PLATON –

Planning Process and Tool for Step-by-Step Conversion of the Conventional or Mixed Bus Fleet to a 100% Electric Bus Fleet

Deliverable: 3.1 Input Data

Milestone 3 is completed by D3.2 Input data formats

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Contents

1 Introduction

The Deliverable presents the results of the project work carried out by consortium partners in the WP 3 Input data.

The results of this work package are focused on input data and data models used for the PLATON planning process.

The Deliverable describes issues of input data in a bus fleet conversion process, features of the tool and related input data for this process, basic input data on a transport system, input data for tasks of highest level, data models on typical working cycles for buses including aspects of driving style, passenger load and traffic obstacles and congestions, results of experimental study of working process of electric bus by example of Belkommunmash, patent information research, creation and development of databases on electric buses and their working process.

2 Issues of input data in a fleet conversion process

The general scheme (Fig. 1) of transition to electric bus fleet has been developed under initial stages of the Project [1].

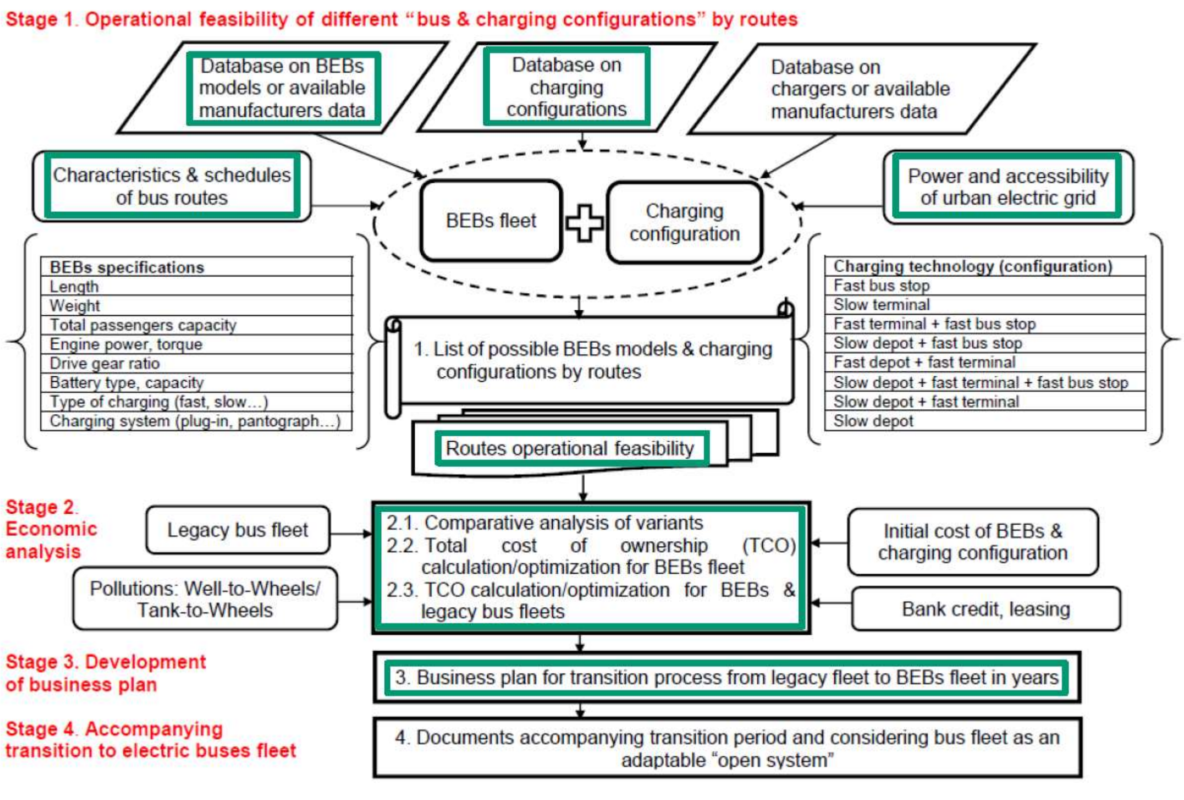


Figure 1 Basic stages in transition to electric bus fleet

In this Deliverable one of the key problems in the calculated support of the process is considered. This is a problem of input data and data models. Input data in many aspects reflect of using possible approach and method for solution different project tasks. Conversely, the approaches and methods under development largely determine the composition and requirements for project input data.

Note. In Figure 1, Phase 1 (operational feasibility) and Phase 2 (economic analysis) are presented as sequential procedures. However, some of the models developed by the project involve a cyclical process of finding the best solution. In such models, the selection procedure includes an appeal to the "operational feasibility" procedure.

2.1 Features of the tool being created and its input data

The tool is intended for use in the form of a site containing software that gives solutions to problems associated with the transition to the park of electric buses. Such a tool is developed for the first time. The well-known numerous methods are tools in which researchers themselves form the input data, adapting them to the capabilities of the methods they have created.

In this project, the input data must be generated by the users (interested parties). Therefore, of particular importance is the process of formal description of the required set of input data, their correct understanding by users and their possibility of obtaining from known sources in accessible ways.

In addition to a large amount of input data, their heterogeneity and belonging to different areas should be taken into account: technology, economics, ecology, etc. Therefore, the excessive accuracy in the description of objects and their properties can lead to a deadlock both in obtaining initial data and the excessive complexity of the models and methods used.

2.2 General characteristics of input data

The main object of study is the urban transport system related to buses and electric buses. The main elements of this system are routes, electric buses and charging devices for electric buses. Thus, the *basic input data* are the infrastructural, technical and operational data related to this system.

An insufficient operational range of electric buses (and the resulting need of recharging in many cases) is a crucial issue under consideration in the planning process. So, input data and models that allow to estimate the energy consumption of electric buses on a certain set of routes (and annual consumption) are of particular importance.

For making decisions about the development of the urban transport system, various scenarios are considered, which are evaluated using different kind of criteria. In this case, *additional input data* are used (economic, financial, etc.) to form the criteria.

So, for new facilities (electric buses, transformers, chargers, depots), input data should be set to determine capital costs and maintenance costs.

As criteria, there may be Total Cost of Ownership (TCO), environmental pollution and others related to the fleet of diesel and electric buses.

In addition, there may be *limitations*, for example, upper bounds on total capital cost and total operating cost.

3 Description of the transport system

The transport system is descripted by infrastructural, operational and technical data and characteristics.

3.1 Infrastructural and operational data

Using Internet mapping and navigation services

Basic data on road infrastructure can be obtained using Internet mapping and navigation services (Table 1).

Table 1. Use of navigational transport services as sources of route and traffic data

ID	Data	Service	Dimensionality or feature
1	Distance between route points, for example, stops	https://www.google.com/maps https://yandex.com/maps, etc.	m
2	Altitudes of route points h=f(route)	https://earth.google.com/web/ http://www.vhfdx.ru/altitude_map.html	m
3	Traffic lights and/or pedestrian crossings	https://www.openstreetmap.org https://yandex.com/maps , etc.	m (distance from the passed stop)
4	Turns, intersections with another street, square	https://www.google.com/maps https://yandex.com/maps , etc.	m (distance from the passed stop)
5	Traffic jams	https://www.google.com/maps (Options: “live traffic”, “typical traffic” for day and time) https://yandex.com/maps (current mode)	Color on a four-color scale
6	Traffic flow speed	https://yandex.com/maps Option “Traffic conditions”, etc.	1) km/h, 2) color on a four-color scale
7	Vehicle speed profile en route	https://yandex.com/maps Option “Public transport moving in real time”	Real-time vehicle tracking

Routes cycle

To describe the "route" component of the transport system, the concept of a "routes cycle" is introduced (Deliverable 2.2). *Routes cycle*: Sequence of routes and auxiliary runs such as Pull-out, Pull-in, Dead head.

Routes cycle (RC) is a more flexible concept than Vehicle Cycle. RC can be used to describe any part of the transport network (and the corresponding trips in it) and estimate its energy consumption.

In particular cases, the RC may correspond to the vehicle cycle (for example, in the case "slow depot charging", Fig. 2), or to one route (in the case of “opportunity charging” with chargers at the termini of the route, Fig. 3).

For contrast, routes cycle corresponding to vehicle cycle for one bus on one route for “opportunity charging” is shown in Fig. 4.

In these figures the following notation is used:

1= pull-out from depot D

2= route between termini A and B

3= route between termini B and A

4= dead-head from bus-line AB to bus-line CE

5= route between termini C and E

6= route between termini E and C

7= pull-in to depot D.

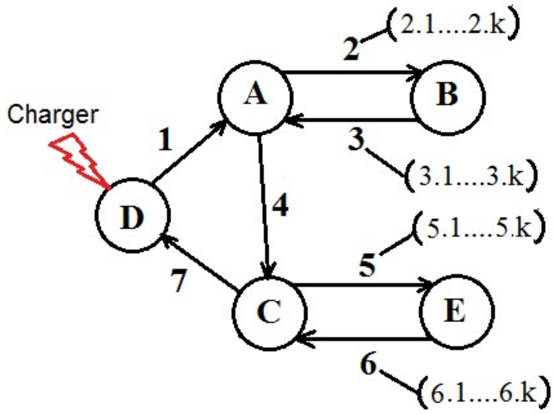


Figure 2 Routes cycle corresponding to the transport cycle (slow depot charging)

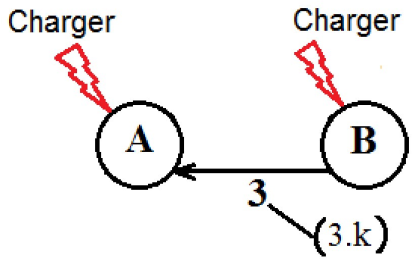


Figure 3 Routes cycle corresponding to one route (opportunity charging)

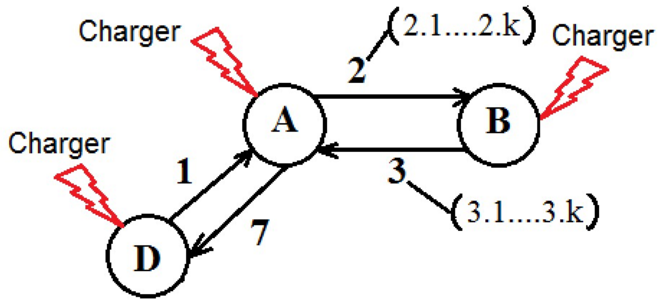


Figure 4 Routes cycle corresponding to vehicle cycle for one bus on one route (straight and back, opportunity charging at termini)

Routes and schedules

For a formal description of routes and schedules, it should be borne in mind that the same route may have a different schedule depending on the time of its beginning. That is why each route identifier has additional indexes (see Fig. 2…4), for example, 2.1, 2.2, ..., 2.k. The additional indexes (1, 2, ..., k) are used to determine the start time as well as schedule for each route with ID = 2 from the daily list of routes. Basic data on a route (from point of view of Infrastructure) in a formalized form are shown in Table 2.

Table 2 Route description, the first level (infrastructure)

No	Parameter	Data presentation
1.	Route ID (infrastructure)	IDroute
2.	Route length	*L*
3.	Number of stops	*N*
4.	Distances to stopping points; the first point has s(1)=0, the end point has *s*(*N*+1)=*L*	*s*(1), *s*(2), …, *s*(*N*+1)
5.	Altitudes above stopping points	*h*(1), *h*(2),…, *h*(*N*+1)

Route data (from point of view of schedule and passenger load) in a formalized form are shown in Table 3.

Table 3 Route description, the second level (schedule, passenger load)

No	Parameter	Data presentation
6.No_{List}	The route identifier in the schedule list (infrastructure, starting order)	IDroute, No_{List}
7.No_{List}	Travel times between stopping points (segments from-stop-to-stop)	$t(1), t(2), \ldots, t(N)$
8.No_{List}	Times spent at the bus stops	$\Delta t_{dwell}(1),\ldots, \Delta t_{dwell}(N)$
9.No_{List}	Passenger load between stopping points	$P_{\mathrm{Load}}(1), \ldots, P_{\mathrm{Load}}(N)$

Passenger load identifier $P_{\mathrm{Load}}(i)$ can be 0, 1, ..., 4:

- 0= No passengers
- 1= up to 25% passengers
- 2= 25—50% passengers
- 3= 50—75% passengers
- 4= 75—100% passengers.

It is supposed that times spent at the bus stops $\Delta t_{dwell}(i)$ are correlated with $P_{\mathrm{Load}}(i)$:

$P_{\mathrm{Load}}(i)$:	0…1	2	3	4
$\Delta t_{dwell}(i)$, s:	12	17	22	27

3.2 Electric buses data

Typical electric buses data are in Table 4. All positions contain default data (in brackets). Presented data are well-known and easy available for manufactures and transport companies. They are widely used by researches in numerous publications, for example [2], [3], etc. Minimum set of data for calculation of the bus energy consumption under season temperature that does not require of HVAC is as follow: δ*, A, K_B, f*, TtW, r_{reg} as well as calculated bus weight m_A. All of them can be taken by default from the Table 4.

Table 4. Electric bus data

No	Parameter	Denotation	Unit
1	Body type: single-deck (SD), articulated (AB), be-articulated (BA), 2-axle double-deck (DD), 3-axle double-deck (DD3) (default is SD)	SB, AB, BA, DD2, DD3	
2	Bus length (default is 12 m)	L_A	m
3	Curb weight (without battery and charge system) (default is 10500 kg)	m_{curb}	kg
4	Rotation inertia factor (default is 1.05)	δ	
5	Max technical weight (actual or planned) (default is18000 kg)	m_{GVW}	kg
6	Weight of battery and charge system (actual or planned) (default is 1500 kg)	m_{bat}	kg
7	Maximum allowable weight of the battery and charging system (default is 1700 kg)	m_b	kg

No	Parameter	Deno-tation	Unit
8	Electric motor output (actual or planned) (default is 140 *kW*)	P_{em}	*kW*
9	Battery capacity (actual or planned) (default is 40 *kWh*)	C_b	*kWh*
10	Type of charging (actual or planned: Fast, Slow, etc.) (default is Fast)	I_{charg}	
11	Charging system (actual or planned: plug-in, pantograph, etc.) (default is pantograph)	I_{way}	
12	Recommended allowable charge state of a discharged battery (actual or planned) (default is 30%)	*SOC*	%
13	Standard weight of one passenger (default is 70 kg)	m_{pas1}	kg
14	Passenger capacity, persons (default is 85)	N_{pas}	
15	Maximum electrical power of auxiliary system (HVAC) or its subsystems with battery energy consumption (default is a=8 kW-for the driver's cabin and ventilation, b=24 kW-for the entire bus)	P_{aux}	kW
16	Cross section area (default is 6.6 m^2)	*A*	m^2
17	Drag coefficient (default is 0.4 Ns^2/m^4)	K_{B}	Ns^2/m^4
18	Rolling resistance (for planned types of tires and road surfaces) (default is 0.008)	*f*	
19	TtW (Tank-to-Wheel)=Efficiency including η_{PE} η_m η_t (default is TtW=0.88)	TtW	
20	• average efficiency of the invertor (default is 0.98)	η_{PE}	
21	• average efficiency of the motor (default is 0.95	η_m	
22	• average efficiency of the transmission (default is 0.95)	η_t	
23	Regeneration (recuperation) factor (default is 0.6)	r_{reg}	

Note. In process of calculation, the calculated bus weight m_A is used that includes m_{curb}, m_{bat} and passenger load depending on segment of a route.

As a help in choosing bus parameters, the database can be used that has been created and is currently undergoing further development.

3.3 Charging configuration

One of the typical tasks is selection of the rational capacity for the electric bus battery under different bus charging configurations. Some popular charging configurations are presented in Table 5 [4].

Table 5. Electric bus charging configurations in EU (as a result of analysis of data from [5] and other sources)

ID	Charging configuration	Number of cases	% of cases
1	Flash (15–20 s)	0	0
2	Fast Bus Stops (1–5 min)	0	0
3	Fast Terminal (5–15 min: pantograph, induction, connecting poles, plug)	3	2.59
4	Slow Terminal (0.5–2 h)	0	0
5	Fast Depot/Selected Bus Stops (0.5–3 h)	1	0.86
6	Slow Depot (2–8 h)	49	42.24
7	In-Motion Charging	1	0.86

ID	Charging configuration	Number of cases	% of cases
8	Fast Terminal + Fast Bus Stops	6	5.17
9	Fast Depot + Fast Terminal	3	2.59
10	Slow Depot + Fast Depot	8	6.90
11	Slow Depot + Slow Terminal	10	8.62
12	Slow Depot + Fast Terminal	21	18.10
13	Slow Depot + Fast Bus Stops	3	2.59
14	Slow Depot + Fast Terminal + Fast Bus Stops	1	0.86
15	Slow Depot + Flash	1	0.86
16	In-Motion Charging + Fast Terminal/Depot	4	3.45
17	Fast Depot + Slow Terminal	2	1.72
18	Fast Terminal + Flash + Fast Depot	1	0.86
19	Fast Terminal + Fast Bus Stops	1	0.86
20	Fast Terminal + Fast Bus Stops + Fast Depot	1	0.86
	Total	116	100

Charging configurations “Fast terminal” and “In-Motion charging” are not very popular in EU. But these configurations are becoming more common in other countries. They provide the minimum size of the electric bus battery and due to this a greater number of passengers. For example, configuration “Fast terminal” has been used in Shanghai (China) for about 10 years. Belkommunmash (Minsk) produces electric buses for “Fast terminals” charging configuration too.

Rate of charging. Table 5 contains original configurations (ID: 1…6) and combined configurations (having “+”). For combined configuration it is especially important to know **rate of charging (kWh/min)** for chargers that serve the electric bus en-route.

In-Motion charging. In countries with trolleybus lines, the “In-Motion charging” solutions can be effective. Especially for the busiest lines (articulated buses, long daily routes and hilly terrain) another types electric buses may be limiting technically or economically. On 15th October 2017, Prague Public Transit Company started a new project of bus electrification E-Bus with In-Motion Charging. Official launch of test operations of the vehicle, which is in principle a battery trolleybus, took place 45 years after closing conventional trolleybus operations in Prague. Belkommunmash has experience in the production of such electric buses, which are currently operated in Grodno (Belarus) and St. Petersburg (Russia).

The operational requirements for such electric buses in St. Petersburg are as follows. On an autonomous mode, electric buses must travel at least 7.5 km on each run. During autonomous run sections it is required to maintain an operating speed of at least 20 km/h, taking into account movement and stops. The share of movement without contact network must be at least 40 % of the movement time.

Detailed data on the design and route of mentioned Belkommunmash buses are presented in [4].

