, using a data logger device at a sampling rate of 1 Hz. The variables are read and stored using a program code developed in Labview. In addition, the start and end of rides are recorded. The taxi is monitored for a month, and the variable mass of the unit in service is recorded; road gradient effects are considered. Then, based on the fundamental theory of vehicle dynamics, the traction energy consumption of the taxi is obtained using Matlab Simulink; the TDC is defined by applying the Minimum Weighted Differences, whose characteristic parameters are the energies of the different forces opposing the vehicle motion. The vehicle completed 660 rides in the whole month, which is equivalent to an average of 54% of the traction energy; the rest of the energy, the taxi circulated without users. The TDC corresponds to ride 5, on day 11, with a traction energy consumption of 0.57 kWh, being 49.48% associated with inertia resistance.

RESUMEN: Esta investigación tiene como objetivo definir un Ciclo Típico de Conducción (TDC) de un taxi eléctrico en Loja, Ecuador, una ciudad andina intermedia, considerando la unidad en servicio. En primera instancia, la velocidad, posiciones del taxi, corriente y voltaje de la batería se adquieren en tiempo real a través del puerto OBDII del KIA SOUL EV, utilizando un dispositivo registrador de datos a una frecuencia de muestreo de 1 Hz. Las variables se leen y almacenan utilizando un código de programa desarrollado en Labview. Además, se registran el inicio y el final de los viajes. Se realiza el monitoreo del taxi durante un mes, y se registra la masa variable de la unidad en servicio; se consideran los efectos del perfil de pendiente. Aplicando la teoría fundamental de la dinámica vehicular se obtiene, en Matlab Simulink, el consumo de energía de tracción del taxi; el TDC se define aplicando las Diferencias Mínimas Ponderadas, cuyos parámetros característicos son las energías de las diferentes fuerzas que se oponen al movimiento del vehículo. El taxi realizó 660 viajes en todo el mes, lo que equivale a un promedio del 54% de la energía de tracción; el resto de la energía, el taxi circuló sin usuarios. El TDC corresponde al viaje 5, del día 11, con un consumo de energía de tracción de 0,57 kWh, donde el 49,48% está asociado a la resistencia por inercia.

1. Introduction

The transportation sector is one of the most significant contributors to global environmental pollution and greenhouse gas emissions, leading to increased attention from governments worldwide [1, 2]. Given this, the progress of electric vehicles as a sustainable transportation alternative has been significantly promoted [3]. Although electric vehicles offer zero exhaust emissions and high energy efficiency, their range and performance are affected not only by intrinsic factors but also by

* Corresponding author: Jairo Castillo-Calderón
E-mail: jairocastilloc07@gmail.com

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external factors and driving style. In this direction, driving cycles (DC), understood as a time series of vehicle speeds, have been used intensively, among other applications, to estimate polluting emissions and fuel consumption of vehicles operating with thermal engines, evaluate the energy management, range, and estimate the energy consumption of the hybrid and electric vehicle (EV), assess traffic impact and for vehicle powertrain design [4, 5]. DCs can be divided into two categories in terms of application range: standard and non-standard [6]. Government entities involved in the approval of motor vehicles use standard DCs, such as FTP-75, to generally evaluate the fuel/energy consumption and emissions of automobiles. However, these standardized procedures carried out under controlled conditions, such as in a laboratory, do not reflect actual driving behavior, that is, their representativeness of the actual driving pattern in a given city or region [7]. In fact, the characteristics of driving cycles in specific areas are diverse, as they have significant differences in road structure, types of roads and vehicles, traffic conditions, driving culture, geographical characteristics, economic level, and the scale of the city [8]. Hence, the interest in the construction of a non-standard DC, or Typical Driving Cycle (TDC), focused on evaluating the behavior of the vehicle in real driving conditions and the fundamental importance of each region having a TDC [9].

In Ecuador, the deployment of electric vehicles is considerably low. According to the National Institute of Statistics and Censuses [10], in 2020, 637 EVs were registered in the nation, equivalent to 0.027% of the national vehicle fleet, made up of more than 2.3 million motor vehicles. In this sense, from an energy and environmental point of view, the transition from combustion engine vehicles to EV is a great challenge, as well as a great necessity, considering that transportation is the sector that demands the highest energy consumption in the country [11–13]. In the context of promoting the deployment of electric vehicles in the national market, it is imperative to develop research on vehicles that operate with electric propulsion systems, and evaluate their behavior in real-world driving conditions, since they present an opportunity to achieve enormous benefits in the fight against the growing effect of GHGs [14].

