DOI:10.34918/87422

Zbigniew CZAPLA[1]

2. TRAVEL PARAMETERS ON URBAN BUS ROUTES INTENDED FOR OPERATION WITH ELECTRIC BUSES PROPELLED BY TRACTION BATTERIES

2.1. Introduction

Collective bus transport is used in many cities. At present, on urban bus routes, increasingly electric buses propelled by traction batteries are utilized. Operation of electric buses causes reduction of exhaust emissions and decreases air pollution in cities, especially in city centres. The main disadvantage in the operation of electric buses propelled by traction batteries is their range which significantly depends on capacity of traction batteries and current energy consumption. When the electric bus is driving, the energy consumption is variable and results from travel parameters. The travel parameters depends on many factors such the topology of a bus route, a height profile along a bus route, ambient temperature, traffic volume, a driving style, timetables, a number of stops, queuing and bunching.

The electric energy consumption of electric vehicles can be predicted[2]. The presented approach is based on statistical models of energy consumption and considers the correlation of electric energy consumption and kinematic parameters of vehicle movement. It is reliable to compare vehicles of the same type propelled by a battery electric engine and an internal combustion engine[3]. The comparison includes energy consumption in various driving scenarios.

---

[1] Silesian University of Technology, Faculty of Transport and Aviation Engineering, Department of Transport Systems, Traffic Engineering and Logistics, Katowice, e-mail: zbigniew.czapla@polsl.pl.

[2] De Cauwer C., Van Mierlo J., Coosemans T.: Energy consumption prediction for electric vehicles based on real-world data, Energies, 2015, Vol. 8, pp. 8573–8593.

[3] Braun A., Rid W.: Energy consumption of an electric and an internal combustion passenger car. A comparative case study from real word data on the Erfurt circuit in Germany, Transportation Research Procedia, 2017, Vol. 27, pp. 468–475.

Automatic location data for bus lines and automated vehicle data for urban areas can be collected and then used to model the travel time and determine its fluctuation[4]. Historical profiles enable the prediction of bus travel time[5]. For the prediction of short term travel time, historical behaviour and current travel time at points of interest are analysed.

GPS data are useful for predicting bus travel time[6]. Travel time is predicted with the use of models based on historical average, Kalman filtering, and artificial neural networks, and then the accuracy and robustness of the analysed models are compered. Machine learning methods are applied for the prediction of bus travel time[7]. Bus travel time and bus speed are predicted on the basis of GPS data and with the use of implemented artificial neural networks, support vector machines, and Bayes networks and then compered. The bus travel time between stations can be predicted using a support vector machine[8]. The prediction of the bus travel time is performed using GPS data and the division of road sections into segments.

The accuracy of GPS data is a complex issue and various methods for improving GPS data inaccuracy are considered and analysed[9]. To improve the inaccuracy of GPS data, reference station networks methods, software algorithms, and perceptive GPS are used.

The bus travel time on urban bus routes can be analysed using GPS data[10]. The considered bus route is divided into two types of sections, stopping sections and running sections. For individual sections and the entire bus route, the stopping and running times are estimated on the basis of GPS data. The assumption of the utilization of GPS data and the division of the urban bus route into stopping and running section also allows for the description of urban bus routes by movement parameters[11]. The stopping sections are described by the stopping time, and for the running sections, the stopping time, the time at constant speed, and the times of acceleration and deceleration are determined.

---

[4] Comi A., Nuzzolo A., Brinchi S., Verghini R.: Bus travel time variability: some experimental evidences, Transportation Research Procedia, 2017, Vol. 27, pp. 101–108.

[5] Cristobal T., Padron G., Quesada-Arencibia A., Alayon F., de Blasio G., Garcia C.R.: Bus travel time prediction model based on profile similarity, Sensors 2019, Vol. 19:2869.

[6] Fan W, Gurmu Z.: Dynamic travel time prediction models for buses using only GPS data, International Journal of Transportation Science and Technology, 2015, Vol. 4, No. 4, pp. 352–366.

[7] Julio N., Giesen R, Lizana P.: Real time prediction of bus travel speeds using traffic shockwaves and machine learning algorithms, Research in Transportation Economics, 2016, Vol. 59, pp. 250–257.