3.4 Operation conditions: traffic obstacles and interferences

The variation in the energy consumption of an electric bus en-route depends on the *passengers loading, ambient temperature, driver's actions, operation conditions in time*, etc. In this sub-section, in addition to the generally accepted parameters described in Sub-sections 3.1-3.3 "traffic obstacles and interferences" are introduced as essential factors for energy consumption.

Basic traffic obstacles and interference determining a speed mode (and speed profile) en route are the following:

1 Turns (constant factor)

2 Intersection (factor of constant action)

3 Artificial irregularity (factor of constant action)

4 Pedestrian crossings without traffic lights (factor of variable action: it may be it may be without pedestrians)

5 Traffic lights or traffic lights with pedestrian crossings (factor of variable action)

6 Traffic speed, including traffic jams.

These number of the list (1, …,6) will be used as identifiers of mentioned factors types.

The location of the factors 1 ... 5 is determined by the distances relative to the **left initial points of the corresponding segments "from-stop-to-stop"**.

Traffic speed. To simplify the identification of the location of the speed factor in any N_s-segment, this segment is divided into 4 sub-segments *SS*(1) ... *SS*(4). For each *SS*(*i*), the speed level is indicated (Table 6). The number of speed levels is 4, which refers to the speed number levels in the Internet navigation system (see Table 1).

Table 6. Description of speed factors (figures are given as examples)

ID_{route}, No_{List}, No_S	***SS*(1)**	***SS*(2)**	***SS*(3)**	***SS*(4)**
2, 13, 5	2	1	3	4

Note. "1" = up to 7 km/h, "2" = 7… 15 km/h, "3" =15…30 km/h, "4" = 30…60 km/h.

3.5 Characterizing routes by means of kinetic intensity

The routes with hard speed-acceleration modes are a problem for the city. This problem can be solved by the priority implementation of electric buses.

For the analysis of drive cycle characteristics en-route, it may be used the *Kinetic intensity* as a significant metric to evaluate conditions for a prioritized electrification of a given transit bus route. The Kinetic intensity measures the driving dynamics in terms of acceleration of the vehicle driving the real service route including scheduled stops and traffic related stops at intersections.

By using a data logger, the position, elevation, velocity and acceleration profile is recorded for each second of the driving cycle (Fig. 5). The data is collected from a bus trip in a Diesel bus between two terminal stations within the time period of 1400 s (23 min) in the German city of Magdeburg. The velocity and acceleration of the bus is observed as bus driving cycles with moderate maximum acceleration values to ensure passenger comfort.

The equal quality of driving style is assumed to be obeyed by deploying electric buses. Although higher accelerations may be achieved through higher motor torque available, the adherence to public transport standards is considered as essential to guarantee the attractiveness of public transportation. Therefore, it can be expected that the use of the collected data is justified for analysis of bus routes with respect to their suitability for electrification.

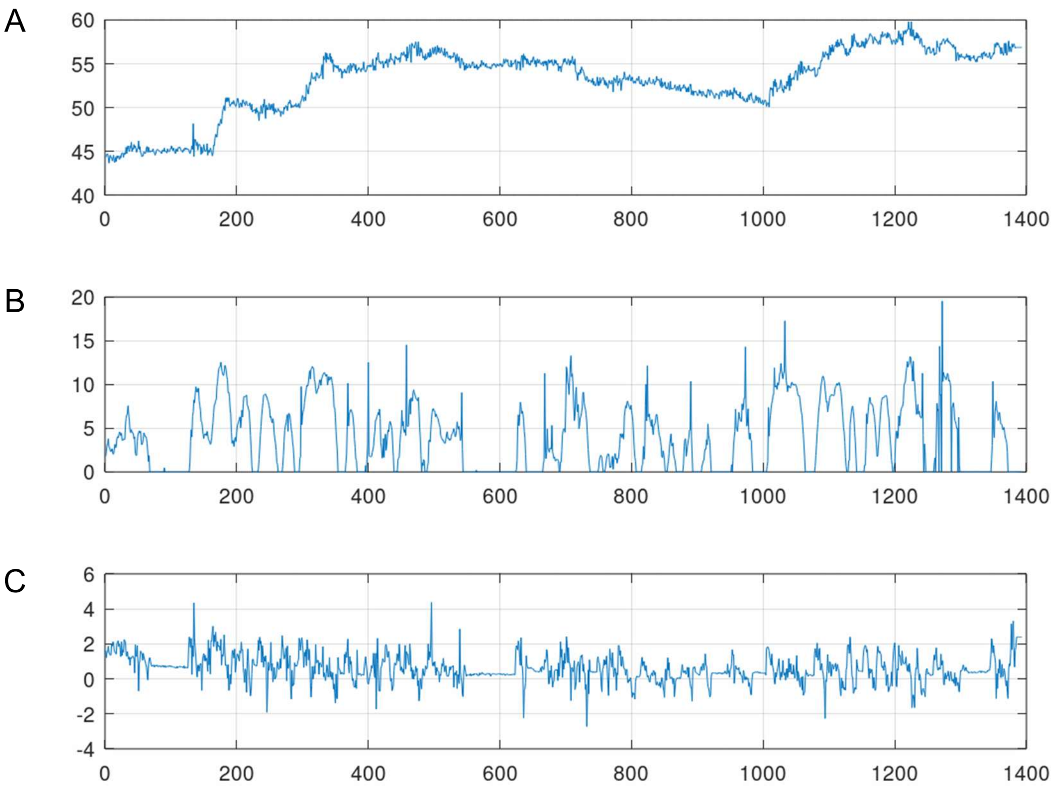


Figure 5 Driving cycle profile for A – elevation in meters above sea level, B – velocity in m/s, C – acceleration in m/s² of an urban transit bus in peak traffic condition

The collected time series of logged velocity and acceleration are the input data for drive cycle characterization by *Characteristic acceleration*, *Aerodynamic speed* and *Kinetic intensity*. *Kinetic intensity* demonstrates well the electric vehicle's advantage for vehicle operations where regenerative braking can be applied more frequently in urban traffic conditions and small stop distances than in contrast to suburban or interurban duty cycles.

The following equations are applied to the collected data set to generate the aggregated values:

$$Characteristic\ acceleration\quad \tilde{a} = \frac{\sum_{j=1}^{N-1} positive(\frac{1}{2} \cdot \left(v_{j+1}^2 - v_j^2\right) + g \cdot (h_{j+1} - h_j))}{D} \tag{1}$$

$$Aerodynamic\ speed\quad v_{aero}^2 = \frac{\sum_{j=1}^{N-1} \overline{v_{j,j+1}^3} \cdot \Delta t_{j,j+1}}{D} \tag{2}$$

$$Kinetic\ intensity\ \ k_i = \frac{\tilde{a}}{v_{aero}^2} \qquad (3)$$

with velocities v_j, elevations h_j, total distance D, and earth gravitational acceleration g. For a detailed analysis of duty cycle evaluation using the above equations refer to [6].

Fig. 6 shows the application of parameter *Kinetic intensity* to assess the nature of the movement of the fleet of electric buses Proterra [7]. When comparing the average daily kinetic intensity depending on the average speed of movement (Fig. 6), it is clear that there are very few changes in the data set, since 99.7% of all values fall into a rectangle representing values within ± 3σ, where σ is the standard deviation.

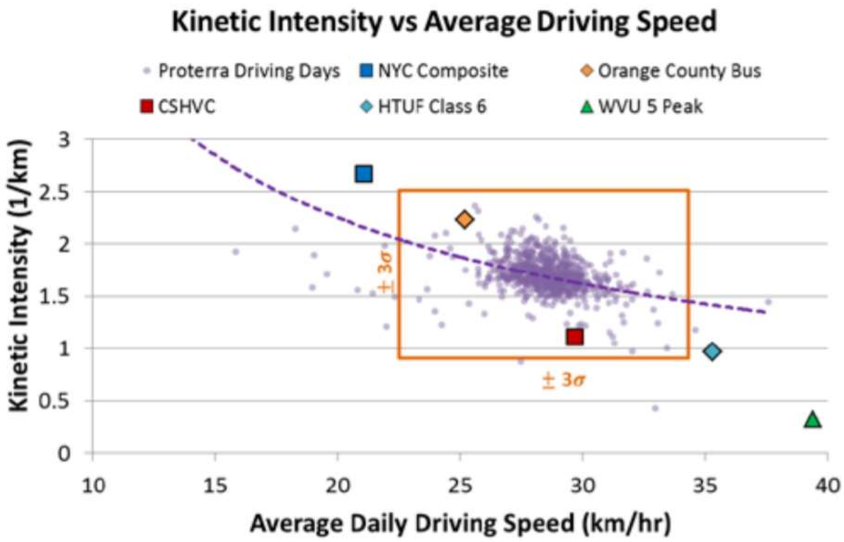


Figure 6 The kinetic intensity vs. the average speed of movement for Proterra electric buses with a field of ± 3σ. Also shown are the values for standard test cycles: CSHVC (City Suburban Heavy Vehicle Cycle) and others

For the presently collected data of Fig. 5 the following values where calculated: $\tilde{a} = 0.833\ m/s^2$, $v_{aero}^2 = 65{,}8\ m^2/s^2$ and $k_i = 7{,}8\ per\ mile$. The average driving speed is 8.85 mph. The present drive cycle that is denoted as MD73 cycle. For comparison of with typical urban drive cycles, the MD73 cycle is marked in Fig. 7 by a green square.

Note that the lower the *Average driving speed* and the higher the *Kinetic intensity*, the more is the analyzed bus route suited to be serviced by an electric bus fleet. Hence, for the analyzed route the prioritized deployment of electric buses **can be certified**.

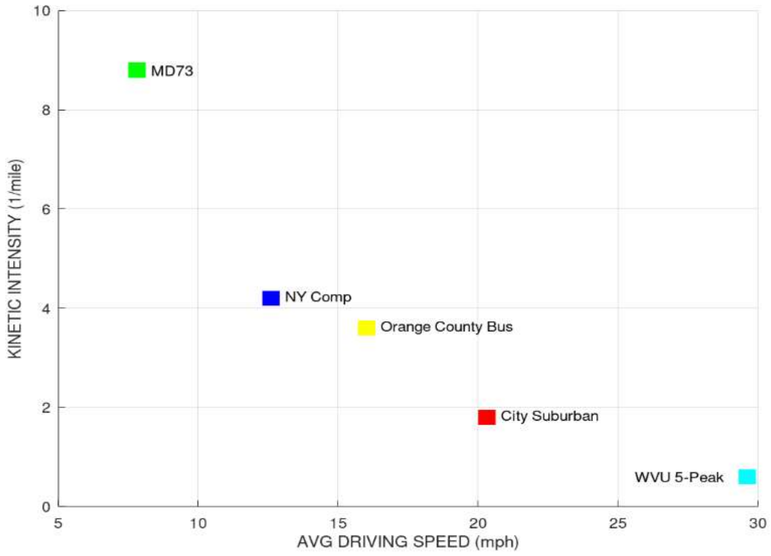


Figure 7 Kinetic intensity of MD73 drive cycle in comparison to typical drive cycles

3.6 E-bus energy consumption in the overall structure of the data model and project tasks

Overall structure of the data model and tasks of the project is presented in Fig. 8.

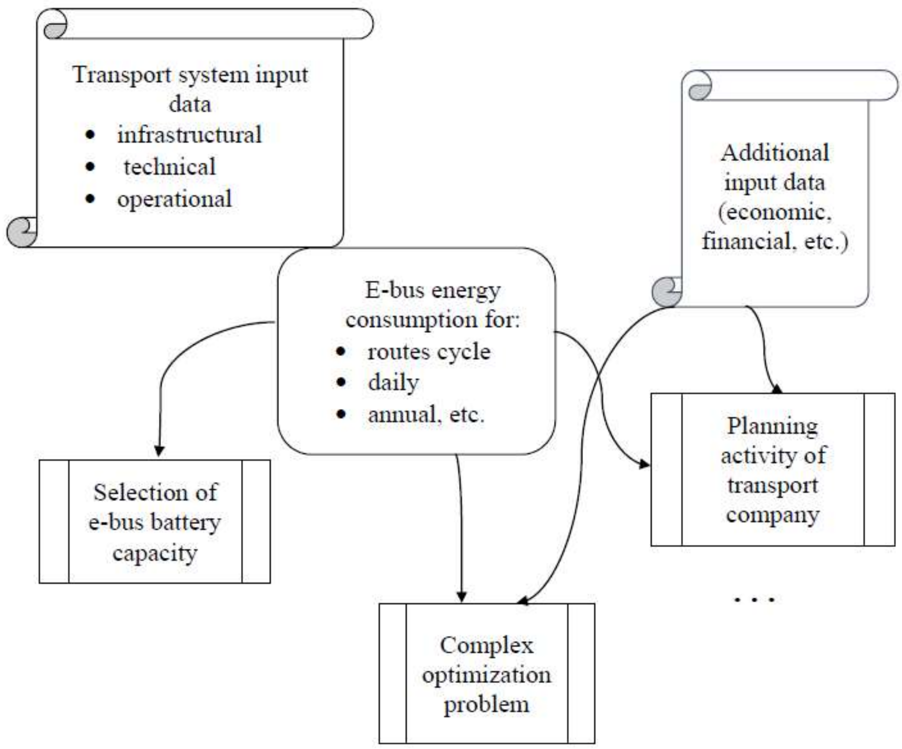


Figure 8 Data model and tasks of the project

The easiest way to estimate the energy consumption of an electric bus is to use **data of a manufacture**. But this data is very abstract and not suitable for a particular route or routes cycle.

The statistics of energy consumption on a variety of machines and routes gives a great variation to values of the indicators (Fig.9).

On the other hand, energy consumption on a certain route cannot also be considered definite (see Fig. 10). But in this case variation may be less than for the previous case (for set of machines and routes).

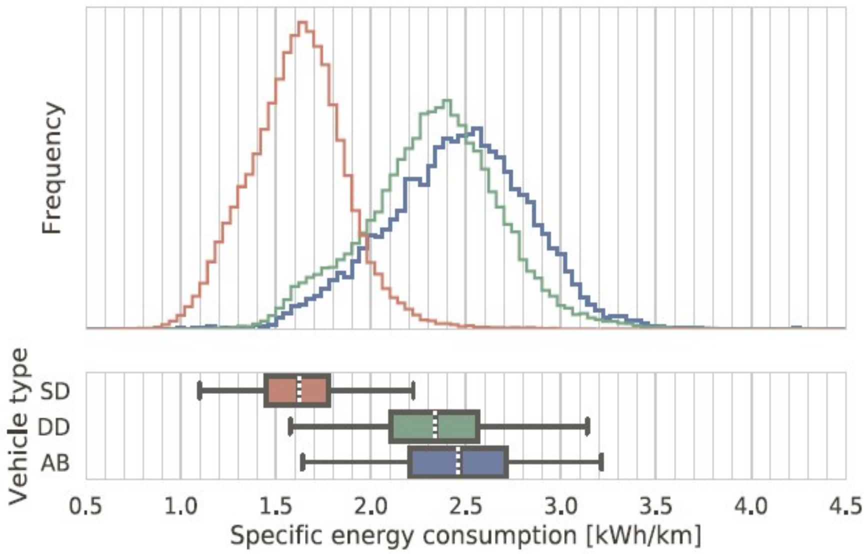


Figure 9 Distribution of the specific energy demand averaged over a journey (terminus to terminus) by bus type: articulated (AB), single-deck (SD), double-deck (DD). (Box plot whiskers set at 2nd and 98th percentiles) [2]

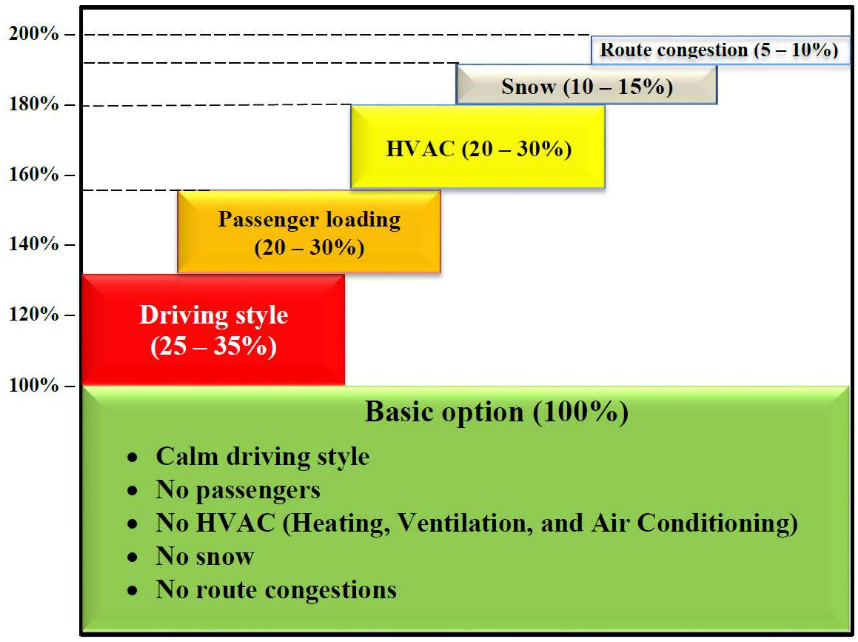


Figure 10 Structure of energy consumption (12-m electric bus) on the route

Therefore, it is necessary to develop a probabilistic approach to the consideration and assessment of energy consumption of the same electric bus during its operation on the route (route cycle).

3.7 Probabilistic approach to evaluating the electric bus energy consumption

The main idea is as follows: determining energy consumption for individual cases does not solve the problem. It is necessary to consider many possible situations and on this basis to justify the calculated case.

For electric buses, the distribution of the energy consumption in the relative (dimensionless) form is proposed [8]. The way to build the distribution is shown in Fig. 11.

A parameter ***P* is relative energy consumption** $P=E/E_0$, where E_0 is certain base value, for example, modal value (most probable energy consumption).

The original relative curve $f(P)$ corresponds to the normal distribution. The variation coefficient of this curve is 0.25, and the relation between the light loading (*L*-case) and the modal value (*M*-case) is 0.8. Then this distribution is truncated (limited) on the left by the energy consumption value for the case of the bus movement without passengers (No Passengers, *L*-case). As result distribution $f_1(P)$ is created [8].

Typical distributions and their parameters for estimating relative energy consumption are shown in Fig. 12. The LN05 and LN03 are based on lognormal distribution.

The LN05 is a close analog of the distribution $f_1(P)$. The LN05 and $f_1(P)$ are recommended for cases with wide variation all factors (all seasons and operation conditions) presented in Fig 7: driving style, passenger load, action of HVAC, snow appearance, route congestion.