Even though the research and standardization process began in the early 1970s, the creation of CDs remains a developing topic in the scientific and technical literature, even more so when applied to EVs. In [15], the Markov chain and Monte Carlo (MCMC) method are used to construct the TDC of an electric vehicle used as a taxi in the city of Xi'an, China; Specifically, a BYD e6 is used. It is concluded that the developed driving cycle provides a reliable basis for the study of the estimation of energy consumption, driving range and equivalent emissions. Similarly, the authors in [6] generate a TDC for passenger EVs using statistics and the Markov chain method in Beijing. The evaluation results show that the developed TDC represents real-world data well and that it can help evaluate and analyze the life cycle of electric vehicles in the urban study area. On the other hand, the authors in [7] monitor a fleet of electric vehicles using a non-invasive data recording system in Florence. The velocity versus time data series were processed for filtering and grouping. The main product of the research is a set of CDs obtained by pseudo-random selection of original data based on microtrips. The similarity of the synthetic DCs with the acquired data has been verified by validating the cycle parameters. The method followed for creating the DCs has been implemented in a software package in Matlab. In [16], a real-world urban driving cycle with a road gradient profile is developed for the hilly urban terrain of Islamabad city. The TDC was constructed using the Markov chain and Monte Carlo method that demonstrated the weights of different types of roads in the geographic area under study. Powertrain simulations were carried out on 24 vehicle models of different vehicle technologies operating in 8 different driving cycles to determine central factors, such as energy consumption, and autonomy, among others. The results indicate that, without the road gradient profile, errors ranging from 10.2 to 22.2% accumulated in the powertrain simulation, in addition to substantial impacts on the factors considered. In [17], a TDC was developed using a driving database of a fleet of electric vehicles over a six-month period in Dublin, Ireland. A stochastic, Markov chain, and statistical methodology are used to develop and evaluate the representativeness of the driving cycle. It is shown that the developed driving cycle consists of the exact proportions of driving conditions in terms of road types and traffic conditions as those observed in real-world operating conditions. The authors conclude that the developed driving cycle would help design electric vehicles that are working, not only in Dublin, but also in urban areas of other medium-sized cities. An optimization-based method for the practical development of a driving cycle for electric vehicle energy management applications in Shenyang, China, is presented in [18]. TDC is determined using a genetic algorithm with a variable number of microtrips. The presented method can achieve a more representative driving cycle that is 2.49% closer to the real data than the traditional Markov chain method.

In the literature consulted, there are no TDC developments applied to EVs that operate as taxis in an Andean region, which can serve as a starting point for future research related to the evaluation of the real driving behavior of these vehicles in this particular orography. Thus, this research aims to define the TDC of an electric taxi, considering the unit in service. For this purpose, the Minimum Weighted Differences of Characteristic

Parameters (MWD-CP) methodology, developed by [19], is used. The research was carried out in Loja, an intermediate Andean city with an urban population of more than 250,000 inhabitants. The city is located at an altitude of 2060 meters above sea level, in the Southern Sierra Region of Ecuador. The contributions of the present work are noteworthy, as they broaden the field of knowledge on electric vehicles in real driving conditions in Andean cities, defining a TDC. In addition, the application of the MWD-CP methodology to estimate the TDC, whose characteristic parameters are the energies of the different forces that oppose the movement of the vehicle, is novel. It is also relevant that the effects of the road gradient are considered for the purpose of weighting the energy consumption and that the smoothing of the slope was performed differently and methodically, starting from the correction of the instantaneous altitude data of the vehicle with the EU 646 standard, shown in [20]. And, finally, the fact that the EV used in this research provides its services as a means of public transport in the taxi mode has not been studied.

The paper is developed as follows: Section II explains the data acquisition method, model, and methodology for defining TDC. The analysis of results is shown in Section III, and finally, Section IV presents the conclusions of the study.