[8] Junyou Z., Fanyu W., Shufeng W.: Application of support vector machine in bus travel time prediction, International Journal of System Engineering, 2018, Vol. 2, No. 1, pp. 21–25.

[9] Thin L.N., Thin L.Y., Husna N.A., Husin M.H.: GPS systems literature: inaccuracy factors and effective solutions, International Journal of Computer Networks & Communication, 2016, Vol. 8, No. 2, pp. 123–131.

[10] Czapla Z., Krawiec S.: GPS data-based estimation of travel time parameters for electric buses, [in:] Stajniak M. et al. (eds): Challenges and modern solution in transportation. Spatium, Radom, 2019, pp. 135–146.

[11] Czapla Z., Krawiec S.: Travel time description for urban routes operated with electric buses, [in:] Rozicka J. (ed.): Smart Cities Symposium Prague. IEEE, 2020.

In the proposed method of determining the travel parameters on urban bus routes, GPS data are used. The considered urban bus route is divided into sections with a uniform structure. For each section and the entire urban bus route, the travel time is determined by assigning the bus speed to the defined speed ranges. The goal of the work is the determination of travel parameters based on GPS data for urban bus routes intended for operation with electric buses propelled by traction batteries. The travel parameters are calculated using the distribution of the speed of the bus along the bus route. The energy consumption of the bus driving on the bus route depends on its speed and travel time. The calculated times of the bus speed from individual speed ranges indicates the energy demand on the considered bus route and allow for the assessment of its suitability for operation with electric buses. The determined travel parameters are related to the energy consumption of electric buses and can be useful for planning charging and preparing timetables.

2.2. Principle of the method

The considered bus route is divided into sections. The division into section is based on the layout of the bus stops. The sections are disjoint and they cover the entire bus route. Each section consists of a part of the bus route between two neighbouring bus stops. To the section also belongs the bus stop to which a bus goes. The bus begins to drive on the next section when it starts to move from the bus stop.

The bus moving along a bus route is equipped with a GPS receiver. The GPS receiver determines the location data of consecutive track points with a constant frequency. The location data of individual track points are recorded in a data file. Each track point is described by its ordinal number, the latitude and longitude, and the date and time of measurement.

The distance between two consecutive track points is determined on the basis of their latitude and longitude. Location data are recorded with a constant frequency, and hence the average speed between consecutive track points can be calculated. For each track point the speed is calculated in relation to the previous track point and supplements the location data.

The energy consumption of electric buses depends on many factors. For the bus route considered, the energy consumption of electric buses can be estimated by analysing the bus speed profiles of individual sections. The medium speed is the most beneficial to the energy consumption of electric buses. The energy consumption increases at a speed greater than the medium speed. The increase of the energy consumption also causes the speed which is less than the medium speed. The low speed is usually caused by frequent slowing down and accelerating, that results from traffic conditions. Estimation of the energy consumption of electric buses for the entire bus route can be carried out by aggregation of the data obtained for the individual sections.

2.3. Input data

The input data are location data recorded by a GPS receiver in a data file. The data file is in GPX format that uses an XML schema. A track is recorded and stored in the GPX file and consists of track points. Each track point p_i is described by the set of parameters as follows:

$$p_i = \{i, long_i, latit_i, elev_i, date_i, time_i\}, \tag{2.1}$$

where i is the ordinal number of the track point, $long_i$ is the longitude in decimal degrees, $latit_i$ is the latitude in decimal degrees, $elev_i$ is the elevation above sea level in meters, $date_i$ is the current date and $time_i$ is the current time.

The distance between the current track point i and the track point i–1, which directly precedes the current track point, is given by

$$dist_i \approx \frac{40075.704 \cdot 10^3}{360} \sqrt{(latit_i - latit_{i-1})^2 + [(long_i - long_{i-1}) \cos latit_i]^2}\,. \tag{2.2}$$

The longitude and latitude are given in decimals degree, and then the distance between two consecutive track points is given in meters. The average speed between two consecutive track points is expressed by the equation

$$speed_i \approx \frac{dist_i}{time_i - time_{i-1}}\,. \tag{2.3}$$

The location data are acquired with a constant frequency, and hence the average speed between two consecutive track points can be given by

$$speed_i \approx \frac{dist_i}{T}, \tag{2.4}$$

where T is a time period between two successive acquisitions of the location data. The distance between two consecutive track points is given in meters, and when the time period between two successive acquisitions of the location data is expressed in seconds, the speed at the current track point is given in meters per second.