The LN03 is recommended for cases when a part of factors is known and taken into account (season, snow appearance, action of HVAC) and at the same time other factors (driving style, passenger load, road congestion) are varied.

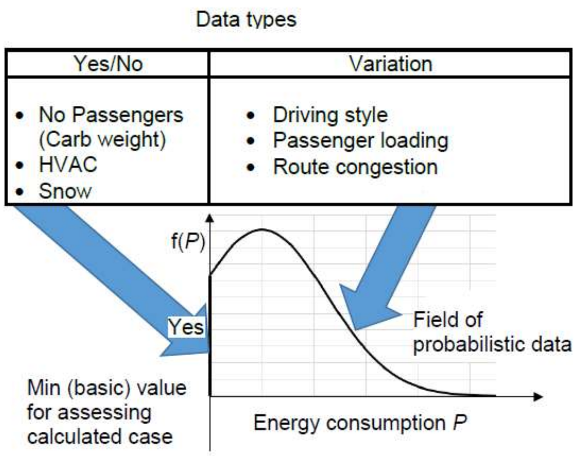
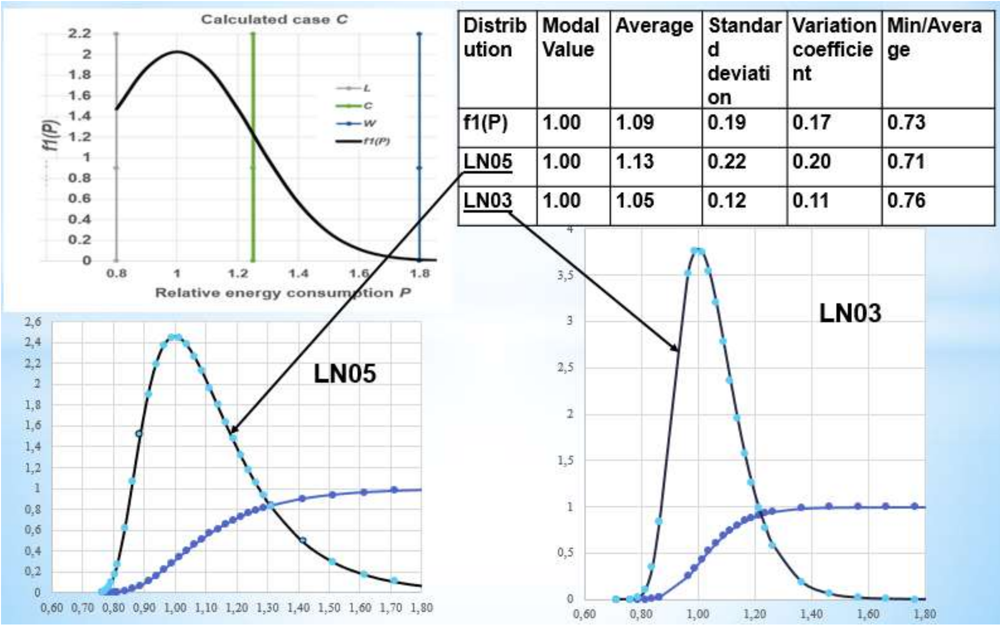


Figure 11 Data types in structure of energy consumption of electric bus



Distribution	Modal Value	Average	Standard deviation	Variation coefficient	Min/Average
f1(P)	1.00	1.09	0.19	0.17	0.73
LN05	1.00	1.13	0.22	0.20	0.71
LN03	1.00	1.05	0.12	0.11	0.76

Figure 12 Typical distributions for estimating relative energy consumption (the LN05 and LN03 are based on log-normal distribution)

Application of probabilistic approach

Probabilistic approach can be applied to evaluate bus energy consumption on routes cycle, one route or singe segment “from stop-to-stop”, i.e. in all cases when should be select the calculated value of energy consumption in processes of solution for different kind of tasks, for example, when determining battery capacity, checking whether the electric bus can overcome certain sequences of segments or routes with the recommended SOC level for a given battery capacity, etc.

To use the approach, it is necessary to determine or take at least one characteristic value on energy consumption (for example average, most probability or minimum value). Then should determine what type of data this characteristic value relates: “wide case” (LN05 and $f_1(P)$ are recommended for cases with wide variation all factors) or “narrow case” (LN03 is recommended for cases when a part of factors is known and taken into account).

After these action it should be selected calculated value in related form and pass from it to an absolute value of energy consumption.

Example

For the considered routes cycle and case “All seasons and operation conditions” it was determined (by simulation, experiments or data of a transport company for bus-analogs) that the **average energy consumption** is 1.64 kWh/km.

This value in the distribution $f_1(P)$ corresponds to a relative value of 1.09.

The relative energy consumption for the calculated case with a probability F=0.8 corresponds to the value PC80=1.25; the absolute calculated value of energy consumption is

$$E_{C80} = \left(\frac{1.64}{1.09}\right) 1.25 = 1.88 \frac{\text{kWh}}{\text{km}} \quad (4)$$

If user (interested party, stakeholder) want select calculated case with the probability F=0.9, then the calculated energy consumption in relative units is PC90=1.35, and the absolute value is

$$E_{C90} = \left(\frac{1.64}{1.09}\right) 1.35 = 2.03 \frac{\text{kWh}}{\text{km}} \tag{5}$$

4 Typical working cycles of electric buses. Driving style, passenger load and traffic congestions

4.1 Bus movement model

Force and energy flows of the electric bus ae presented in Fig. 13. The signs “+” and “–” mark the area of possible values of forces.

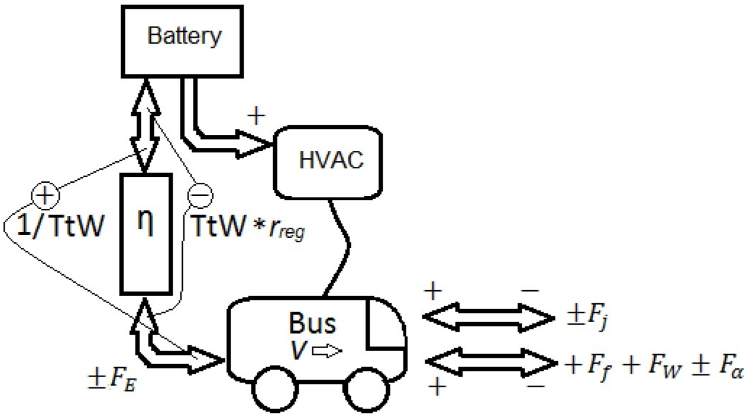


Figure 13 Force and energy flows of the electric bus

Total traction force

$$F_E = F_f + F_W + F_\alpha + F_j \tag{6}$$

Rolling resistance force

$$F_f = f m_A g \cos\alpha \tag{7}$$

where α=inclination angle of the road, m_A=vehicle weight, kg.

Climbing resistance force

$$F_\alpha = m_A g \sin\alpha \tag{8}$$

Acceleration resistance force

$$F_j = \delta m_A j \tag{9}$$

Air resistance force *Fw*

- under constant speed *V*

$$F_{Wc} = k_B A v_c^2 \tag{10}$$

- under constant acceleration j

$$F_{Wekv}(j, S) = k_B A j S \tag{11}$$

where S = distance.

When driving with constant acceleration and deceleration, the work of the air resistance force can be determined using equivalent resistance force $F_{Wekv}(j,S)$ and distance S by the formula

$$A_{FW} = k_B A j S^2 = F_{Wekv} S \quad 12)$$

Note. Formulas above are most suitable for calculation energy consumption when speed profile contain line horizontal and incline elements (movement as set of elementary modes with constant speed or acceleration). In this case energy is calculated as Work=Force*Distance.

In addition, a simple calculation of traction force and the determination of its sign allows to set the type of mode: traction or recuperative. This is important for properly accounting for the energy recovered.

4.2 Route as a set of typical segment from stop-to-stop

Well-known approaches to design a typical working cycle of an electric bus

As it is pointed in the paper [2], a number of state-of-the-art approaches to determining the energy requirements of electric buses use individual specific energy demand values or rely on standard driving cycles, though these do not consider local bus route characteristics. Others require high-resolution measurements of the vehicles' driving profiles, which is impractical for large bus fleets.

In well-known SORT approach [9] that is similar to standard driving cycles, a standardized set of trapezes is used. A criterion for the proximity the SORT cycle and real route is the key parameter: the same commercial speed V_c.

The three SORT base cycles (modules) in shape of trapezes are used to form artificial SORT route. Where are

- Heavy urban cycle (V_c = 12 km/h)
- Easy urban (mixed) cycle (V_c = 18 km/h)
- Easy suburban cycle (V_c = 25 km/h)

The consumption C can be obtained by using the formula:

$$\mathrm{C = a * C\_SORT1 + b * C\_SORT2 + c * C\_SORT\,3} \quad (13)$$

The definition of the coefficients a, b, and c is the responsibility of the operator.

So the SORT method is intended for measurements of bus performance under standardized on-road cycles, and according to experts such measurements cannot reflect the specific application of buses (vehicle configuration, topography, driver influence, climate, loading conditions, etc.).

The paper [2] presents a method of building a speed profile based on trapezes and triangles which are combined to reach average speed of bus on segment "from stop-to-stop". In this aspect the approach [2] differs from the SORT method.

Features for the construction of the speed profile in [2] are as follows.

The duration of each trip between two visited bus stops Δt_{trip} and the dwell time at each stop Δt_{dwell} is calculated from arrival and departure times. Combined with the known distance D between the stops, this yields **the average speed of the trip $v_{avg} = D/\Delta t_{trip}$.**

In order to better reproduce the real driving conditions to which a bus is exposed, a simplified speed profile is derived dynamically for each trip between each pair of bus stops so that it matches the available real-world data (inter-stop distance D and trip duration Δt_{trip}). It consists of a succession of $n_h + 1$ **identical phases** of the length $D' = D/(n_h + 1)$. n_h corresponds to the number of **intermediate halts** between two stops, e.g. in order to stop at a traffic light or give way at an intersection.

Each phase starts with constant acceleration a_+ over distance d_0, followed by constant speed v_1 over distance d_1 and comes to a halt with constant deceleration rate a_- over distance d_2, so that $d_0 + d_1 + d_2 = D'$ (see Fig. 14).

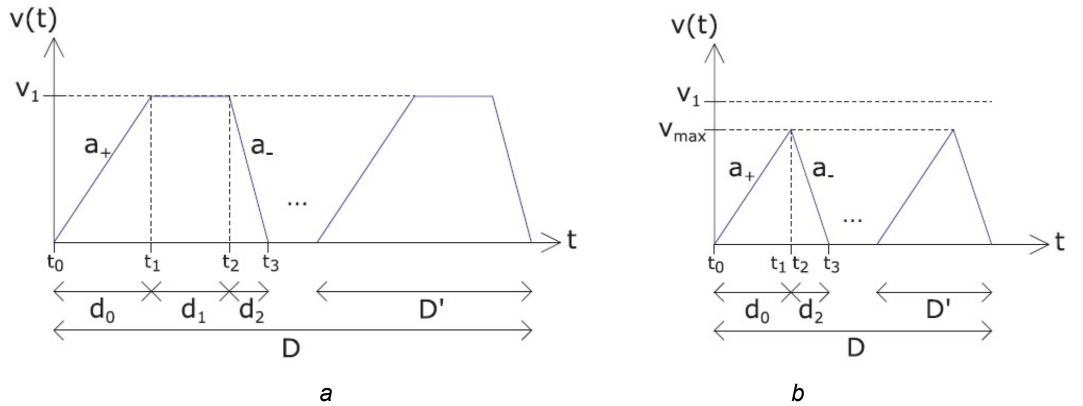


Figure 14. Simplified speed profile: *a* = Case when the total distance D is long enough for the constant speed v_1 to be reached, *b* = Case when the coasting speed is not reached because the total distance D is too short.

The constant speed v_1 is set for each trip so that $v_1 = 1.5 v_{avg}$, but with a lower limit of 15 km/h and an upper limit defined as the maximum between v_{avg} and 60 km/h.

The analyzed approach [2] is closer to real routes than SORT but it contains some restricts. For example, it does not reflect driving style and traffic obstacles that are important features of any bus routes. As well as it is not clear in relation of passenger loads, season and some other important factors.

The approach [2] in aspect of representation of route as a sequence of cycles “from stop-to-stop” is close to approach described in sub-chapter 31.3 “Construction of typical cycles of movement of electric buses "from stop to stop” of monograph [10] (relates to the Project, Monograph contents is presented in [11]).

4.3 Development concept of typical working cycle for an electric bus. Different driving styles and cycles “from-stop-to-stop”

In [10] three type of cycles “from-stop-to-stop” are considered. The options of simplest Cycle 1 (non-stop) is shown in Fig. 15.

The initial data of the Cycle 1. They are: 1) the time of movement on the schedule to the next stop t_b = 53 s; stop time t_S=30 s; 2) the distance (path) between stops S_D= 506.94 m; 3) the permissible level of acceleration (deceleration) j_{max}=3.0 m/s^2; 4) the maximum speed on the route v_{max}=60 km/h (for every segment); in a number of countries, a driver can exceed this value till the limiting value v_{lim}= 70 km/h. The typical ratio of acceleration j_1 to deceleration ($-j_2$) for speed profiles L is assumed to be $j_1/(-j_2)$=1.0.

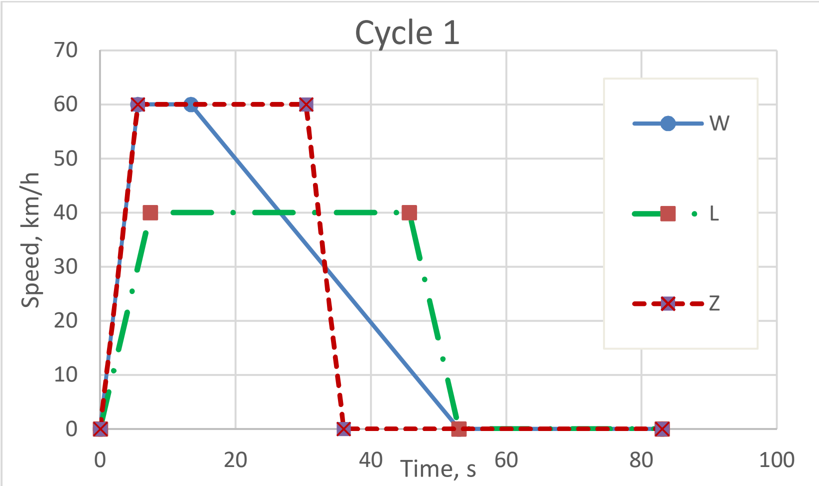


Figure 15. Speed profiles for Cycle 1 non-stop

Path S_D can be traversed at various values of acceleration (deceleration), steady-state speed v_D and, accordingly, the time of movement t_a with this speed. When calculating j_1, depending on v_D, relations (14) — (17) are used, and for given accelerations, equation (17) is solved to determine the speed v_D:

$$t_a = 2S_D/v_D - t_b \quad (14)$$

$$t_1 = (t_b - t_a)/(1 + t_2/t_1) \quad (15)$$

$$j_1 = v_D/t_1 \quad (16)$$

$$[0.5(1/j_1 + 1/j_2)](v_D)^2 - t_b v_D + S_D = 0 \quad (17)$$

The resulting speed profiles *W*, *L* and *Z* are shown in Figure 15. Profile *W* corresponds to the aggressive driving style, which is characterized by speed up with an acceleration j_{max} to maximum speed v_{max}. Profile *L* is obtained from the motion condition with the speed v_D provided that the acceptable acceleration j_1 is used [formula (16)].

Fig. 16 demonstrates interrelationship of speed v_D and acceleration j_1. Reducing the speed v_D below 40 km/h leads to an acceleration j_1 in excess of 1.5 m/s^2, which is the generally accepted upper value for a "non-aggressive" driving style. This value (1.5 m/s^2) is used in *L*-speed profile. And seems that this *L* profile is the least energy-intensive.

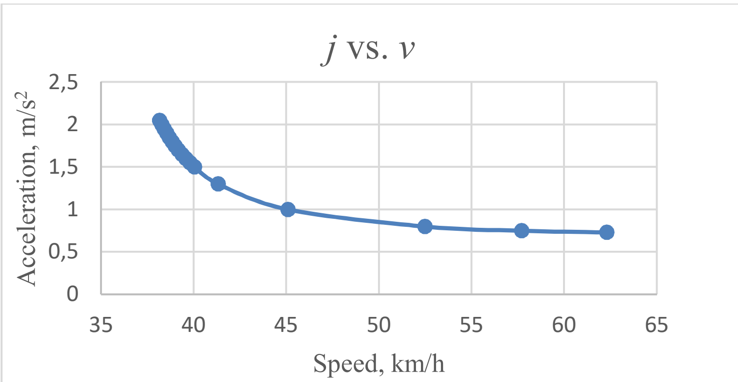


Figure 16 Interrelationship of speed v_D and acceleration j_1

Speed profiles *W* and *L* imply deceleration modes with recuperation. In the future, these cycles are modified depending on the type of intermediate stop. Profile *Z* corresponds to the super aggressive driving style. This profile is extreme in acceleration and deceleration and therefore is not modified further.

"Cycle 2" with intermediate stop expected (planned) by driver. The cycle corresponds to the case of travel through this segment taking into account the experience accumulated by the driver (or the predicted situation) when there is a high probability of an intermediate stop.

Additional initial data (compared with Cycle 1) is a pause t_p and the share z_D of the distance traveled to the stopping point (it is taken z_D=0.5).

It is assumed that the driver plans a speed mode, taking into account the pause in the movement, the steady-state speed v_D before and after the pause is the same. The calculation results are shown in Fig. 17.