2. Methodology

2.1 Data acquisition method

The electric taxi used in the research is the KIA SOUL EV, whose technical specifications are detailed in Table 1. On the other hand, the experimental scenario comprises the free travel of the electric taxi in the urban area of Loja, Ecuador, located at an average altitude of 2060 meters above sea level. This information was considered in the calculation of air density. Since the vehicle circulates at a higher altitude, the air density would have lower values and, consequently, the air resistance as well. Thus, an air density of 0.88 kg/m^3 was considered. The unit is monitored for one month, in daily workdays, acquiring in real time the speed, geographical variables, current, and battery voltage through the OBDII port of the KIA SOUL EV, using a data logger device, model OBDLink MX+, which includes GPS, at a sampling rate of 1 Hz. The reading and storage of variables is performed with a program code developed in Labview, which was used in previous research [21, 22]. In addition, the initial and final time of each run is recorded, and the number of passengers is counted. This allows obtaining a variable mass of the unit in service. That is, when the taxi circulates without passengers, the value of the mass of the taxi is considered to be the empty weight of the vehicle, which is 1492 kg, plus the weight of the driver which is 70 kg. Whereas, if the taxi circulates with a ride, the mass of the unit will vary according to the number of passengers. NTE INEN 1323:2009, detailed in [23], stipulates that the mass of an occupant is 70 kg. Figure 1 shows the satellite map of the electric taxi route on day 3, with a total of 49,775 monitored data. EU regulation 646 is used to establish the road gradient to be used in the vehicle dynamic model. It considers 4 sequential processes of altitude smoothing and 2 of road gradient smoothing. The smoothing starts by taking the geographical variables of latitude, longitude and instantaneous altitude of the vehicle as starting points. Thus, Figure 2 shows the final smoothing of altitude, where a maximum value of 2,262 masl is highlighted. Meanwhile, Figure 3 shows the final road gradient smoothing, with a maximum value of 0.28 radians, when compared with the road gradient obtained with the GPS Visualizer online application, where the monitored values of latitude and longitude of the vehicle are entered

Table 1 Vehicle specifications

Feature	Specification
Type of motor	AC permanent magnet synchronous
Maximum torque	285 Nm
Maximum power	81.4 kW
Battery type	Lithium-ion polymer
Battery capacity	27 kWh

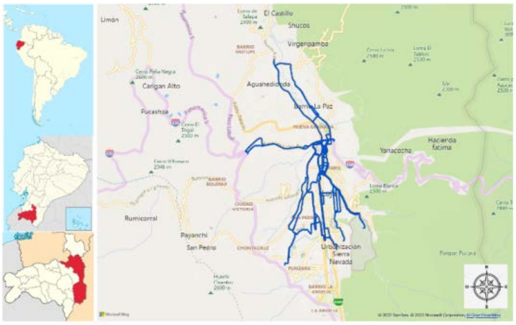

Figure 1 Satellite map of the EV's route on day 3.

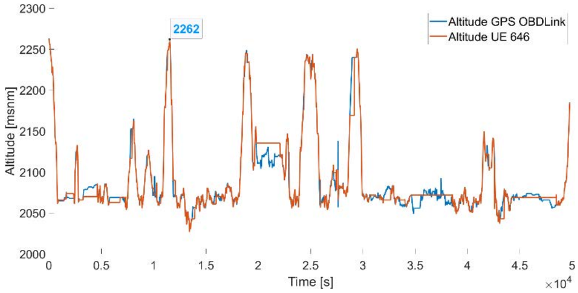

Figure 2 Altitude profile of the EV's route on day 3.

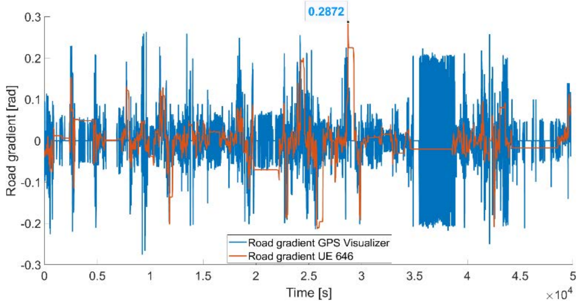

Figure 3 Road gradient of the EV's route on day 3.

2.2 Model

According to Newton's law of motion, the acceleration of the vehicle satisfies the differential Equation 1.

$$m \cdot \frac{dv(t)}{dt} = F_t(t) - F_r(t) \tag{1}$$

Where *Ft* is the traction force that must be provided by the engine to the wheels for the vehicle to move. *Fr* is the sum of the drag forces, and *m* is the total mass of the vehicle, including the rotating parts; *Fr* comprises the rolling resistance force Ff, the aerodynamic drag force *Fd* and the gravitational force related to the vehicle inclination *Fc*. Under this context, and by clearing *Ft*, Equation 1, which represents the equation of longitudinal motion of the vehicle, can be rewritten as indicated by Equation 2; it is to be noted that $m \cdot dv/dt$ has been substituted for the inertial force *Fa*.

$$F_t = F_f + F_c + F_d + F_a \tag{2}$$

The equivalences of the different resistance forces are shown in Equations 3, 4, and 5 below [24].

$$F_f = f_r mg \cos\alpha \tag{3}$$

$$F_c = mg \operatorname{sen}\alpha \tag{4}$$

$$F_d = \frac{1}{2} C_d A \rho_a \left(V_x\right)^2 \tag{5}$$

Where *Vx* is the vehicle speed and α is the road gradient in radians. The terminology used in the previous equations, as well as their values, is detailed in Table 2.