After the data of the track are supplemented with the distance and the speed, the set of parameters describing the single track point is expressed by

$$p_i = \{i, long_i, latit_i, elev_i, date_i, time_i, dist_i, speed_i\}. \tag{2.5}$$

On the basis of input data, the travel parameters are determined. The travel parameters enable assessment of suitability of the considered urban bus route for operation with electric buses.

2.4. Travel parameters

Travel parameters are calculated on the basis of the speed at individual track points. The distribution of speed data on the bus route depends on many factors, especially on the topology of the bus route and traffic conditions. The speed determined at individual track points is divided into ranges. There are defined four ranges: a zero speed range, a low speed range, a medium speed range, and a high speed range and four speed pointers z_i, l_i, m_i, and h_i, that correspond to appropriate ranges. The initial value of all speed pointers is equal to 0

$$\begin{aligned} z_i &= 0, \\ l_i &= 0, \\ m_i &= 0, \\ h_i &= 0. \end{aligned} \tag{2.6}$$

The assignment of a speed at a single track point is carried out according to the expression

$$\begin{aligned} z_i &= 1 \quad \text{for} \quad speed_i \le v_{z\max}, \\ l_i &= 1 \quad \text{for} \quad speed_i > v_{z\max} \wedge speed_i \le v_{l\max}, \\ m_i &= 1 \quad \text{for} \quad speed_i > v_{l\max} \wedge speed_i \le v_{m\max}, \\ h_i &= 1 \quad \text{for} \quad speed_i > v_{m\max}, \end{aligned} \tag{2.7}$$

where $v_{z\max}$ is the maximum speed for the zero speed range, $v_{l\max}$ is the maximum speed for the low speed range, and $v_{m\max}$ is the maximum speed for the medium speed range. The maximum speed for the zero speed range is defined due to inaccuracy of the location data resulting in a non-zero small speed recorded when a bus is not driving. The speed ranges are disjoint, including all possibly speeds. The maximum speeds of the speed ranges satisfy

$$v_{z\max} < v_{l\max} < v_{m\max}, \tag{2.8}$$

hence for each track point one pointer is equal to 1 only when the others are equal to 0.

The track points are assigned to the sections. Each track point is assigned to exactly one section denoted by the section number j. The track points that belong to the section j have the ordinal numbers limited by a beginning number beg_j and an end number end_j

$$beg_j \le i \le end_j, \tag{2.9}$$

thus the number of truck points N_j included in the section is described by

$$N_j = end_j - beg_j + 1, \tag{2.10}$$

The sections are described by section row vectors $\mathbf{S_j}$ that contain the section number, the number of track points in the section, and the sums of pointers

$$\mathbf{S_j} = \left[j, N_j, \sum_{k=beg_j}^{end_j} z_k, \sum_{k=beg_j}^{end_j} l_k, \sum_{k=beg_j}^{end_j} m_k, \sum_{k=beg_j}^{end_j} h_k \right]. \tag{2.11}$$

Denoting the sums of pointers by Z_j, L_j, M_j, and H_j, respectively, the section row vectors take the form

$$\mathbf{S_j} = \left[j, N_j, Z_j, L_j, M_j, H_j\right]. \tag{2.12}$$

The bus route divided into J sections is described by the section matrix **S** of J rows, each of which describes one section

$$\mathbf{S} = \begin{bmatrix} 1 & N_1 & Z_1 & L_1 & M_1 & H_1 \\ 2 & N_2 & Z_2 & L_1 & M_2 & H_2 \\ & & & & & \\ J & N_J & Z_J & L_J & M_J & H_J \end{bmatrix}. \tag{2.13}$$

After aggregation of data, the entire bus route is described by the route row vector **R** containing sums of all pointers

$$\mathbf{R} = \left[\sum_{j=1}^{J} N_j, \sum_{j=1}^{J} Z_j, \sum_{j=1}^{J} L_j, \sum_{j=1}^{J} M_j, \sum_{j=1}^{J} H_j\right]. \tag{2.14}$$

Denoting the sum of the track points by N, and the sums of pointers Z, L, M, and H, respectively, the route row vector for the entire bus route takes the form

$$\mathbf{R} = \left[N, Z, L, M, H\right]. \tag{2.15}$$

The section matrix **S** and the route row vector **R** contain travel parameters that describe the bus route considered for one ride. For assessment of the suitability of the consider bus route for the operation with electric buses, the travel parameters should be determined for rides in different traffic condition. Each ride gives description of the travel parameters in the form of the section matrix **S** and the route row vector **R**.