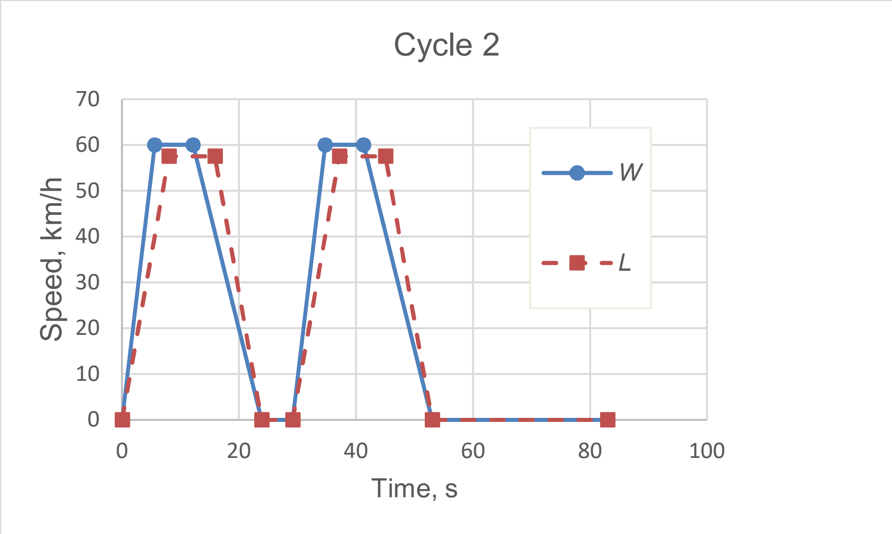


Figure 17 Speed profiles for Cycle 2 with an expected intermediate stop

"Cycle 3" with an intermediate stop unexpected (unplanned) by driver. The initial data are the same as for Cycle 2. Additionally, for the second section of the cycle, the speed limit v_{lim}=70 km/h is applied.

Cycle 3 starts with acceleration, as in Cycle 1. When a situation arises that leads to a forced stop, the driver slows down, as in Cycle 2. After a pause of t_p, the driver selects a possible mode to complete the motion cycle in the allotted time. When playing the first part of the cycle (before the pause), a check is made: whether the distance in the driving mode with acceleration and deceleration of Cycle 1 exceeds the distance to a sudden stop. If this is the case, then the transition point from the accelerated mode to decelerated one is determined without a transition to the steady-state speed. Speed profiles for Cycle 3 are shown in Fig. 18.

The main parameters of the cycles. The main parameters are given in Table 7. In Cycle 3, the duration exceeds the scheduled time 83 seconds. It can be assumed that the stopping time in this cycle can be reduced by 20%. The rest of the excess, if necessary, is compensated by the subsequent cycle. It is obvious that an unexpected stop leads to a super aggressive style in order to withstand the schedule of the electric bus.

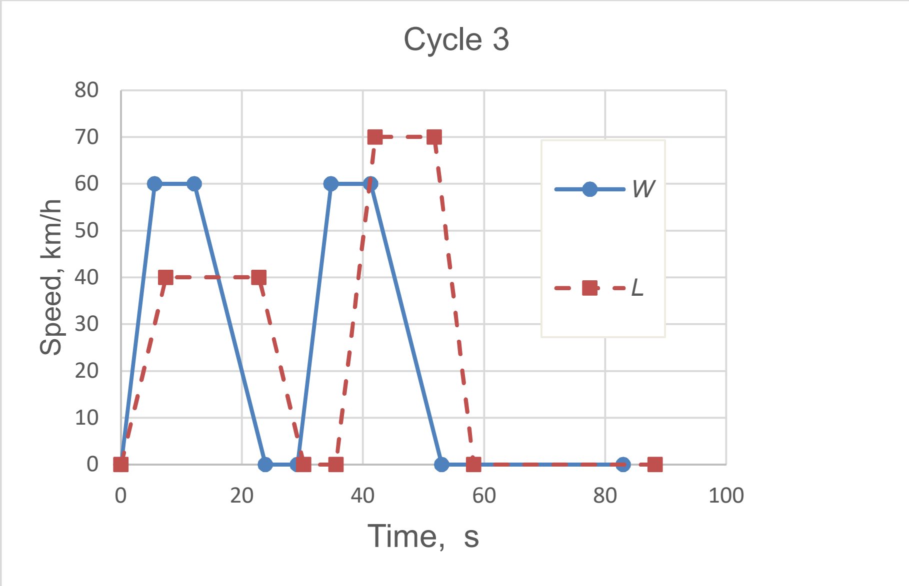


Figure 18 Speed profiles for Cycle 3 with an unexpected intermediate stop

Table 7. Cycles parameters

Cycle	**Section 1**			**Pause**	**Section 2**			**Cycle**
	v_D, km/h	j_1, m/s^2	j_2, m/s^2	t_p, s	v_D, km/h	j_1, m/s^2	j_2, m/s^2	**duration, s**
1 *W*	60.0	3.0	−0.42	—	—	—	—	83.0
1 *L*	40.0	1.5	−1.5	—	—	—	—	83.0
1 *Z*	60.0	3.0	−3.0	—	—	—	—	83.0
2 *W*	60.0	3.0	−1.4	5.3	60.0	3.0	−3.0	83.0
2 *L*	57.5	2.0	−2.0	5.3	57.5	2.0	−2.0	83.0
3 *W*	60.0	3.0	−1.4	5.3	60.0	3.0	−3.0	83.0
3 *L*	40.0	1.5	−1.5	5.3	70.0	3.0	−3.0	88.3

4.4 Development concept of typical working cycle for an electric bus. The effect of different driving styles and passenger load for cycles of different lengths

Recent new theoretical and experimental research performed in the frame of the Project (see below) showed that it is important to take into account driver style, passenger load and traffic obstacles in creating speed profile for a concrete route and every its segments, which generally have a different length.

A typical 300-meter cycle was taken as a base with a minimum length (Fig. 19).

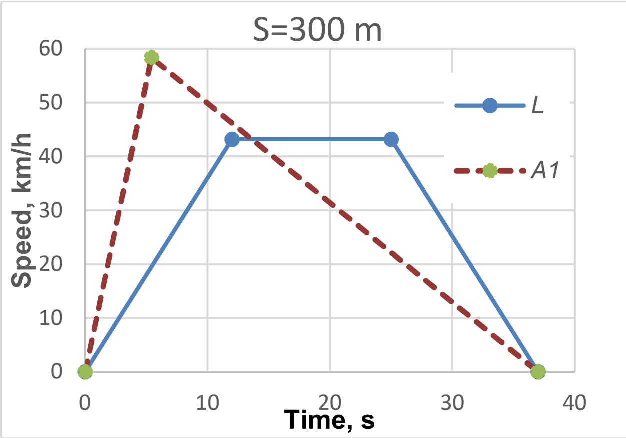


Figure 19 Typical 300-m cycle as basis

As a result of an analysis of relationship between acceleration and distance speed v_D (Fig. 20), it was taken for the *L*-speed profile that the acceleration j_1=1 m/s^2 and j_2=−j_1.

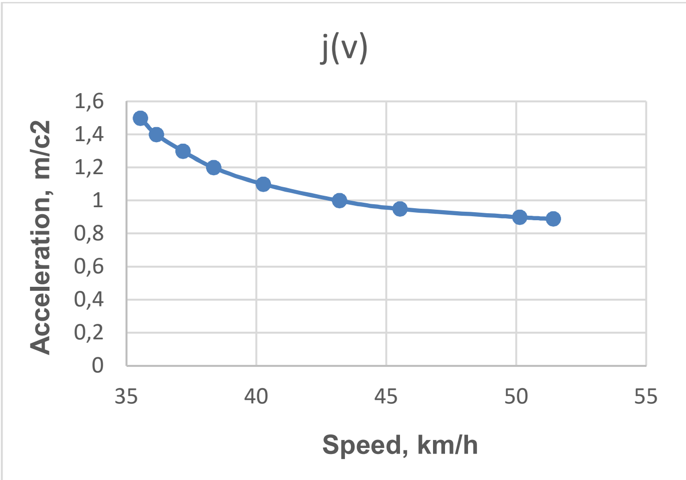
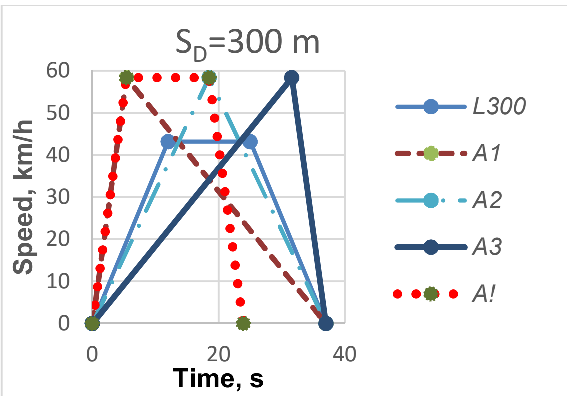


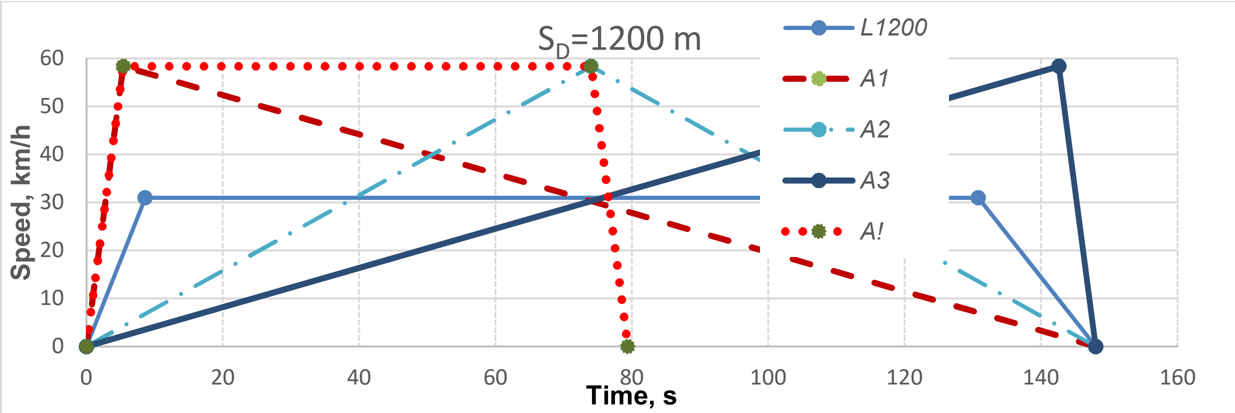
Figure 20 Relationship between acceleration and distance speed v_D

Additionally, to aggressive style "W" and super aggressive "Z" from sub-section 4.3 (their names below are "A1" and "A!"), the aggressive styles "A2", "A3" are entered.

So for further analysis there are 5 driving styles: quiet (calm) L, three aggressive A1=W, A2, A3 and super aggressive A!=Z (see Fig. 21) and 4 distances S_D : 300, 600, 900 and 1200 m.



a



b

Figure 21 Typical speed profiles for different distance

Bus parameters (δ, *A*, K_B, *f*, TtW, r_{reg}) used for calculation are in Table 4 (as default). Results of the energy consumption calculation are depicted in Table 8.

Table 8. Energy consumption (EC) vs. driving style and distance (Full bus weight m=15000 kg)

Distance S_D, m	300	600	900	1200
Time t_b, s	37	74	111	148
EC_{Light}, kWh/km	1.06	0.63	0.55	0.51
EC_{Agr1}, kWh/km	1.51	0.85	0.62	0.51
EC_{Agr1}/EC_{Light}	1.42	1.34	1.14	1.00
t_1/t_b	0.15	0.07	0.05	0.04
EC_{Agr2}, kWh/km	1.60	0.96	0.74	0.64
EC_{Agr3}, kWh/km	1.69	1.07	0.86	0.76
$EC_{Agr!}$, kWh/km	1.80	1.19	0.99	0.89
t_p, s (for $EC_{Agr!}$)	13.09	31.59	50.09	68.59

From these results follows a paradox: the aggressive style (Agr1) do not become aggressive for long distance. If time of acceleration t_1 is less than 0.04 t_b than aggressive style is preferable. This is explained by the fact that the overcoming of resistance to movement occurs due to the inertia (**coasting**) in largest part of the segment.

Energy consumption vs. driving style, bus weight and distance is depicted in Table 9.

Table 9. Energy consumption vs. driving style, bus weight (m=12000, 15000, 18000 kg) and distance (S_D= 300, 600, 900, 1200 m)

Driving Style	**Full weight m, kg**	**300**	**600**	**900**	**1200**
Light	12000	0.854	0.517	0.451	0.423
	15000	1.059	0.630	0.549	0.514
	18000	1.264	0.743	0.647	0.605
Agr1	12000	1.214	0.683	0.506	0.417
	15000	1.508	0.845	0.624	0.514
	18000	1.803	1.008	0.743	0.610

These results show that an increase in passenger load from 0 (bus full weight =12000rg) to max (bus full weight =18000 kg) increases EC 1.4-1.5 times. If to go from the average value of energy consumption, the deviation is ± 20%

If to suppose that segment of S_D=1200 m has 3 intermediate stops (after 300, 600 and 900 m) then three intermediate stops increase EC for this segment 2 times (under quiet style), 3 times (under aggressive style).

If to assume that the segment SD = 1200 m has 3 intermediate stops after 300, 600 and 900 m, (i.e. it consists of 4 segments with S_D=300 m), then it is clear that these intermediate stops increase the EC for the segment under consideration by 2 times (with a calm style) and 3 times (with an aggressive style).

4.5 Impact of rolling resistant and driving style

Data on energy consumption (kWh/km) vs. rolling resistant coefficient *f*, driving style and distance S_D are in Table 10. Bold numbers refer to the case when the aggressive style A1 gives less or equal energy consumption compared to the calm style *L*.

Table 10. Energy consumption (kWh/km) vs. rolling resistant coefficient, driving style and distance

S_D, m	**300**	**300**	**600**	**600**	**900**	**900**	**1200**	**1200**
Driving Style	**L**	**A1**	**L**	**A1**	**L**	**A1**	**L**	**A1**
f=0.008	1.06	1.51	0.63	0.85	0.55	0.62	0.51	**0.51**
f=0.012	1.22	1.60	0.81	0.93	0.73	**0.71**	0.70	**0.59**

From these data it follows that the coefficient of rolling resistance is a very significant and influential factor. Its calculated values should be set for the conditions "summer" and "winter" separately.

In addition, aggressive style A1 is preferred for conditions with high rolling resistance for long distance S_D.

4.6 Energy-efficient driving

Presented results (with aggressive driving style *A*1 for long distances) refer to a problem of “eco-driving” [12]. Basic principle of eco-driving methodology: **Coasting, instead of braking**, is an efficient method for providing required decelerations.

The article **[13]** proposes a method for solving this problem by developing an **energy-efficient law** for controlling the movement of an electric bus along a city route.

The task of the energy-efficient law of controlling the speed of an electric bus between stops on a city route is formulated as an optimization problem: to determine the law of change in the speed v (s) of the electric bus’s traversed route.

The resulting energy-efficient law of motion of the electric bus is shown in Fig. 22.

This dependence can be divided into three zones: acceleration with an acceleration equal to the established limit (1 m/s2); coasting; recuperative braking with maximum retarding torque. Also, according to the obtained dependency, the driver should not use the working brake system - he needs it only to completely stop the electric bus.

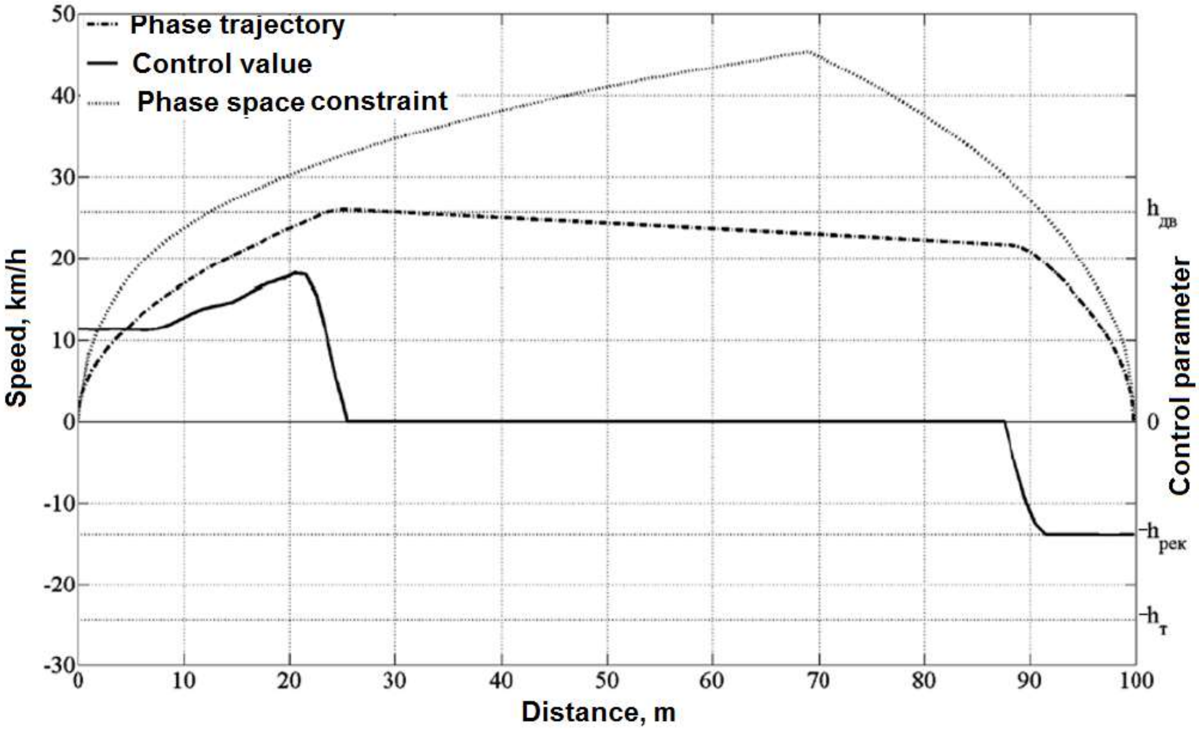


Figure 22 Energy efficient law of motion of the electric bus

It is noted that with increasing dynamism, irretrievable energy losses increase, the optimal control law even on the simplest routes is quite complicated, and the driver, maintaining the average speed of movement, will not be able to implement it practically. It was concluded that the movement of the electric bus between stops should be obtained using the proposed method, taking into account the specified traffic conditions, solving the equation of state in real time on board the electric bus. The control system must implement the obtained optimal law of changing the speed of the electric bus on the route, the driver only has to manage the “desire” to move and interfere with the management in emergency situations.

Turning to the driving style A1 it should be noted that this style is close to energy-efficient driving. A1 consists of short intensive acceleration and subsequent coasting. Thus, for long segments the **driving style A1 is close to optimal**.