Table 2 Variables of the longitudinal dynamics of the EV

Variable	Description	Value	Unit
f_r	Rolling resistance coefficient	0.017	-
g	Gravity	9.81	m/s^2
C_d	Aerodynamic drag coefficient	0.35	-
A	Frontal area vehicle	2.3	m^2
ρ_a	Air density	0.88	Kg/m^3

The power required for a vehicle traveling at a given speed can be estimated using Equation 6.

$$\begin{aligned} p_x = F_t \cdot V_x = \\ \left(ma + \tfrac{1}{2} C_d A \rho_a V_x^2 + mg \operatorname{sen}\alpha + mg f_r \cos\alpha\right) V_x \end{aligned} \tag{6}$$

On the other hand, the total energy consumption, understood as the total electricity used for a trip, is calculated by integrating the power during the travel time T, as shown in Equation 7.

$$e_x = \int_0^T p(t)dt \tag{7}$$

To calculate the energy demand or consumption, only the positive energy $e_x(+)$, is considered, since it is the one needed to provide traction and move the vehicle [25]. The negative energy is channeled through the regeneration system of the EV. The positive energy from the different forces opposing the motion of the vehicle would be equal to the energy demand or consumption.

2.3 Methodology for defining TDC

The Minimum Weighted Differences of Characteristic Parameters (MWD-CP), a methodology developed by [19], is used to obtain the TDC. The methodology comprises three phases: route selection, driving cycle sampling, and representative cycle selection. The first two phases were already addressed in previous sections of this article. However, it is emphasized that the definition of the TDC focuses specifically on the rides made by the electric taxi during the month. That is, it excludes from this analysis when the taxi circulates without passengers. Regarding the last phase, the objective is to choose among all the sampled rides the one that represents them, expressing each ride in terms of characteristic parameters or performance values. P_{ij} is defined as the value of parameter i obtained for cycle j. First, the arithmetic mean of each parameter, $\bar{P}_i$, is calculated for all the sampled cycles. The second step consists of comparing each characteristic parameter with respect to the mean value of the same parameter for all the sampled cycles, $\left|P_{ij} - \bar{P}_i\right|$, and then summing the differences obtained for each parameter. However, some parameters are more relevant than others. Therefore, the sum of the differences should be weighted according to the relevance of each parameter in determining, for example, the energy demand, as in [26], where the proposed characterization parameters are the energies demanded by the types of loads, and their weight will be the percentage of their contribution to the total energy demand. Finally, as described in Equation 8, the cycle, or ride, with the smallest sum of weighted differences, is selected as representative of all cycles in the sample and, therefore, as the TDC.

$$C = \operatorname{Arg}\left\{\min_j \left(\sum w_i \left|P_{ij} - \bar{P}_i\right|\right)\right\} \tag{8}$$

3. Analysis of Results

3.1 General performance of the electric taxi in its working day

The histogram in Figure 4 represents the frequency distributions of the rides classified by time of day. The electric taxi performed 660 rides in the whole month, comprised between 03:00 am and 19:00 pm. The results show a mean of the set of rides set at 09:25 am. The distribution of the data exhibits a considerable predominance of rides in the morning hours, suggesting higher labor productivity. The first quartile (Q1) indicates that 25% of the rides occur up to the 7 - 8 am interval. The second quartile, Q2, which is the median value, indicates that half of the rides occur up to the 9 - 10 am interval. Q3 states that three quarters of the rides take place up to the 12 - 13 pm interval. Per month, the taxi performed more rides, 75 in total, in the 8 - 9 am time slot, and only one ride in the 6 - 7 pm time slot.

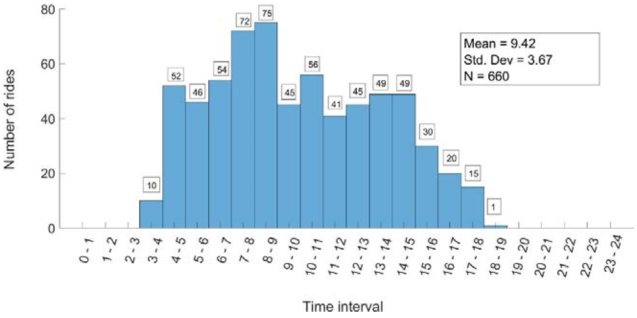

Figure 4 Histogram of rides per hours a day.