2.5. Measurements

The measurements have been carried out on the number 297 bus route in Katowice city. This bus route starts in the centre of Katowice city at the bus terminal near the railway station and leads south to the Odrodzenia housing estate, which is located in the Piotrowice district. From the Odrodzenia housing estate, the bus route heads back to the same bus terminal in the city centre where it starts. The number 297 bus route consists of 26 sections. The sections of intensive traffic are located mostly in the city centre and the sections of low traffic are mainly outside of the city centre. Table 2.1 presents the sections of the number 297 bus route.

In the sections of intensive traffic may occur traffic congestions especially in peak hours. Input data have been acquired during two rides called Ride 1 and Ride 2. Ride 1 has been performed in off-peak hours, and Ride 2 in peak hours. The location data at individual track points have been recorded in the data files with an interval of 1 second. The track of Ride 1 consists of over 3900 track points while the track of Ride 2 of over 4500 track points.

Table 2.1

Sections of the number 297 bus route

Section number	Section name
1	Katowice Dworzec – Katowice Mikołowska
2	Katowice Mikołowska – Katowice AWF
3	Katowice AWF – Brynów W. Pola
4	Brynów W. Pola – Brynów Dworska
5	Brynów Dworska – Brynów Kościuszki
6	Brynów Kościuszki – Brynów Pętla
7	Brynów Pętla – Ochojec Wapienna
8	Ochojec Wapienna – Ochojec Sadowa
9	Ochojec Sadowa – Ochojec Ziołowa
10	Ochojec Ziołowa – Piotrowice Tyska
11	Piotrowice Tyska – Odrodzenia Radockiego
12	Odrodzenia Radockiego – Odrodzenia Łętowskiego
13	Odrodzenia Łętowskiego – Odrodzenia Bażantów
14	Odrodzenia Bażantów – Odrodzenia Kościół
15	Odrodzenia Kościół – Odrodzenia Szewska

continue table 2.1

16	Odrodzenia Szewska – Piotrowice Osiedle
17	Piotrowice Osiedle – Ochojec Ziołowa
18	Ochojec Ziołowa – Ochojec Sadowa
19	Ochojec Sadowa – Ochojec Wapienna
20	Ochojec Wapienna – Brynów Kościuszki
21	Brynów Kościuszki – Brynów Dworska
22	Brynów Dworska – Brynów W. Pola
23	Brynów W. Pola – Katowice AWF
24	Katowice AWF – Katowice Mikołowska
25	Katowice Mikołowska – Katowice Mikołowska Sąd
26	Katowice Mikołowska Sąd – Katowice Dworzec

Source: Own work.

The travel parameters have been determined on the bases of the input date of Ride 1 and Ride 2. The zero, low, medium, and high speed ranges are defined. The zero speed pointers are set to 1 for speeds not exceeding 1 m/s (3.6 km/h). The low speed pointers are set to 1 for speeds above 1 m/s (3.6 km/h) and less or equal to 4 m/s (14.4 km/h), the medium speed pointers are set to 1 for speeds above 4 m/s (14.4 km/h) and less or equal to 10 m/s (36.0 km/h), and high speed pointers are set to 1 for speeds above 10 m/s (36.0 km/h). The bus speed is calculated at all track points. For each track point, on the basis of calculated speed, the value of speed pointers is determined. The assignment of track points to the individual speed ranges is presented in Table 2.2 for Ride 1 in off-peak hours, and in Table 2.3 for Ride 2 in peak hours.