4.7 Schematization of traffic obstacles and interference

Sub-section 3.4 “Operation conditions” contains typical traffic obstacles and interference. For their schematization and implementation into speed profile of the segment "from-stop-to-stop" the inverted trapezes (Fig. 23) are used with asked parameters that depicted below:

v_D = current electric bus speed (adopted for examples v_D =40 km / h)

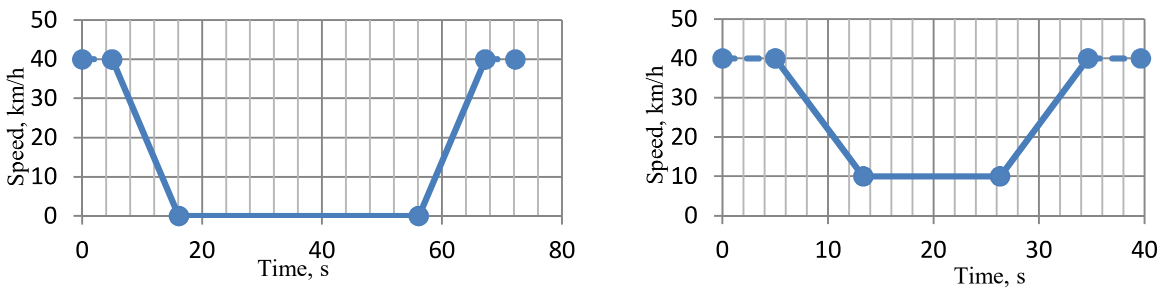
Δs_0- obstacle area

j_1 = deceleration (adopted for examples j_1= −1.0 m / s^2)

j_2 = acceleration (adopted for examples j_2=1.0 m / s^2)

L_A = bus length (adopted for examples L_A=12 m)

m_A = bus calculated weight (adopted for examples m_A =15000 kg)



a *b*

Figure 23 Speed profiles with typical traffic interferences: *a*= Traffic light (red), Left Turn, Intersection; *b* = Artificial irregularity, Pedestrian crossing, Right turn

The formulas for Δs_0 and results of calculation for energy consumption (EC) are given in Table 11.

Table 11. Parameters for typical traffic obstacles and interference

Parameter	**Artificial irregularity**	**Pedestrian crossing**	**Right turn**	**Traffic light, Left turn, Intersection**
Δs_0, m	$0.9L_A$	$2L_A$	$3L_A$	0
Δt_0, s	3.89	8.64	13.0	40.0
EC, kWh	0.212	0.201	0.219	0.208

To embed the speed profile of an interference (obstacle) in the velocity profile of a segment, a transition point is determined from the current speed of the segment to the first point of the interference (obstacle) range.

4.8 The detail scheme for calculating energy consumption

Scheme for calculating energy consumption based on above mentioned factors is shown in Fig. 24. This scheme was somewhat developed compared to the scheme presented in Deliverable 2.2

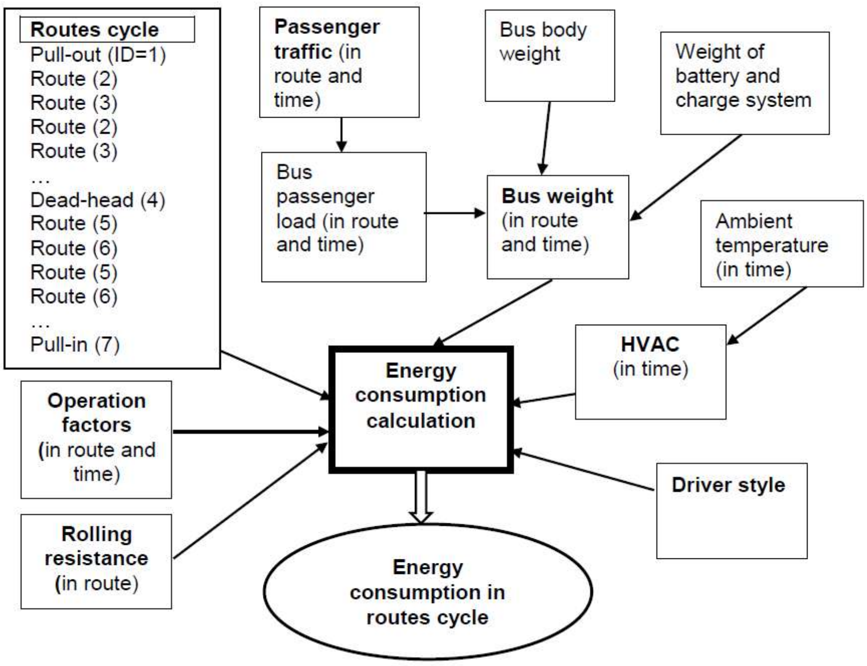


Figure 24 Scheme for calculating energy consumption

This scheme was somewhat developed compared to the scheme presented in Deliverable 2.2. Operation factors was added and Routes cycle was corrected.

5 Input data for tasks of highest level

In this section, sets of input data related to the tasks of highest level (see the Deliverable 2.2 and [4]) in the transition process to the electric bus fleet are considered.
It should be noted that tasks of the Project on a date of given Deliverable 3.1 are in stages of developing. Now working versions are available. These versions may be some corrected in future in terms of input data.

5.1 Planning activity of a transport company

The input data to the decision support system for planning activity of a transport company are as follows.

BNF – beneficiary variables

- $BNF_{PV_{bus}}$ – beneficiary of PV_{bus} (present value of bus)
- $BNF_{PVOC_{bus}}$ – beneficiary of $PVOC_{bus}$ (present value of the operating costs)
- $BNF_{PV_{infr}}$ – beneficiary of PV_{infr} (present value of the infrastructure)
- $BNF_{PVE_{exter}}$ – beneficiary of PVE_{exter} (present value of the external costs)
- $BNF_{PVL_{liq\_bus}}$ – beneficiary of PVL_{liq_bus} (present value of the proceeds of liquidation)

PRCS – process (dynamic) variables

- t_{Req_var} – time (timestamp) of request for a new *var* value in the *TCO* analysis process
- var – designation of the variable whose registration was recorded in the TCO analysis process
- $Value_{var\_}t_{Req\_var}$ – the value of the variable whose registration was recorded in the TCO analysis process at time (timestamp) t_{Req_var}

BUS – technical variables

- Bat_{cap} – battery capacity [kW]
- Bat_{life} – lifetime of the bus battery [years]
- Bus_{life} – bus life [years]

BUS – economic variables

- Bus_{cost} – bus costs [EUR]
- $Bat_{unit_{Cost}}$ – cost of battery unit capacity [EUR/kW]
- $Capac_{cost}$ – costs for double-layer capacitors [EUR]
- $AC_{bat2\_self}\ (t = Bat_{life}\ )$ – acquisition costs of spare battery [EUR] after period *t* equal lifetime of the bus battery *bat_life*
- pl_r – residual value rate of the bus [-]

BUS – financial variables

- Bus_{sub} – subsidies for bus [EUR]
- Bus_{self_r} – self-financing rate of bus acquisition [-]

- Bus_{cred_r} – credit rate of bus acquisition [-]
- N_{bus} – bus credit period [years]
- s_{bus} – loan of bus interest rate [-]
- M_{bus} – repayment term [years]
- i_{bus} – market interest rate [-]
- i_{bat2} – market interest rate for bat2 [-]

BUS – operational variables

- Bus_{oper_ann} – annual operational use [km/year]
- $Ener_{cons}$ – energy consumption [kW/km]
- $Ener_{cost}$ – cost rate of energy [EUR/kW]
- Tax_{relief} – tax relief [EUR/kW]
- $Ener_{supp\_cost\_r}$– energy supply cost rate [EUR/km]
- $Poll_{cost\_r}$ – cost rate of pollutant emmisions by 1 bus [EUR/km]
- $Noise_{cost\_r}$ – cost rate of noise emission by 1 bus [EUR/km]

BUS – maintenance variables

- $Work_{staff\_service}$ – staff service hours [staff-service-hours/bus]
- $Staff_{cost\_r}$– staff service cost rate [EUR/staff-service-hours]
- OC_{insur} – annual insurance costs [EUR]

INFRASTRUCTURE – technical variables

- $Infra_{life}$ – infrastructure life [years]

INFRASTRUCTURE – economic variables

- AC_{infra_dep} – acquisition costs of depot conductive plug-in charging [EUR]
- AC_{infra_swap} – acquisition costs of battery swapping-charging [EUR]
- AC_{infra_panto} – acquisition costs of pantograph charging [EUR]
- AC_{infra_stop} – acquisition costs of on bus-stop charging [EUR]
- AC_{infra_induct} – acquisition costs of in-motion inductive charging [EUR]

INFRASTRUCTURE – financial variables

- $Infra_{sub}$ – subsidies for infrastructure [EUR]
- $Infra_{self\_r}$ – self-financing rate of infrastructure acquisition [-]
- $Infra_{cred\_r}$ – credit rate of infrastructure acquisition [-]
- N_{infra} – infrastructure credit period [years]
- s_{infra} – loan infrastructure interest rate [-]
- M_{infra} – repayment term of infrastructure [years]
- i_{infra} – market interest rate of infrastructure [-]

INFRASTRUCTURE – operational variables

INFRASTRUCTURE – maintenance variables

- MC_{infra_dep} – maintenance costs of depot conductive plug-in charging [EUR]
- MC_{infra_swap} – maintenance costs of battery swapping-charging [EUR]

– MC_{infra_panto} – maintenance costs of pantograph charging [EUR]
– MC_{infra_stop} – maintenance costs of on bus-stop charging [EUR]
– MC_{infra_induct} – maintenance costs of in-motion inductive charging [EUR]

5.2 Complex optimization problem

A tool for complex optimization problem is planner of passenger transportation operations and electrical infrastructure. This tool must be capable to determine the fleet of electric buses, their assignment to routes, their timetables, locations for charging stations and transformers and their links.

Input data for a complex optimization problem are as follows:

1) Set of routes.

2) Set of e-bus types.

3) Set of charging station types.

4) Set of transformers.

5) Set of edges connecting locations of charging stations and transformers.

The following detailed information are below.

1) For each route:

- depot node,
- the same first and last bus stop node visited immediately after (and, respectively, before) the depot, which is eligible (!) for opening a charging station,
- the sequence of bus stop nodes eligible (!) for opening a charging station, which are visited cyclically,
- for each node of the same route, we need to know the most distant node that can be reached by fully charged e-bus for each e-bus type,
- set of transformer nodes eligible for linking with this node and estimation of or tight upper bound on the charging time of one e-bus of the same type at a charging station of the same type installed at this node to the recommended SOC level, which, for the en route stop, accounts for the time required for passenger loading/unloading, and for a terminal stop or a depot, it accounts for the required setup and maintenance time,
- upper bound on the traffic interval of e-buses of any type,
- duration of the single shortest time period during the day, when the maximum number of e-buses are in their depot (for example, it can be a night period),
- estimation of or tight upper bound on duration of one cyclic run of any e-bus (drive plus stop times),
- the defining time period (peak time period),
- energy cost (or its estimation) of all runs of one e-bus of the same type in a year for each e-bus type,
- numbers of conventional vehicles of each type and their passenger capacities which are used in the defining time period.

2) For each e-bus type:

- set of eligible charging station types,
- set of eligible routes,

- passenger capacity of one e-bus,
- capital cost of one e-bus,
- operating cost of one e-bus in a year, without the energy cost.

3) For each charging station type:

- nominal power of one charging station,
- capital cost, which is the cost of purchase and installation of one charging station, without the transformer connection costs,
- operating cost, which is the cost of operating one charging station in a year,
- set of nodes eligible for opening a charging station of this type,
- set of e-bus types eligible for charging at a station of this type.

4) For each transformer node:

- nominal power to supply charging stations,
- capital (building) cost.

5) For ach edge connecting locations of a charging station and a transformer:

- cost of linking transformer location and charging station location.

6) Upper bounds on total capital cost and total operating cost.

Note. The model does not directly require all bus stops and energy consumption between them. It requires only those stops which are eligible for opening a charging station and a knowledge of whether an e-bus can feasibly drive from one node to another. However, getting eligible drive indicators will require all bus stops and energy consumption between them.

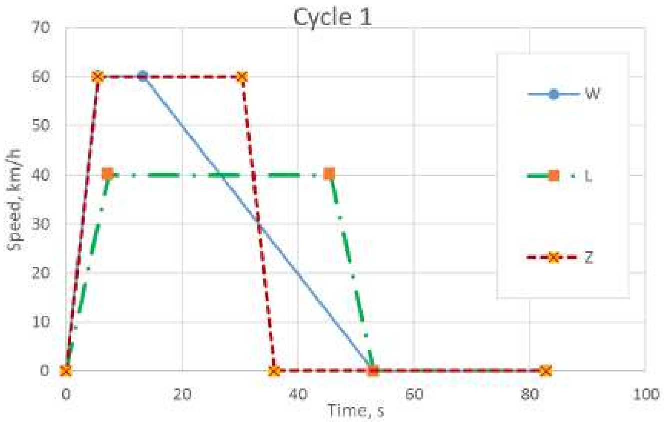
6 Experimental study of working process of electric bus by example of Belkommunmash

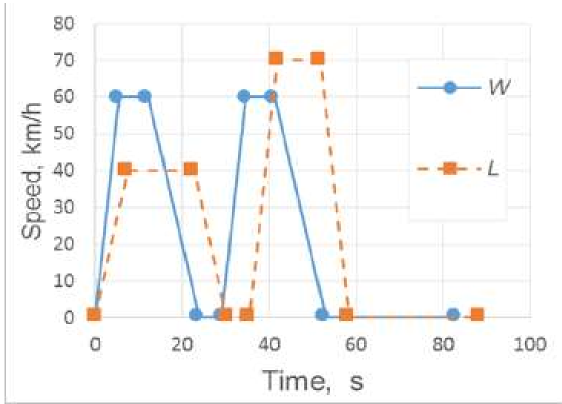
6.1 Test objective

Test objective is determination of the energy consumption depending on the electric bus loading, driving style and route factors

Bus loading	Bus mass, kg
No passengers	12 000
Average passengers	15 000
Max passengers	18 000

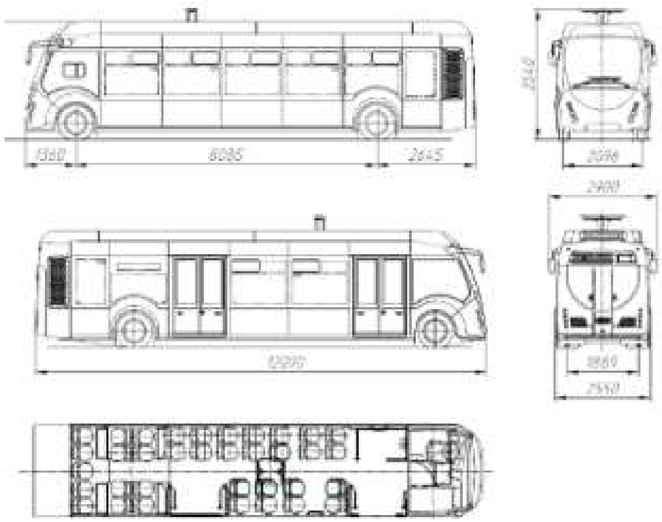
Speed profiles (Cycle 1 **non-stop**) for **driving styles**:
L=Calm; **W=Aggressive**; Z=Super-aggressive





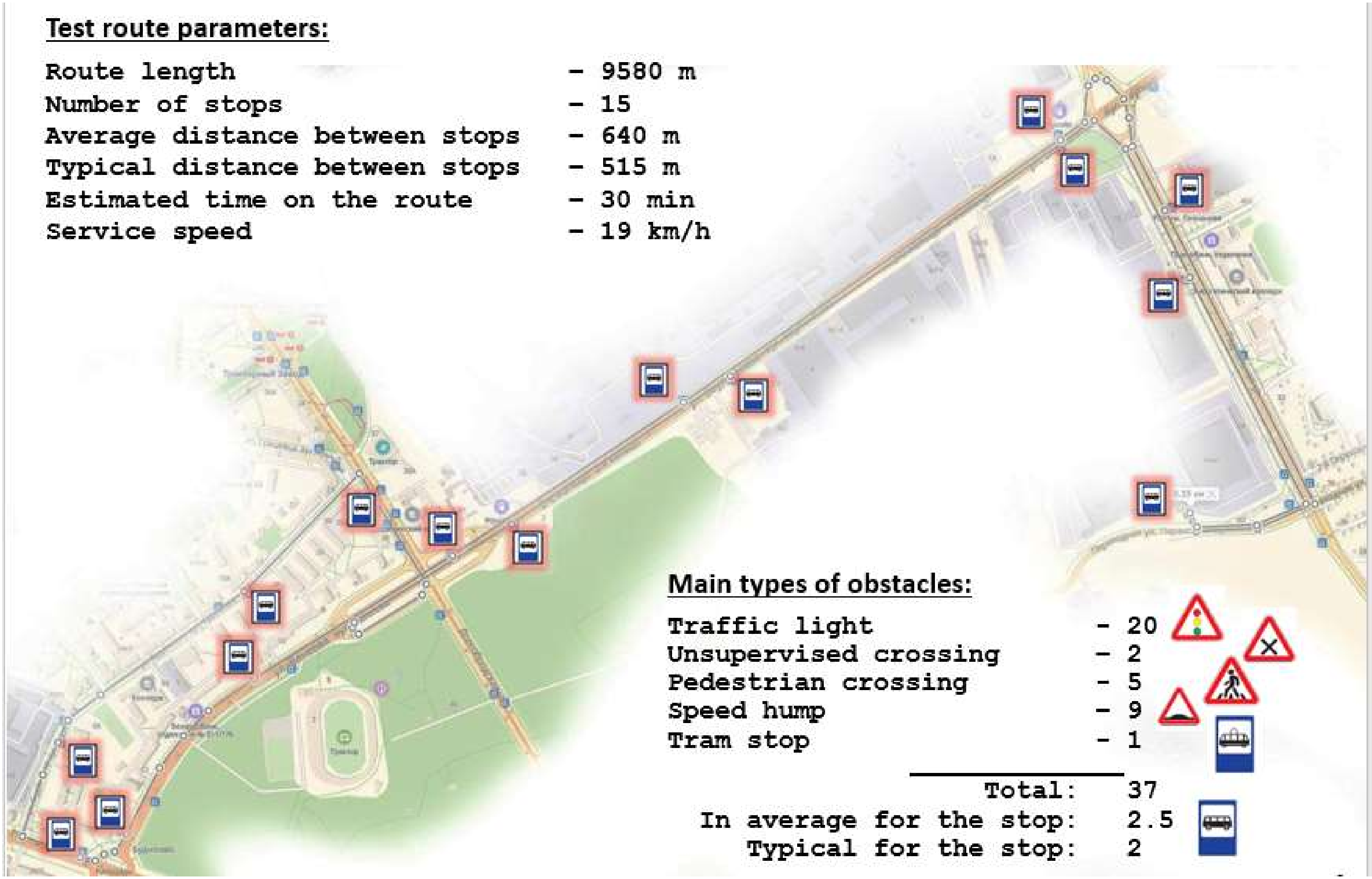
Speed profiles for Cycle 3
with an unexpected intermediate stop