On the other hand, the battery energy performance by hours of the day is shown in Figure 5. The electric taxi travels an average of 153 km per day and has an average battery performance of 8.44 km/kWh, showing consistency with the results of [27] for city driving in mild weather without the use of air conditioning. A higher energy performance stands out, that is, 13.41 km/kWh, in the interval from 3 to 4 am, justified by low traffic conditions. On the contrary, there is a lower energy performance, with 3.80 km/kWh, from 6 to 7 pm, as this is a time with more traffic congestion.

Regarding the traction energy $e_x(+)$, a daily average of 54% of it, the taxi circulated with passengers. In other words, almost half of the vehicle's route was without passengers, as shown in Figure 6. This data is of interest to the cab driver in adopting possible strategies to optimize his working day.

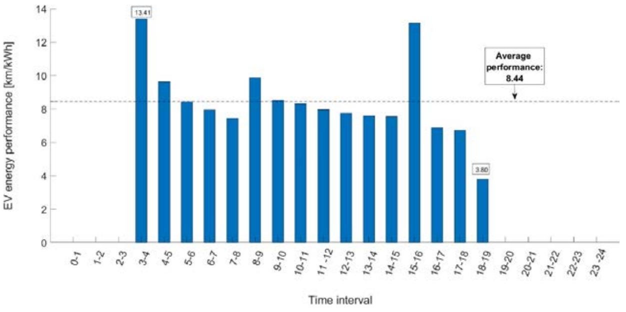

Figure 5 EV's energy performance per hours a day.

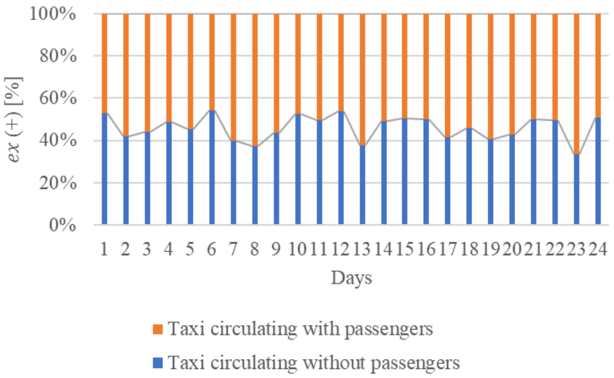

Figure 6 Disaggregation of positive wheel energy by travel condition for the 24 days monitored.

3.2 Definition of the TDC of the electric taxi in race conditions

Table 3 summarizes the results derived from the deterministic MWD-CP methodology. The TDC corresponds to ride 5 of day 11, with a sum of weighted differences of 0.25; the lowest among all the 660 rides. Of the characteristic parameters, the percentage of energy demanded by inertia stands out in first place, with 49.48%, and in last place, the percentage of energy demanded by aerodynamic drag, with 3.48%.

Table 4 shows the parameters related to the TDC, corresponding to ride 5 of day 11. Among them, a ride duration of 9 minutes and 8 seconds is highlighted, where 3.4 km were circulated, with one passenger on board. The high proportion of the acceleration and deceleration state of the built TDC can be associated with traffic congestion conditions in the urban area where the electric taxi circulates [15].

The typical driving cycle constructed for the electric taxi, by the proposed method, is shown in Figure 7. Figure 8 represents the speed-acceleration probability distribution (SAPD) of the established real-world driving cycle. From it, it can be seen that the velocity probability is highest in the range from 0 to 10 km/h, and the acceleration is

Table 3 Traction energy consumption results by rides

Day	Ride	$\%EF_d(+)$	$\%EF_f(+)$	$\%EF_c(+)$	$\%EF_a(+)$	$\sum$
11	5	3.48	27.82	19.22	49.48	0.25

Table 4 TDC Parameters

Parameter	Value	Unit
Total time	548	[s]
Total distance	3.4	[km]
Average speed	22.32	[km/h]
Maximum speed	45	[km/h]
Proportion of idle time	22.40	[%]
Proportion of cruising	16.58	[%]
Proportion of time accelerating	35.88	[%]
Proportion of time decelerating	25.14	[%]

mainly distributed between -0.5 to $0.5 m/s^2$. These results indicate that the electric taxi starts and stops several times, accelerations and decelerations are frequent, and the velocity is low, which is in agreement with the findings of [28]. This driving condition is typical of a vehicle driving in an urban area, where traffic is considerable, and there are many traffic lights.