Table 2.2

Assignment of track points to speed ranges for Ride 1

Section number j	Track Points N_j	Zero Speed Z_j	Low Speed L_j	Medium Speed M_j	High Speed H_j
1	292	70	144	78	0
2	226	93	54	79	0
3	117	18	15	34	50
4	268	95	30	77	66
5	117	31	10	50	26
6	131	75	26	30	0
7	223	79	52	65	27
8	214	51	105	58	0

continue table 2.2

9	68	17	8	43	0
10	103	33	18	52	0
11	294	171	25	91	7
12	57	13	8	21	15
13	55	15	7	24	9
14	63	13	8	16	26
15	79	20	7	22	30
16	136	60	24	39	13
17	65	14	9	42	0
18	100	26	7	67	0
19	112	36	15	40	21
20	269	141	35	51	42
21	185	51	34	72	28
22	189	42	29	65	53
23	113	18	25	14	56
24	127	58	24	45	0
25	119	37	18	52	12
26	213	69	123	21	0

Source: Own work.

Table 2.3

Assignment of track points to speed ranges for Ride 2

Section number j	Track Points N_j	Zero Speed Z_j	Low Speed L_j	Medium Speed M_j	High Speed H_j
1	352	88	190	74	0
2	167	38	61	67	1
3	124	27	12	25	60
4	287	46	62	177	2
5	120	37	12	43	28
6	65	16	21	25	3
7	798	501	246	51	0
8	374	215	95	64	0
9	58	14	7	19	18
10	92	23	16	53	0
11	127	22	18	51	36
12	67	22	6	34	5

continue table 2.3

13	84	42	7	35	0
14	66	17	6	14	29
15	73	15	7	24	27
16	155	58	46	40	11
17	76	22	9	38	7
18	98	21	16	52	9
19	87	23	6	27	31
20	231	109	36	36	50
21	190	44	25	117	4
22	143	16	10	48	69
23	147	17	35	54	41
24	85	15	24	46	0
25	208	69	78	61	0
26	290	162	100	28	0

Source: Own work.

The location data at the consecutive track points are recorded with a constant interval of 1 second, and thus the sum of the track points assigned to the individual speed ranges corresponds to the time in which the bus drives with the speeds included in those ranges.

2.6. Analysis of travel parameters

For analysis of travel parameters, data for the individual sections and for the entire consider bus route are used. The aggregated data for the entire bus route obtained in Ride 1 in off-peak hours and in Ride 2 in peak hours are presented in Table 2.4.

Table 2.4

Travel time with assignment to speed ranges

Ride	Travel time N (s)	Zero Speed Z (s)	Low Speed L (s)	Medium Speed M (s)	High Speed H (s)
Ride 1	3935	1346	860	1248	481
Ride 2	4564	1679	1151	1303	431

Source: Own work.

For Ride 1 in off-peak hours, the travel time for the entire bus route is 3935 s (about 1 h 6 min) and consists of a zero speed time of 1346 s (about 22 min), a low speed time of 860 s (about 14 min), a medium speed time of 1248 s (about 21 min), and a high speed time of 481 s (about 8 min). In pick hours, Ride 2 lasted longer and is 4564 s (about 1 h 16 min) consisting of a zero speed time of 1679 s (about 28 min), a low speed time of 1151 s (about 19 min), a medium speed time of 1303 s (about 22 min), and a high speed time of 431 s (about 7 min).

In peak hours the travel time for the entire bus route increased by 10 min which is about 15%. The increase of the travel time concerns the time assigned to the zero speed range and the low speed range while the changes of the travel time assigned to the medium speed range and the high speed range are minor.

2.6. Conclusion

The energy consumption of electric buses depends on travel parameters including driving time and speed profiles during the movement along the bus route. Analysis of travel parameters enables estimation of the typical energy consumption on the considered bus route. The considered bus route is divided into section according to location of bus stops along the bus route. The travel parameters at the consecutive track points of the bus route are determined on the basis of GPS data. Assignment of determined speeds to the defined speed ranges and their analysis allows assessment of the suitability of the considered bus route for operation with electric buses. Measurements in off-peak hours and in peak hours make it possible to take into account the impact of prevailing ambient traffic conditions on the travel parameters of the considered bus route. For bus routes located in mountainous areas, the division of speeds into speed ranges can be supplemented by elevation parameters, which allow consideration of impact of variable height.