6.2 Main technical characteristics of the E420 Belkommunmash electric bus

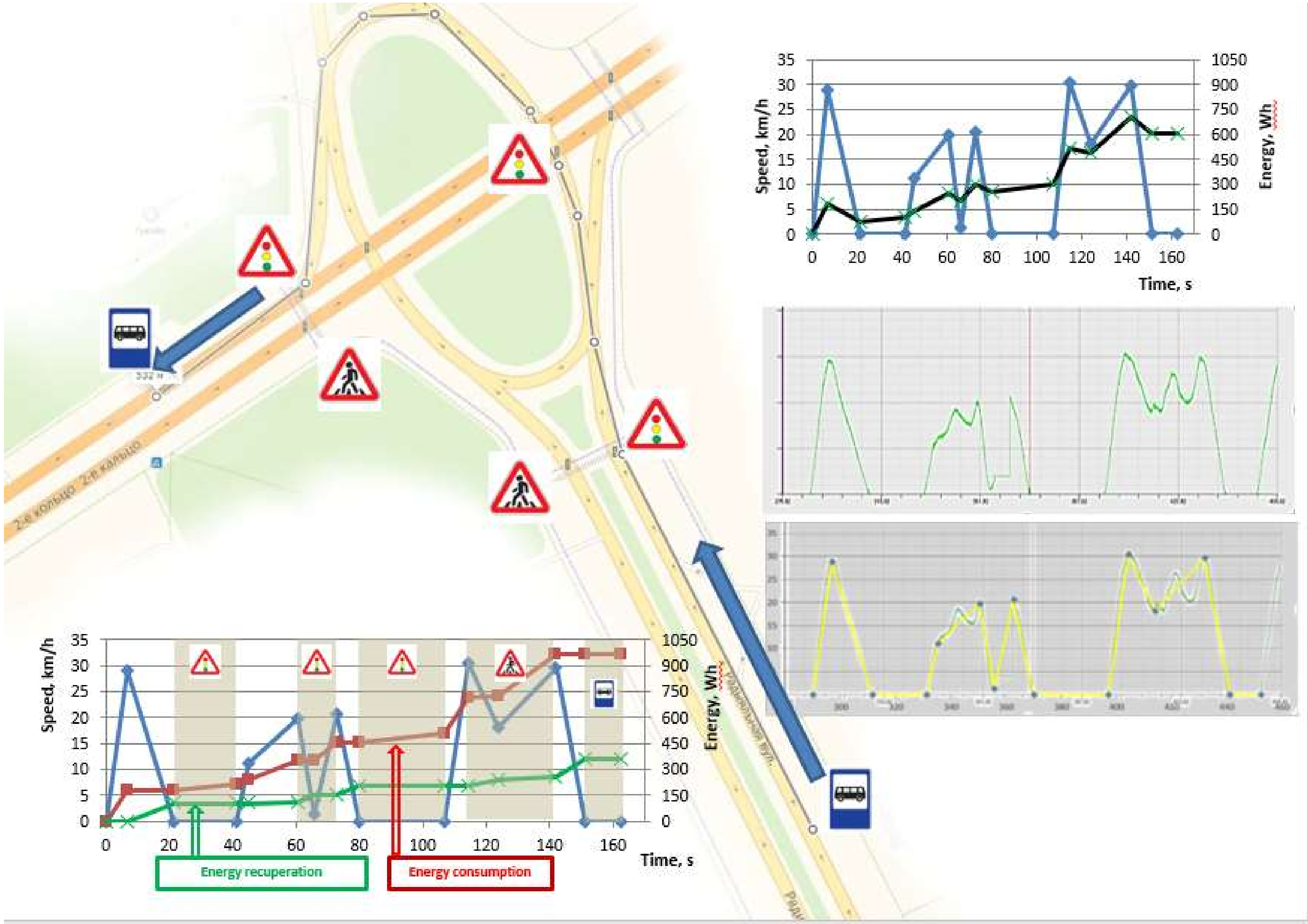


Parameter name	Parameter value
Total number of passengers	86
Number of seats	35
Length, m	12
Tire	275/70 R22,5
Frontal area, m^2	6,59
Technically permissible maximum mass, kg	18000
Kerb mass, kg	11960
Traction motor power, kW	160
Efficient energy storage of supercapacitors, kWh	34
Maximum speed, km/h	60
Gradeability with maximum technical mass, %	8
Wheel arrangement / driving wheels	4x2 / rear
Kilometrage at the maximum technical mass and the work of all consumers on one charge, taking into account the energy reserve of at least 10%, km, at least	25
Charging time of the electric bus at a current of 400A, min: – with a residual charge at least 10% – at the complete discharge	 15 15
Supercapacitors: – rated voltage, V – working charge current, A	 530 120
Acceleration time of the electric bus with the maximum technical mass from a standstill to a speed of 40 km/h on a straight horizontal section at the maximum operating voltage of the supercapacitors, s	15

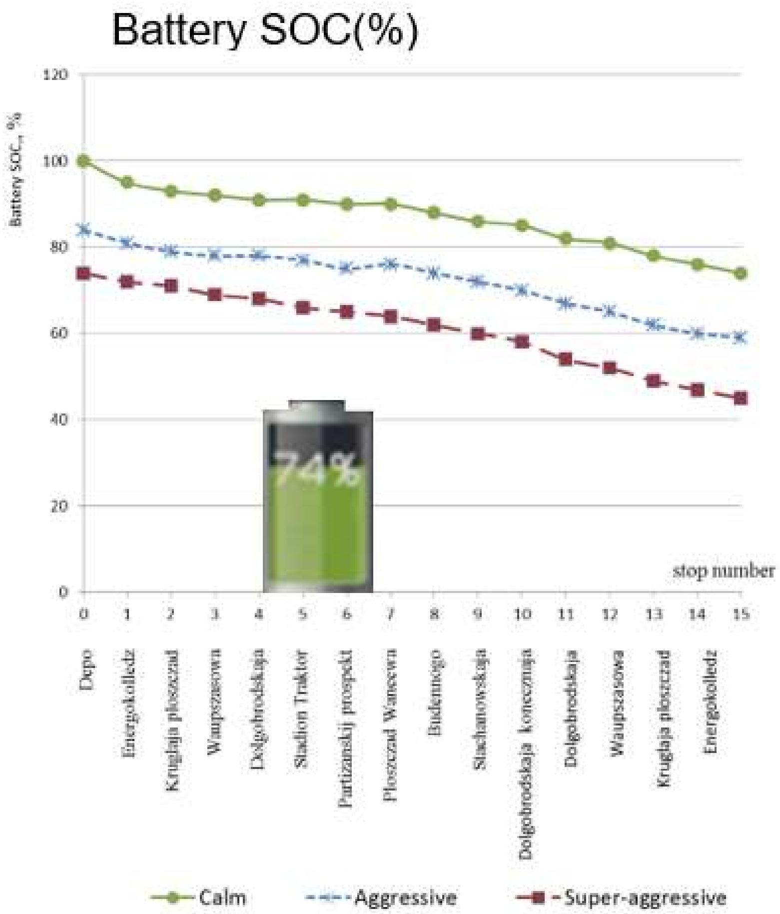
6.3 Test route



6.4 Test route segment "from–stop-to-stop"



6.5 Battery SOC for different driving styles



Power transfer

$$P_{SC} \rightarrow P_{AD} \rightarrow \Delta P_C \rightarrow U_{TM} \cdot I_{TM} \rightarrow T_{TM} \cdot \omega_{TM} \leftrightarrow F_T(t) \cdot V(t),$$

P_{SC} – supercapacitor power;

P_{AD} – power spent on auxiliary drives;

ΔP_C – power loss in converter;

U_{TM}, I_{TM} – voltage and current of traction motor;

T_{TM} – torque of traction motor;

ω_{TM} – angular velocity of traction motor;

$F_T(t)$ – tractive force on driving wheels;

V – electric bus speed;

t – time

ELECTROMECHANICAL POWER PLANT EFFICIENCY

$$\eta_{EPP} = \eta_C \cdot \eta_{TM} \cdot \eta_M = 0,88,$$

η_{EPP} – electromechanical power plant efficiency;

η_C = 0,98 – converter efficiency;

η_{TM} = 0,95 – traction motor efficiency;

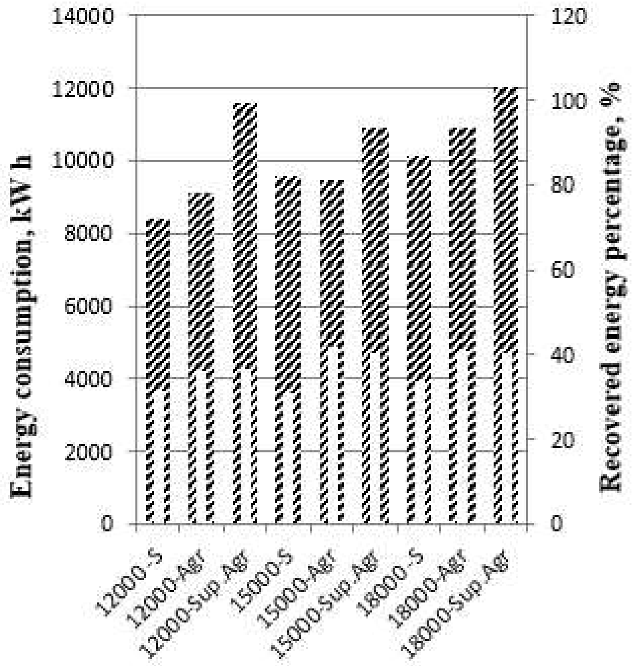
η_M = 0,95 – efficiency of the mechanical part of the power plant (reducer).

6.6 Energy consumption depending on the electric bus loading & driving style

Driving style	The energy consumption taking into account the recovery, Wh	Recovered energy percentage, %	Power consumption per kilometer, kWh/km	Driving style Factor
	No pass – 12000 kg			
Calm	8422,48	31,40%	0,88	
Aggressive	9152,09	36,30%	0,96	1,09
Super-Aggressive	11583,73	36,60%	1,21	1,38
	Av pass – 15000 kg			
Calm	9564,03	31,00%	1,04 *	
Aggressive	9461,94	41,70%	0,99	0,95
Super-Aggressive	10923,48	40,60%	1,16 *	1,12
	Max pass – 18000 kg			
Calm	10155,55	33,65%	1,11	
Aggressive	10919,13	40,76%	1,14	1,03
Super-Aggressive	12048,43	40,40%	1,25	1,13

Loading	Mass, kg	Energy Consumption, kWh/km
No pass	12 000	0.88/0.96/1.21
Av pass	15 000	1.04*/0.99/1.16*
Max pass	18 000	1.11/1.14/1.25

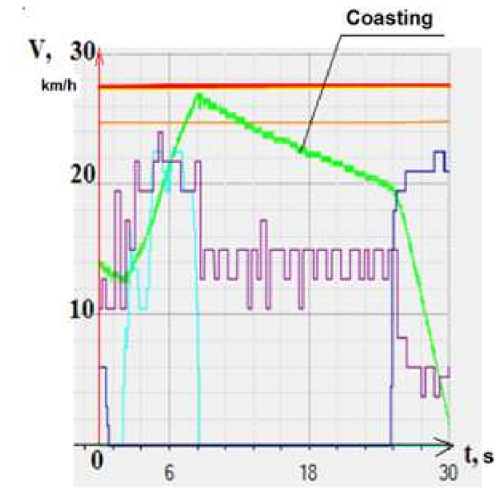
* Busy hour

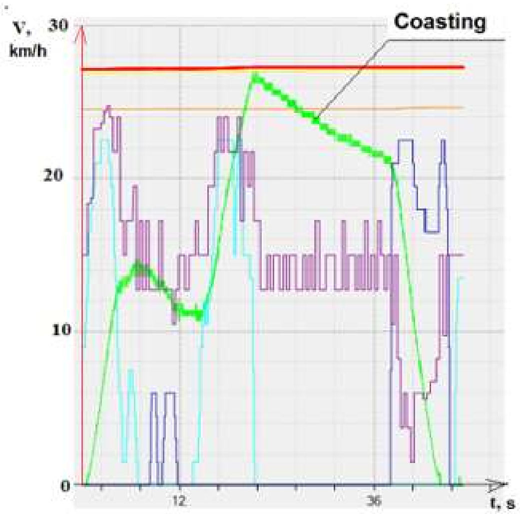


Experimental values of energies:

- The energy consumption taking into account the recovery (▒)
and
- Recovered energy percentage (□)

6.7 Experimental determination of rolling resistance coefficient under free running-out of electric bus





Mathematical model

$$\frac{\delta m(V_1^2 - V_2^2)}{2} = \psi m g S_{12} + \int_{t_1}^{t_2} k_a F_a V^3 dt$$

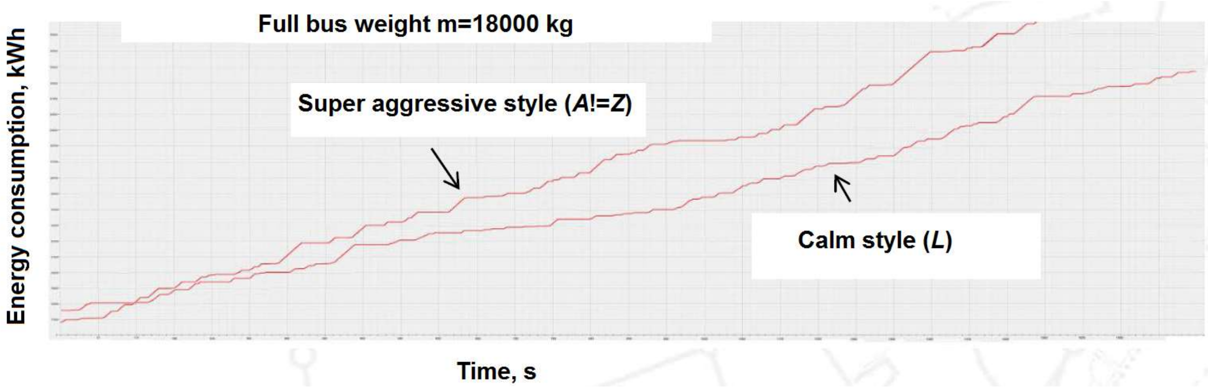
δ – rotational inertia coefficient of the electric bus;
m – electric bus mass;
V_1, V_2 – electric bus speed at the beginning and end of the coasting;
ψ – rolling resistance coefficient;
g – acceleration of gravity;
S_{12} – coasting distance;
t_1, t_2 – start and end time of coasting;
k_a – air resistance coefficient;
F_a – frontal area of the electric bus

Calculation results:

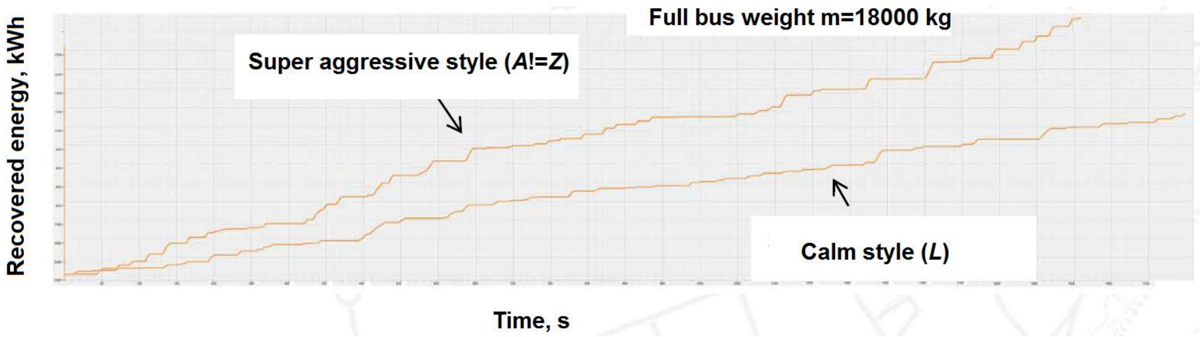
$$\psi_1 = 0,011; \quad \psi_2 = 0,013$$
$$\psi_{ave} = 0,012$$

6.8 Energy consumption and recovery processes during typical traffic phases

During the tests, the processes of consumption and energy recovery were recorded by two different sensors. To estimate the net energy consumption, it is necessary to use the difference in readings of the indicated sensors. Below there are typical records of these processes (Figures 25-28).