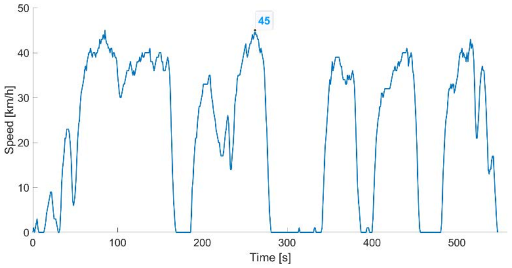

Figure 7 EV's typical driving cycle per rides

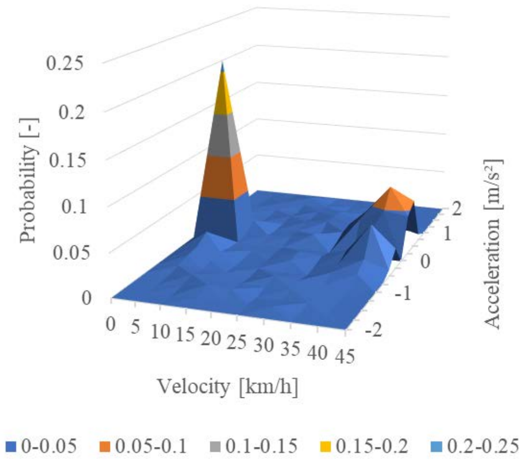

Figure 8 Speed-acceleration probability distribution of the TDC

3.3 Comparison of typical city driving cycles

In this section, nine evaluation parameters of three urban TDCs are compared with the driving cycle developed in this research. This is in order to discuss the similarities and differences between them and evaluate the representativeness of the results obtained in real driving conditions. The EV TDCs for the cities of Xi'an [15], Dublin [17], and Beijing [6] are specifically analyzed. The results of the comparison are shown in Table 5. From the results of the comparison, it is noted that the average acceleration value of the TDC of Loja is lower than the TDC of Xi'an and Dublin. As these last two TDCs experience a wider range of accelerations, it could cause a greater demand for energy consumption to the driving cycle [29]. However, the energy regeneration perceived by the driving cycle must be taken into consideration. The average speed and maximum speed of the TDC of Loja are lower than the TDC of the other cities. This may be associated with the larger size of cities and greater distances to travel, where roads and highways allow higher speeds to be reached. The proportion of acceleration and deceleration states for the driving cycles in the four cities are similar, demonstrating analogous traffic conditions. Finally, similar battery energy consumptions are obtained for the driving cycles of Loja, Dublin, and Beijing. In fact, congruence is observed in the results obtained when comparing the energy consumption of the Loja TDC with that given by the manufacturer in real driving conditions, that is, 0.112 kWh/km [27]. It is noteworthy that the Xi'an TDC turns out to be the least efficient in terms of energy consumption, with a value of 0.239 kWh/km.

4. Conclusions

The purpose of this study was to define a typical driving cycle of an electric taxi in an Andean city, considering the unit in service, that is, while circulating with passengers, using the deterministic methodology MWD-CP. From the results obtained, it is concluded that the electric taxi travels an average of 153 km per day and has an average battery performance of 8.44 km/kWh. It is highlighted that this energy consumption is from the tank to the wheel. The unit made 660 rides in the month, where three quarters of these occurred up to the interval of 12 - 13 pm, suggesting higher work productivity in the morning hours. The TDC corresponds to ride 5 on day 11, with a sum of weighted differences of 0.25, a traction energy consumption of 0.57 kWh and a battery energy consumption of 0.1584 kWh/km. The characteristic parameters used were the energies of

Table 5 Comparison of the results for typical city driving cycles

Parameter	Loja	Xi'an	Dublin	Beijing
Vehicle type	EV	EV	EV	EV
Road type	Urban	Urban	Urban	Urban
Average speed [km/h]	22.32	23.82	30.87	23.96
Maximum speed [km/h]	45	63.86	84.5	69
Average acceleration [m/s²]	0.3930	0.73	0.62	0.3675
Average deceleration [m/s²]	0.4865	0.76	0.64	0.3961
Proportion of idle time [%]	22.40	10.58	20.7	24.41
Proportion of cruising [%]	16.58	27.41	27.6	10.88
Proportion of time accelerating [%]	35.88	29.67	26.7	33.56
Proportion of time decelerating [%]	25.14	32.25	25.0	31.15
Energy consumption (battery) [kWh/km]	0.1584	0.239	0.154	0.1267

the various forces that oppose the movement of the vehicle, where the percentage of energy demanded by inertia had the greatest prominence, with 49.48%. The TDC had a duration of 9 minutes and 8 seconds, where the electric taxi circulated 3.4 km, with a passenger on board. A high proportion of the acceleration and deceleration state of the built TDC was obtained, with 33.88% and 25.14%, respectively, associated with real-world driving conditions in the urban area of the city, where traffic and traffic lights have a predominant role. This also justifies the low speed of the unit, with an average of 22.32 km/h. Through the SAPD diagram, it was identified that the speed probability is higher for the range of 0 to 10 km/h and the acceleration is distributed between -0.5 to $0.5 m/s^2$. Finally, a daily average of 54% of the traction energy, the taxi circulated with passengers. That is, almost half of the vehicle's route was without passengers. This finding is conclusive for the driver to adopt possible strategies to optimize his working day.