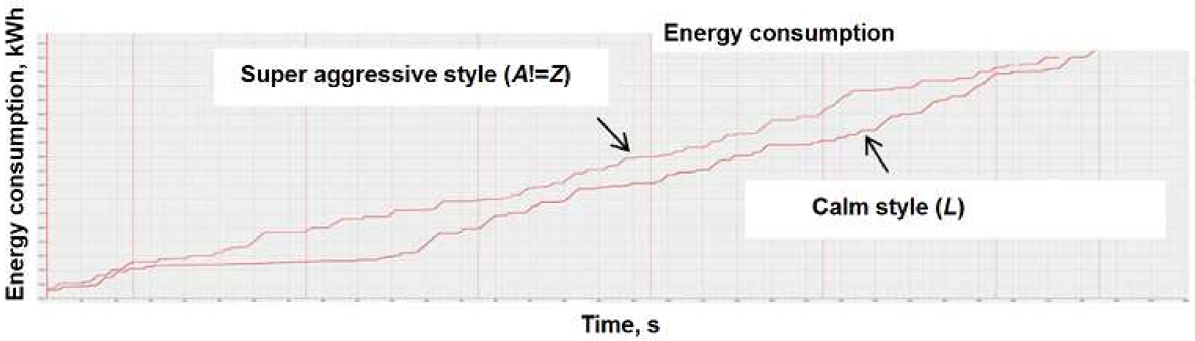


a

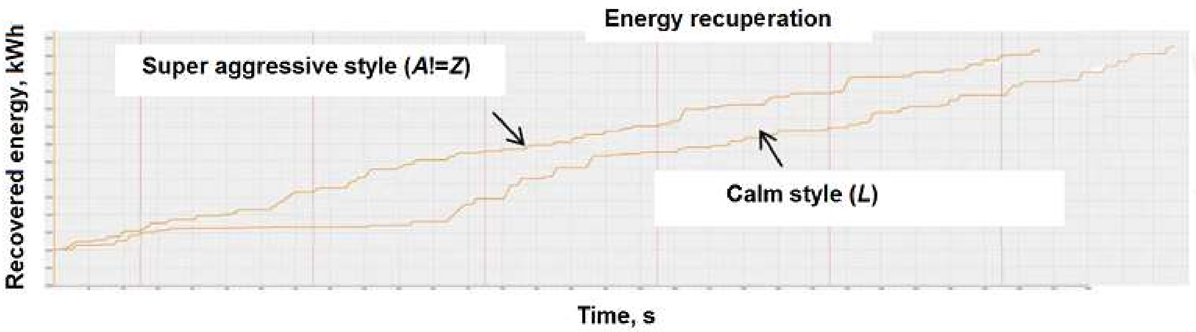


b

Figure 25 Energy consumption (a) and recuperation (b) processes (not busy hour)

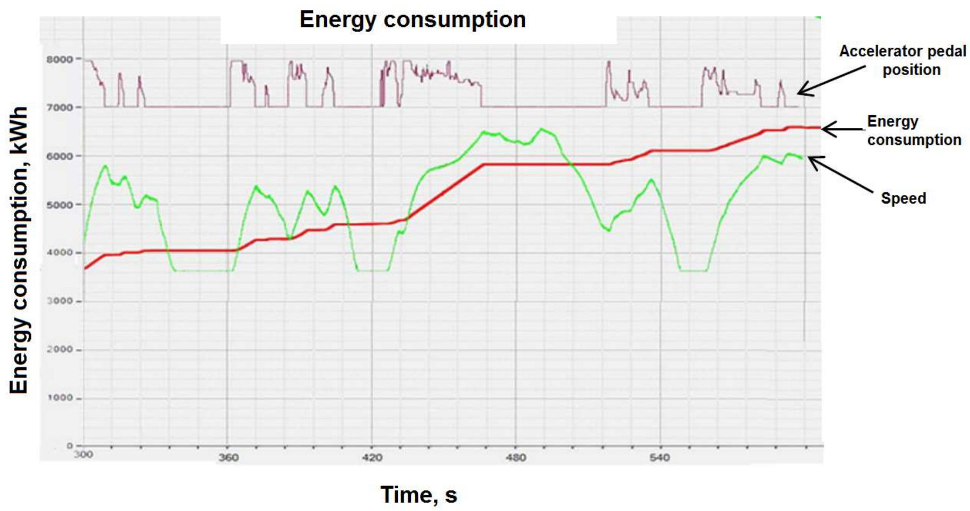


a

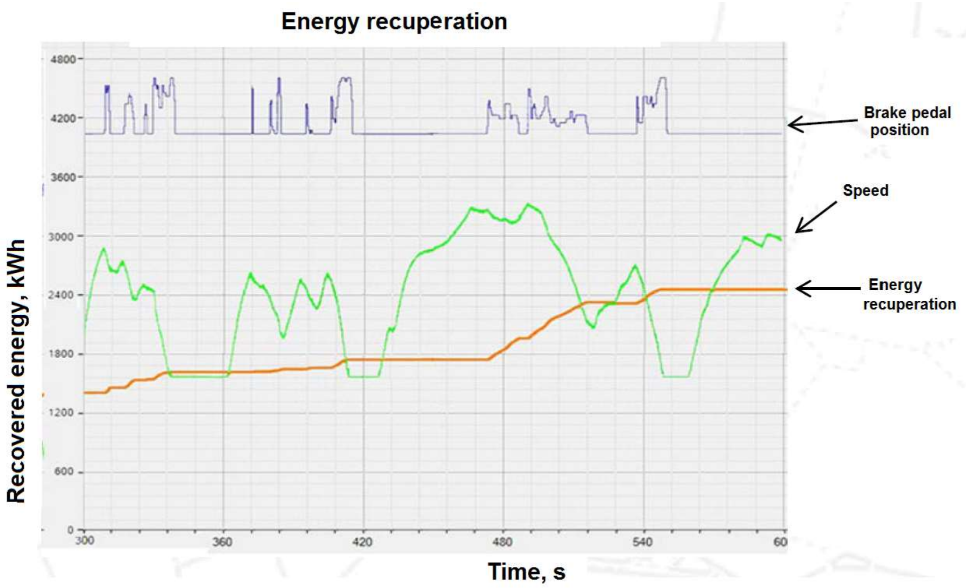


b

Figure 26 Energy consumption (a) and recuperation (b) processes during busy hour

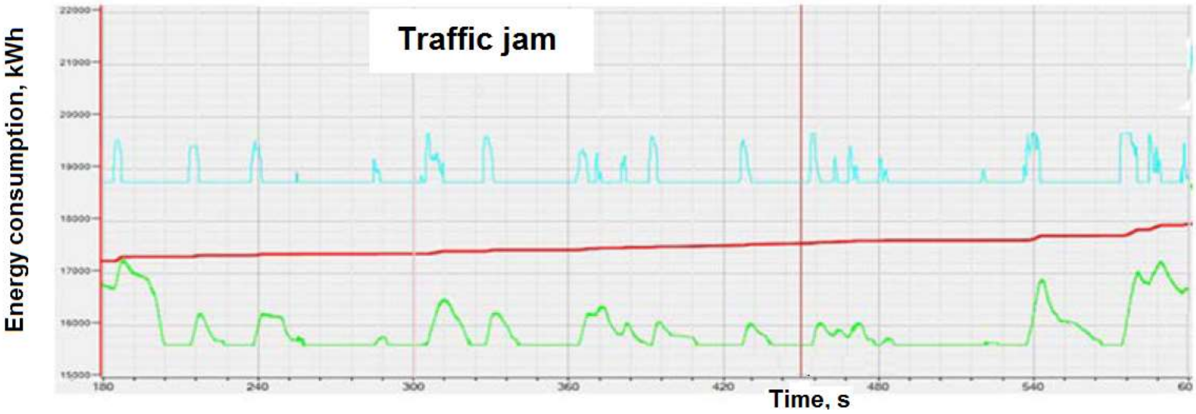


a

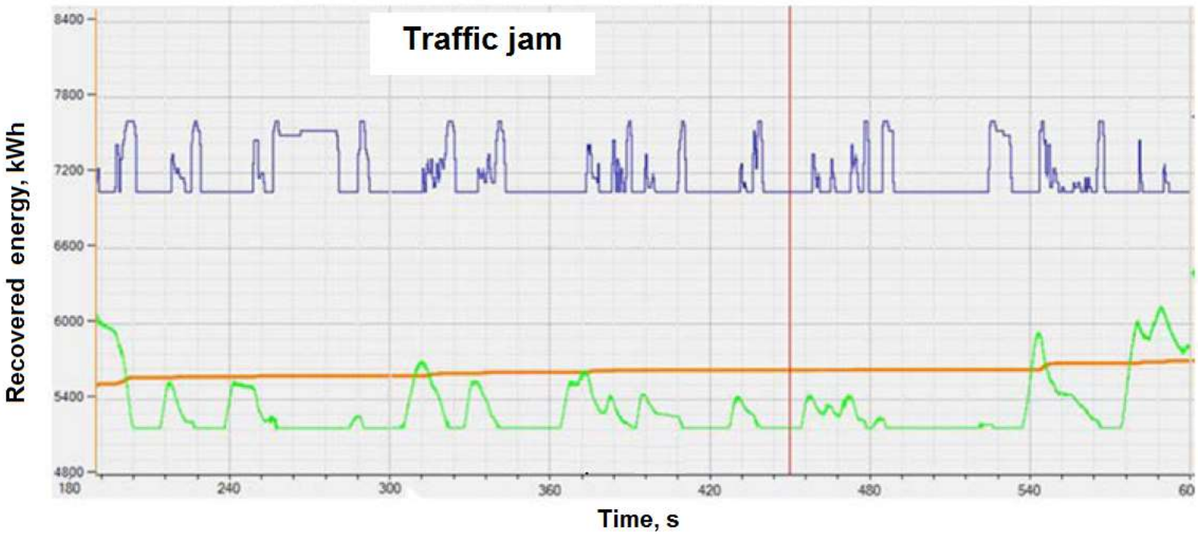


b

Figure 27 Typical control, speed and energetic processes: a=energy consumption, b=energy recuperation



a



b

Figure 28 Energy consumption (*a*) and recuperation (*b*) processes during traffic jam

From the presented data it follows that the difference in driving styles is especially evident during free traffic. At peak hour the difference in driving styles is not significant.

Traffic in traffic jams does not lead to significant energy consumption. However, the negative effect of traffic jams is that the time spent has to be compensated and the driver is forced to use an aggressive driving style for this.

6.9 Conclusion on test results

1. Averaged by driving styles, energy consumption (including recovery) was:
- for an empty e-bus (12,000 kg) 1.02 kWh / km,
- for a fully loaded e-bus (18,000 kg) 1.17 kWh / km, i.e. 15% more.

For aggressive driving style with an increase in the mass of the electric bus 12-15-18 t, energy consumption grows as 0.96-0.99-1.14 kWh / km.

So a heavier bus is less sensitive to changes in driving style.

2. The energy consumption (EC) averaged over the mass of the electric bus (taking into account the recovery) is:
- for a quiet driving style EC= 0.995 kWh / km,
- for aggressive EC= 1.03 kWh / km,

- for super aggressive EC= 1.23 kWh / km (it increases by 23.5%).

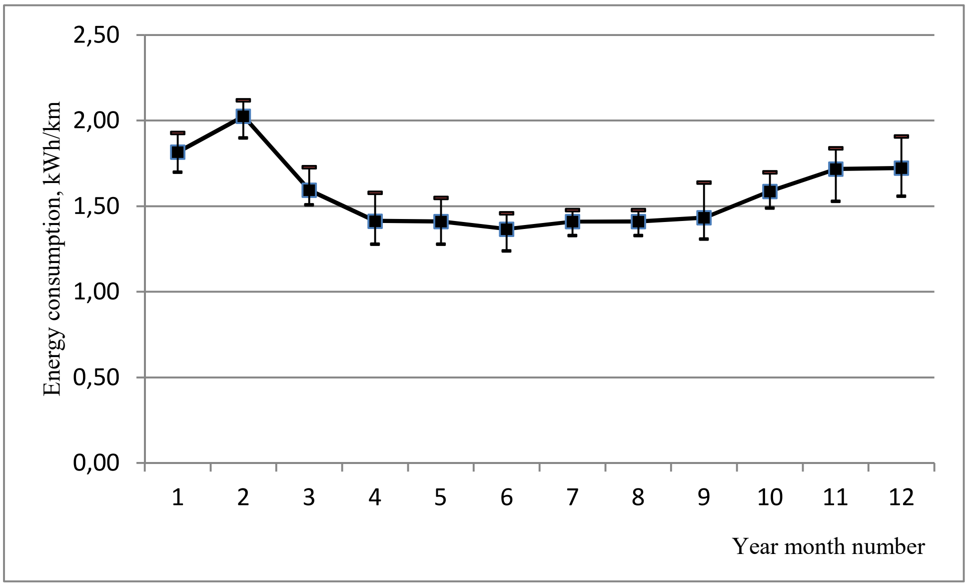
*Thus, the driving style has a greater effect on energy consumption than the mass of the electric bus***.**

3. The ratio of recovered energy to expended energy, depending on driving style and electric bus loading, ranges from 31% to 40.76%.
4. To calculate energy consumption, it is necessary to know the rolling resistance coefficient. The experimentally found values of the results of the study of run-out of the electric bus gave the following values of the coefficients: 0.011 and 0.013, or on average it is equal to 0.012.

6.10 Operation data

Data reflecting the effect of the seasonal factor are presented in Fig. 29. For their formation, data were used on 15 electric buses that run along the same route.

a



b

jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec	annual
−4,5	−4,4	0,0	7,2	13,3	16,4	18,5	17,5	12,1	6,6	0,6	−3,4	6,7

Figure 29 Average energy consumption of 15 electric buses on the same route (*a*) and average temperature in Minsk (*b*) depending on month

The maximum average value is 2.03 kWh / km (February), and the minimum average value is 1.37 kWh / km (June). Their ratio 2.03 / 1.37 = 1.49.

These data can be taken as typical for assessing the impact of the seasonal factor on buses of a similar type. For the type of bus under consideration, it should be noted that:

bus battery is used

- for heating the driver's cab
- manage ventilation

bus battery not used

- for heating the passenger compartment of the bus (Webasto device is used for this)
- for opening and closing doors (for this, a pneumatic system is used)

Increasing in energy consumption during winter months can be explained by using bus battery for heating and ventilating operation, but additional factors are

- increasing rolling resistance because of winter tires,
- road coverage (snow is often),
- more complicated traffic condition, and
- harder battery work under minus temperatures.

7 Patent information research. Creation and development of databases on electric buses and their working process

The object of the study are electric buses, charging methods, modeling the working cycles of the electric bus and energy storage device.

The purpose of the work is to determine the technical level of the object of study as well to identify trends and promising directions of its development.

The research method is analytical review by keywords, names of manufacturing companies, UDC classification headings.

The analysis of the patent and scientific and technical literature on the design of electric buses, electric traction systems, electrical energy storage devices, charging devices and methods, modeling the working cycles of the electric bus and energy storage is carried out. Trends in the development of the object of study are identified.

7.1 General data on object of research

Patent-Information research provides for patent search and review of current and prospective operational, technical, economic and ecological input data (e.g. battery types and capabilities, bus types and capabilities, energy storage devices, charging methods, funding aspects, power grid). Standard battery charging is considered as well as opportunity charging and fast charging.

The formation of the information bases provides the accumulation of information on the characteristics of electric buses, energy storage systems and charging, as well as on the effects of the primary factors such as operating conditions and additional factors (climatic and weather conditions, temperature, topography of the route, driving style, fast or slow charging, etc.) and summary review for their impact on the technical characteristics of energy storage devices.

Support and temporal progress of information databases allows to accumulate, adjust and use in the process of PLATON life cycle information on characteristics of electric buses, energy storage systems and charging for their models according to certain technical and economic characteristics and the criteria determined by the user.

The study of typical operating cycles of electric buses includes selection and formation of the complex model of city routes of passenger land transport, analysis, classification and typification, in terms of passenger traffic (i.e., load of machinery) and characteristics of the route (its distance and elevation changes, number of stops and duration of vehicle downtime during embarkation/disembarkation of passengers, idle time at intersections and traffic lights, busy streets in rush hours, etc.).

The formation of typical working cycles (starting – movement – stopping) for electric buses between stopping points, taking into account the terrain, driving style, climate and weather conditions and their impact on the *processes of degradation of energy storage devices,* provides for analysis of processes of charging, energy recovery and energy consumption in the movement of electric buses within the model cycles.

Keywords

1. Electric bus:

- passenger vehicle

- electric propulsion

- electric energy storage

-charging methods

- feeding power to the supply lines

2. Modelling

- method

- driving cycles of the electric bus and the energy storage

Object of research

Methods of modeling the working cycles of the electric bus, their energy storage devices. Meanwhile, it is taken into account and generalizes the features and the variety of types, designs and values of the parameters of the main components of the electric bus: electric traction systems, electrical energy storage devices, charging methods.

7.2 Search of patent sources

As a result of the analysis of the IPC symbols as well as trial searches for the key words, classification IPC symbols are determined, which are used in the search with data selection.

Classification symbols relating to an electric vehicle, electric bus are used in the search along with the corresponding keywords. Keywords are used (electric vehicle, bus), and also keywords characterizing the main types of energy storage devices: battery, supercapacitor, and the process of their charging.

The classification symbols relating to the simulation of the driving cycles of the electric bus and the energy storage devices are used in the search along with the corresponding keywords: simulation, modelling, working / driving cycle, vehicle, route.

Classification symbols of the IPC for conducting a patent search are selected below. At the same time, higher classification symbols are given, beginning with the corresponding class.

B60 — VEHICLES IN GENERAL

B60L — PROPULSION OF ELECTRICALLY-PROPELLED VEHICLES

B60L 11/00 — Electric propulsion with power supplied within the vehicle

B60L 11/18 • using power supplied from primary cells, secondary cells, or fuel cells

B60M — POWER SUPPLY LINES, OR DEVICES ALONG RAILS, FOR ELECTRICALLY-PROPELLED VEHICLES

B60M 3/00 — Feeding power to the supply lines in contact with collector on vehicles; Arrangements for consuming regenerative powerмощности

B60W— CONJOINT CONTROL OF VEHICLE SUB-UNITS OF DIFFERENT TYPE OR DIFFERENT FUNCTION; CONTROL SYSTEMS SPECIALLY ADAPTED FOR HYBRID VEHICLES; ROAD VEHICLE DRIVE CONTROL SYSTEMS FOR PURPOSES NOT RELATED TO THE CONTROL OF A PARTICULAR SUB-UNIT

B60W 30/00 — Purposes of road vehicle drive control systems not related to the control of a particular sub-unit, e.g. of systems using conjoint control of vehicle sub-units

B60W 30/18 • Propelling the vehicle

B60W 40/00 — Estimation or calculation of driving parameters for road vehicle drive control systems not related to the control of a particular sub-unit

B60W 50/00 — Details of control systems for road vehicle drive control not related to the control of a particular sub-unit

B62— LAND VEHICLES FOR TRAVELLING OTHERWISE THAN ON RAILS

B62D – MOTOR VEHICLES; TRAILERS

B62D 47/00 Motor vehicles or trailers predominantly for carrying passengers

B62D 47/02 • for large numbers of passengers, e.g. omnibus

H01— BASIC ELECTRIC ELEMENTS

H01G — CAPACITORS; CAPACITORS, RECTIFIERS, DETECTORS, SWITCHING DEVICES, LIGHT-SENSITIVE OR TEMPERATURE-SENSITIVE DEVICES OF THE ELECTROLYTIC TYPE

H01G 4/00 — Fixed capacitors; Processes of their manufacture

H01G 11/00 — Hybrid capacitors, i.e. capacitors having different positive and negative electrodes; Electric double-layer [EDL] capacitors; Processes for the manufacture thereof or of parts thereof

H01M — PROCESSES OR MEANS, e.g. BATTERIES, FOR THE DIRECT CONVERSION OF CHEMICAL ENERGY INTO ELECTRICAL ENERGY

H01M 2/00— Constructional details, or processes of manufacture, of the non-active parts

H01M 10/00— Secondary cells; Manufacture thereof

Note(s) In this group, secondary cells are accumulators receiving and supplying electrical energy by means of reversible electrochemical reactions

H01M 12/00— Hybrid cells; Manufacture thereof

H02— GENERATION, CONVERSION, OR DISTRIBUTION OF ELECTRIC POWER

H02J — CIRCUIT ARRANGEMENTS OR SYSTEMS FOR SUPPLYING OR DISTRIBUTING ELECTRIC POWER; SYSTEMS FOR STORING ELECTRIC ENERGY

H02J 7/00 — Circuit arrangements for charging or depolarising batteries or for supplying loads from batteries

H02J 15/00 — Systems for storing electric energy

H02J 50/00 — Circuit arrangements or systems for wireless supply or distribution of electric power

G01— MEASURING; TESTING

G01C— MEASURING DISTANCES, LEVELS OR BEARINGS; SURVEYING; NAVIGATION; GYROSCOPIC INSTRUMENTS; PHOTOGRAMMETRY OR VIDEOGRAMMETRY

G01C 21/00— Navigation

G06 — COMPUTING; CALCULATING; COUNTING

G06F— ELECTRIC DIGITAL DATA PROCESSING

G06F 9/00— Arrangements for program control, e.g. control units

G06F 9/04 • using record carriers containing only program instructions

G06F 17/00 — Digital computing or data processing equipment or methods, specially adapted for specific functions

G06N — COMPUTER SYSTEMS BASED ON SPECIFIC COMPUTATIONAL MODELS

G06N 7/00 — Computer systems based on specific mathematical models

G06Q — DATA PROCESSING SYSTEMS OR METHODS, SPECIALLY ADAPTED FOR ADMINISTRATIVE, COMMERCIAL, FINANCIAL, MANAGERIAL, SUPERVISORY OR FORECASTING PURPOSES; SYSTEMS OR METHODS SPECIALLY ADAPTED FOR ADMINISTRATIVE, COMMERCIAL, FINANCIAL, MANAGERIAL, SUPERVISORY OR FORECASTING PURPOSES, NOT OTHERWISE PROVIDED FOR

G06Q 50/00— Systems or methods specially adapted for specific business sectors, e.g. utilities or tourism

G06Q 50/30 • Transportation; Communications

G07— CHECKING-DEVICES

G07C — TIME OR ATTENDANCE REGISTERS; REGISTERING OR INDICATING THE WORKING OF MACHINES; GENERATING RANDOM NUMBERS; VOTING OR LOTTERY APPARATUS; ARRANGEMENTS, SYSTEMS OR APPARATUS FOR CHECKING NOT PROVIDED FOR ELSEWHERE

G07C 5/00 — Registering or indicating the working of vehicles

G08 — SIGNALLING

G08G — TRAFFIC CONTROL SYSTEMS

G08G 1/00— Traffic control systems for road vehicles

Thus, the following IPC symbols are used to search for technics objects.