Declaration of competing interest

We declare that we have no significant competing interests including financial or non-financial, professional, or personal interests interfering with the full and objective presentation of the work described in this manuscript.

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Author contributions

J. Castillo-Calderón and D. Cordero-Moreno: Conceptualization. J. Castillo-Calderón and D. Cordero-Moreno: Methodology. J. Castillo-Calderón and P. R. Jaramillo-Merino: Data acquisition. B. A. Solórzano-Castillo: Validation. E. E. Fernández-Palomeque: Data curation. J. Castillo-Calderón, D. Cordero-Moreno and E. E. Fernández-Palomeque: Formal analysis. J. Castillo-Calderón and P. R. Jaramillo-Merino: Investigation. All authors have read and agreed to the published version of the manuscript.

Data available statement

The authors confirm that the data supporting the findings of this study are available within the article [and/or] its supplementary materials.

References

[1] X. Zhang, Y. Zou, J. Fan, and H. Guo, "Usage pattern analysis of beijing private electric vehicles based on real-world data," *Energy*, vol. 167, Jan. 2019. [Online]. Available: https://doi.org/10.1016/j.energy.2018.11.005

[2] Y. Zou, S. Wei, F. Sun, X. Hu, and Y. Shiao, "Large-scale deployment of electric taxis in beijing: A real-world analysis," *Energy*, vol. 100, Apr. 2016. [Online]. Available: https://doi.org/10.1016/j.energy.2016.01.062

[3] S. Sharma, A. K. Panwar, and M. M. Tripathi, "Storage technologies for electric vehicles," *J. Traffic Transp. Eng. (English Ed.)*, vol. 7, no. 3, Jun. 2020. [Online]. Available: https://doi.org/10.1016/j.jtte.2020.04.004

[4] H. Achour and A. G. Olabi, "Driving cycle developments and their impacts on energy consumption of transportation," *Journal of Cleaner Production*, vol. 112, no. 2, Jan. 2016. [Online]. Available: https://doi.org/10.1016/j.jclepro.2015.08.007

[5] M. Giraldo, L. F. Quirama, J. I. Huertas, and J. E. Tibaquirá, "The effect of driving cycle duration on its representativeness," *World Electr. Veh. J.*, vol. 12, no. 4, Oct. 2021. [Online]. Available: https://doi.org/10.3390/wevj12040212

[6] H. Gong, Y. Zou, Q. Yang, J. Fan, F. Sun, and D. Goehlich, "Generation of a driving cycle for battery electric vehicles: A case study of beijing," *Energy*, vol. 150, May. 2018. [Online]. Available: https://doi.org/10.1016/j.energy.2018.02.092

[7] L. Berzi, M. Delogu, and M. Pierini, "Development of driving cycles for electric vehicles in the context of the city of florence," *Transportation Research Part D: Transport and Environment*, vol. 47, Aug 2016. [Online]. Available: https://doi.org/10.1016/j.trd.2016.05.010

[8] M. Knez, T. Muneer, B. Jereb, and K. Cullinane, "The estimation of a driving cycle for celje and a comparison to other european cities," *Sustainable Cities and Society*, vol. 11, Feb. 2014. [Online]. Available: https://doi.org/10.1016/j.scs.2013.11.010

[9] G. Wager, J. Whale, and T. Braunl, "Driving electric vehicles at highway speeds: The effect of higher driving speeds on energy consumption and driving range for electric vehicles in australia," *Renewable and Sustainable Energy Reviews*, vol. 63, Sep. 2016.

[10] INEC, "Anuario de estadísticas de transporte 2020," Nov. 2021. [Online]. Available: https://tinyurl.com/y8uy6ya5

[11] J. Díaz and J. Castillo, "Estimación del indicador kilómetro vehículo recorrido (kvr) mediante ecuaciones lineales y sus aplicaciones en consumos energéticos de transporte," *Información Tecnológica*, vol. 32, no. 6, Dec. 2021. [Online]. Available: http://dx.doi.org/10.4067/S0718-07642021000600239

[12] J. C. Sierra, "Estimating road transport fuel consumption in ecuador," *Energy Policy*, vol. 92, May. 2016.

[13] "Balance energético nacional 2020," Ministerio de Energía y Recursos Naturales No Renovables, Aug. 2021. [Online]. Available: https://tinyurl.com/4yhtsevt

[14] M. E. Moeletsi, "Socio-economic barriers to adoption of electric vehicles in south africa: Case study of the gauteng province," *World Electric Vehicle Journal*, vol. 12, no. 167, Sep. 2021. [Online]. Available: https://doi.org/10.3390/wevj12040167

[15] X. Zhao, Y. Ye, J. Ma, P. Shi, and H. Chen, "Construction of electric vehicle driving cycle for studying electric vehicle energy consumption and equivalent emissions," *Environmental Toxicology and Biogeochemistry of Ecosystems*, vol. 27, May. 2020.

[16] A. H. Umar-Bhatti, S. A. Abbas-Kazmi, A. Tariq, and G. Alí, "Development and analysis of electric vehicle driving cycle for hilly urban areas," *Transp. Res. Part D Transp. Environ.*, vol. 99, Oct. 2021. [Online]. Available: https://doi.org/10.1016/j.trd.2021.103025

[17] J. Brady and M. O'Mahony, "Development of a driving cycle to evaluate the energy economy of electric vehicles in urban areas," *Appl. Energy*, vol. 177, Sep. 2016. [Online]. Available: 1https://doi.org/10.1016/j.apenergy.2016.05.094

[18] Z. Chen, Q. Zhang, J. Lu, and J. Bi, "Optimization-based method to develop practical driving cycle for application in electric vehicle power management: A case study in shenyang, china," *Energy*, vol. 186, Nov. 2019. [Online]. Available: https://doi.org/10.1016/j.energy.2019.07.096

[19] J. Huertas, J. Díaz, D. Cordero, and K. Cedillo, "A new methodology to determine typical driving cycles for the design of vehicles power trains," *Int. J. Interact. Des. Manuf.*, vol. 12, Jan. 2017. [Online]. Available: https://doi.org/10.1007/s12008-017-0379-y

[20] R. (UE), "Emisiones procedentes de turismos y vehículos comerciales ligeros," Jan. 2016. [Online]. Available: https://tinyurl.com/3d6dcswb

[21] J. D. Valladolid, D. Patino, G. Gruosso, C. A. Correa-Flórez, J. Vuelvas, and F. Espinoza, "A novel energy-efficiency optimization approach based on driving patterns styles and experimental tests for electric vehicles," *Electronics*, vol. 10, May. 2021.

[22] J. D. Valladolid, R. Albarado, D. Mallahuari, and D. Patiño, "Experimental performance evaluation of electric vehicles (ev) based on analysis of power and torque losses," Feb. 2020. [Online]. Available: https://doi.org/10.1109/ICIT45562.2020.9067241

[23] N. INEN, "Vehículos automotores. carrocerías de buses. requisitos," 2009.

[24] R.-T. Jonas, C. Hunter, and G. Macht, "Quantifying the impact of traffic on electric vehicle efficiency," *World Electr. Veh. J.*, vol. 13, no. 15, 2020. [Online]. Available: https://doi.org/10.3390/wevj13010015

[25] Z. Gao, Z. Lin, T. J. LaClair, C. Liu, J. M. Li, A. K. Birky, and *et al.*, "Battery capacity and recharging needs for electric buses in city transit service," *Energy*, vol. 122, Mar. 2017. [Online]. Available: https://doi.org/10.1016/j.energy.2017.01.101

[26] D. Cordero-Moreno, D. Davalos, M. Coello, and R. Rockwood, "Proposed criteria to determine typical vehicular driving cycles using minimum weighted differences," in *Urban Transport XXIII. WIT Transactions on The Built Environment*, C. Brebbia and S. Ricci, Eds. Southampton: WIT Press, 2017, p. 329–337.

[27] E. Database. Kia e-Soul. [Online]. Available: https://ev-database.org/car/1750/Kia-e-Soul-392-kWh#efficiency

[28] Z. Sun, Z. Wen, X. Zhao, Y. Yang, and S. Li, "Real-world driving cycles adaptability of electric vehicles," *World Electric Vehicle Journal*, vol. 11, no. 1, Feb. 2020. [Online]. Available: https://doi.org/10.3390/wevj11010019

[29] E. G. Giakoumis, *Driving and Engine Cycles*, 1st ed. Cham: Springers, 2017.