1. Electric bus/vehicle:

- Electric propulsion with power supplied within the vehicle using power supplied from primary cells, secondary cells, or fuel cells: B60L 11/18

- Feeding power to the supply lines in contact with collector on vehicles; Arrangements for consuming regenerative power: B60M 3/00

- Motor vehicles or trailers predominantly for carrying passengers, for large numbers of passengers, e.g. omnibus: B62D 47/02

- Fixed capacitors; Processes of their manufacture: H01G 4/00

- Batteries: H01M 2/00; H01M 10/00

- Hybrid cells: H01M 12/00

- Charging methods: H02J 7/00; H02J 15/00; H02J 50/00

2. Modelling the electric bus/vehicle:

- Propelling the vehicle: B60W 30/18

- Estimation or calculation of driving parameters for road vehicle drive control systems not related to the control of a particular sub-unit: B60W 40/00

- Details of control systems for road vehicle drive control not related to the control of a particular sub-unit: B60W 50/00

- Navigation: G01C 21/00

- Arrangements for program control, e.g. control units, using record carriers containing only program instructions: G06F 9/04

- Digital computing or data processing equipment or methods, specially adapted for specific functions: G06F 17/00

- Computer systems based on specific mathematical models: G06N 7/00

- Systems or methods specially adapted for specific business sectors, e.g. utilities or tourism: Transportation; Communications: G06Q 50/30

- Registering or indicating the working of vehicles: G07C 5/00

- Traffic control systems for road vehicles: G08G 1/00

7.3 Search for scientific and technical information

The object "electric bus" does not have a separate code position in the UDC. Therefore, the search is conducted among sources with more general codes.

UDC codes that have a relation to the object of research:

629.3 - Ground means of transport (except rail);

629.33 - Automobiles. Automotive industry (in general);

629.34 - Vehicles for the carriage of passengers.

Analysis of publications with the keyword "electric bus" shows that they are coded both as 629.33 and as 629.34. Therefore, when searching for the "electric bus" object, the publications relating to both these codes UDC 629.33 and UDC 629.34 are taken into account.

The objects "power storage" in the scientific and technical literature do not have more detailed separate code positions depending on their types and areas of use. Therefore, publications related to the code are taken into account. UDC 621.3 - Electrical engineering.

7.4 Creation and development of databases on electric buses and their working process

Results of Patent information research and creation and development of Databases on electric buses and their working process are in a project cloud [14].

They are additionally used for creating help for interested parties for selecting input data.

Example of HELP: Charging configuration, bus style and energy storage presented below.

HELP: Charging configuration, bus style and energy storage (1/6)

1. **Charging configuration Flash (Зарядная конфигурация Flash)**

	Electric bus model name, Page	Length, m	Total passengers capacity	Gross vehicle weight, kg	Power peak, kW	Torque, Nm	Total energy, kWh	Length of the bus line, km	Average commercial speed, km/h	Total driven/ day, km per day
1.	TOSA BGT-N2D, 106, 131	**18.74**	142	29,000	**240**	1,520	**70**	1	**16.75**	30

2. **Charging configuration Fast bus stop (only) (Зарядная конфигурация Fast bus stop)**

	Electric bus model name, Page	Length, m	Total passengers capacity	Gross vehicle weight, kg	Power peak, kW	Torque, Nm	Total energy, kWh	Length of the bus line, km	Average commercial speed, km/h	Total driven/ day, km per day
1.	Chariot ebus, 126	12	91	19,000	180	2,500	**21**			
2.	Dancer, 127	12	93	6,500	2 wheels 125 kW each	2 wheels 11,000 Nm each	**29.2**			

3. **Charging configuration Terminal (only) (Зарядная конфигурация Terminal)**

	Electric bus model name. Page	Length, m	Total passengers capacity	Gross vehicle weight, kg	Power peak, kW	Torque, Nm	Total energy, kWh	Length of the bus line, km	Average commercial speed, km/h	Total driven/ day, km per day
1.	Optare Solo EV, 139	9.2 and 9.9	55	11,300	**150**	2,000	92-**138**	5	20	140
2.	Modulo C88e, 129	9.457	74	11,050	160	1,019	84			
3.	Optare Versa EV, 139 , 114-116	10.4-11.1	58	12,480	150	2,000	92-138	11/13	17.5	100
4.	Optare Metrocity EV, 139, 111	10.8	58	12,960	150	2,000	92-138	13	15	150-250

HELP: Charging configuration, bus style and energy storage (2/6)

	Electric bus model name. Page	Length, m	Total passengers capacity	Gross vehicle weight, kg	Power peak, kW	Torque, Nm	Total energy, kWh	Length of the bus line, km	Average commercial speed, km/h	Total driven/ day, km per day
5.	SOR EBN 11, 29, 147	11.1	93	16,500	120	968	172	13.4/17.5/ 13.9/18.1	14.3/19.4/ 16.6/14.9	265-340
6.	Ursus Bus Ekovolt. 82, 150	11.96	81	18,000	170	1,100	120	9.5	16.5	120
7.	e. City Gold, 84, 125	11.995	88	19,000	160	1,500	**50-250**	19.62	NC	NC
8.	Skoda Perun HE, 28, 144	12	82	18,600	160	1,800	80	6	25	80-200
9.	Temsa Avenue EV, 148	12	90	19,000	270	2,700	**75**	NC	NC	NC
10.	Ursus Bus City Smile, 150	12	62	18,000	170	1,100	**175**	NC	NC	
11.	Volvo 7900 Electric, 157, 24	12	94	12,000	155	1,200	76	9.5/15/13.2	18/16/13	145/183/ 139
12.	Linkker 12+ LE, 31, 138	12.8	80	16,000	180	7,800	79	8.8-9.4	15	210-260
13.	eCobus, 60, 125	13.92	112	20,000	160	1,500	85	Different routes	**35**	90
14.	HEULIEZ BUS GX437 ELEC, 132	**18**	155	30,000	160/200	2,400/ 5,100	160	NC	NC	NC
15.	Ursus Bus City Smile, 150	**18**	104	28,000	**452**	10,800	105			
16.	VDL Citea SLFA-180 Electric, 50, 154	**18**	145	29,000	210	3,800	**85-248**	6.7-7.0	**16**-18	120
17.	Citea SLFA-181 Electric, 154	**18.15**	136	29,000	210	3,800	85-248	4.4/8.2/ 10.9	18.5-**27.5**	200-300

HELP: Charging configuration, bus style and energy storage (3/6)

4 Charging configuration Slow depot + 1 or 2 or 3 (Зарядная конфигурация Slow depot в сочетании с 1 или 2 или 3)

	Electric bus model name. Page	Length., m	Total passengers capacity	Gross vehicle weight, kg	Power peak, kW	Torque, Nm	Total energy, kWh	Length of the bus line, km	Average commercial speed, km/h	Total driven/ day, km per day
1.	Ursus Bus City Smile, 150	9.95	84	18,000	120	835	210	NC	NC	NC
2.	VDL Citea LLE-99 Electric, 154	9.95	63	14,870	153	2,500	180	NC	NC	NC
3.	Hybricon City bus HCB 12 LF, 103, 133	12	62	18,000	314	2,100	**265**	15/16/ 14	20.0	250
4.	Rampini E12, 142	12	70	19,000	150-160	980-2,180	**180**	NC	NC	NC
5.	Solaris Urbino 12 electric, 145, 54	12	90	19,000	2x125	2x11,000	240	16.0	18.0	300
6.	Hybricon Arctic Whisper HAW 18 LE 4WD, 103, 134	18	100	28,000	628	2,100	**120**	15/16/ 14	20.0	250
7.	BYD 18m Articulated, 123	18	150	28,000	2x150	2x350	NC	NC	NC	NC
8.	Van Hool Exqui.City 18m 100% Battery, 152	**18.61**	117	28,000	2x160	1,500	**215**	NC	NC	NC
9.	Irizar ie tram (previously i2e 18m), 136	**18.73**	150	28,000	230	2,350	120-180	NC	NC	NC
10.	Sileo S24, 122	**24**	-	-	4x120	42,000	**380**	NC	NC	NC

HELP: Charging configuration, bus style and energy storage (4/6)

5. Charging configuration Slow depot (only) (Зарядная конфигурация Slow depot)

	Electric bus model name. Page	Length, m	Total passengers capacity	Gross vehicle weight, kg	Power peak, kW	Torque, Nm	Total energy, kWh	Length of the bus line, km	Average commercial speed, km/h	Total driven/ day, km per day
1.	Modulo C68e, 61 129	7.98	55	10,350	160	1,019	**144**	11.3/1.4/3.3 /4.5/10.36/ 1.8/3.2	10.5/**9.0**/9.7/ 9.0/9.7/9.5/ 8.9	148/125. 3/171.7/ 238.4/14 8/125.3/ 78.9
2.	Ursus Bus City Smile, 150	8.5	61	16,000	170	1,100	175	NC	NC	NC
3.	BYD midi bus, 123	8.7	54	13,000	2x90	2x350	NC	NC	NC	NC
4.	Solaris Urbino 8.9 LE electric, 145, 22	8.95	65	16,000	170	903	160	7.5	19	110
5.	Otokar Electra, 141	9	55	13,500	103	380	170	NC	NC	NC
6.	Temsa MD9 electric CITY, 148	9.3	65	14,000	200	2,200	200	NC	NC	NC
7.	**BYD 10.8m** Variants, 123	9.6-11.5	90	19,000	2x90/150	2x350/ 550	NC	NC	NC	NC
8.	BYD Double Decker, 111, 123	10.2-12	95	20,000	2x150	2x350	NC	13	15	150-250
9.	SOR EBN 10.5, 85, 147	10.37	82	16,500	120	968	172	22.4	15.1	114-187
10.	Optare Metrodecker EV, 139	10.5	99	18,000	200	3,570	**200**	NC	NC	NC

HELP: Charging configuration, bus style and energy storage (5/6)

	Electric bus model name. Page	Length, m	Total passengers capacity	Gross vehicle weight, kg	Power peak, kW	Torque, Nm	Total energy, kWh	Length of the bus line, km	Average commercial speed, km/h	Total driven/ day, km per day
11.	BYD ADL Enviro200EV, 111, 119	10.8	78	18,600	180	700	307	9	15	150-250
12.	Sileo S10, 45, 122	10.7	78	18,000	240	21,000	200	4.6	28	200
13.	Irizar ie bus (previously i2e), 39, 136	11.98	80	20,000	180	1,800	**376**	5.5	14-16	141
14.	BYD ADL Enviro200EV, 111, 119	12	90	18,600	180	700	324	11	12	150-250
15.	APTIS, 43, 120	12	77	NC	180	970	346	12.0	18.0-22.0	90
16.	APTIS, 120	12	77	NC	180	970	272	NC	NC	NC
17.	Bluebus 12m, Source: RATP - Denis Sutton, 41, 121	12	97	20,000	160	2,500	240	10	10	180
18.	Sileo S12, 44, 122	12	79	18,000	2x120	21,000	230	NC	22	200
19.	Ebusco 2.1 HV LF-311-HV-2/3, 67, 128	12	90	12,000	220	3,000	311	15.5	30	161.3
20.	BYD 12m China, 111, 123	12	75	18,000	2x90	2x350	NC	5.84/9.41	22	183/228.5
21.	BYD 12m Overseas, 65, 123	12	75	19,000	2x90/150	2x350/ 550	NC	9.41/11.54	13.5	120
22.	BYD 12m Coach, 123	12	59	19,000	2x180	2x1,500	NC	NC	NC	NC

HELP: Charging configuration, bus style and energy storage (6/6)

	Electric bus model name. Page	Length, m	Total passengers capacity	Gross vehicle weight, kg	Power peak, kW	Torque, Nm	Total energy, kWh	Length of the bus line, km	Average commercial speed, km/h	Total driven/ day, km per day
23.	Ebusco 2.1 HV LF-311-HV-2/3, 67, 128	12	90	12,000	220	3,000	311	15.5	**30**	161.3
24.	HEULIEZ BUS GX 337 ELEC, 40, 131	12	94	20,000	120/190	1,610/ 3,300	349	3.9	18	200
25.	TEG6125BEV03, 133	12	94	19,000	150	2,500	201	NC	NC	NC
26.	Ursus Bus City Smile, 150	12	82	18,000	170	1,100	**170**	9.5	16.5	120
27.	ICe 12, 159	12	69	19,400	350	1,200/ 2,600	258	NC	NC	NC
28.	Electron E19 electric, 129	12.1	90	19,000	2x125	2x11,000	225	NC	NC	NC
29.	Sileo S18, 122	**18**	137	28,000	4x120	42,000	300	NC	NC	NC
30.	Ebusco 18M HV LF-414-HV-3/4, 128	**18**	125	19,500	2x125	2x11,00 0	**414**	NC	NC	NC
31.	Solaris Urbino 18 electric, 145, 89	**18**	129	28,000-30,000	270	1,304	**240**	12.5	12.5	NC

7.5 Placing information in the project cloud and in the National Intellectual Property Center of Belarus

Place of the information about Patent Research Report in the **project cloud** is [14]:

https://nextcloud.ifak.eu/s/QfNqteN8XK8xGex?path=%2FPro-ject%20work%2FJIME%2F!Patent-info%20research_PLATON!

Place of the information in the National Intellectual Property Center of Belarus is determined by **Patent research registration card** # 3241 (Fig. 30):

Регистрационная карта патентных исследований

Национальный центр интеллектуальной собственности

Регистрационный номер работы	Дата регистрации
3241	10 ОКТ 2018

Наименование работы Электробусы, электрические тяговые системы, накопители электрической энергии, способы зарядки и моделирования рабочих циклов

Наименование организации-исполнителя	Министерство ведомство	Код ОКПО	УНН
ГНУ «Объединенный институт машиностроения»	Национальная академия наук Беларуси	ОКПО 37584409	УНН 190410065

Адрес, телефон\факс: 220072, г.Минск, ул.Академическая, 12, тел.210 07 49

Наименование организации-заказчика	Министерство, ведомство	Код ОКПО	УНН
Национальная академия наук Беларуси	Национальная академия наук Беларуси	00019287	101078490

Адрес, телефон\факс: 220072, пр.Независимости, 66, тел. 284 18 01

Шифр работы PLATON

Figure 30 Patent research registration card # 3241

7.6 Conclusion on Patent Information Studies

Taking into account the themes of the PLATON project, analysis of patent and scientific and technical sources on electric buses, energy storages, modeling the working cycles of electric bus and energy storage have been conducted. As result, a database on search results have been formed.

A patent sources analysis allowed us to identify the most active companies and directions of patenting.

The company PROTERRA ([14], Form B1, 1, 7, 35-41) is the most active in patenting its developments. Her inventions relate to the layout of buses, for example*, the placement of batteries*: “The power source may be housed in the floor of the heavy-duty vehicle. In some instances, a plurality of battery packs may be individually mounted into cavities within the floor of a vehicle”. *The systems and methods of charging* the electric bus are also patented, for example: “A method of docking an electric vehicle at a charging station may include identifying the vehicle as it approaches the charging station and transmitting a distance parameter from the charging station to the vehicle. The distance parameter may be a measure of distance. The method may also include determining a desired speed of the vehicle based on the distance parameter using an algorithm in the vehicle, and controlling the vehicle to attain the determined desired speed” or “A vehicle and charging station can be designed such that an electric or hybrid vehicle can operate in a fashion similar to a conventional vehicle by being opportunity charged throughout a known route”.

Also, the company BYD ([14], Form B1, 2, 3, 11, 32, 33) shows high activity. Her inventions relate to the *layout of the electric bus*, for example: “The electric bus comprises: a body; a chassis; and a battery system configured to supply electric power for the electric bus, disposed at a middle part of the body, under a floor of the body and in a rear cabin of the electric bus. The battery system includes: a first battery group disposed above two front wheel caps of the middle part of the body; a second battery group disposed under a floor part of a seat region of the middle part of the body; and a third battery group disposed in the rear cabin under a floor part of a rear seat region of the body and behind a rear seat. By means of the above-mentioned technical solution, the control stability of the bus may be improved”. *Systems and methods for controlling* an electric vehicle are also patented, for example: “The charging system comprises a power battery, a charging and discharging outlet, a charging connecting device, an external power supply device and an energy conversion control device, wherein a vehicle plug of the charging connecting device is used for being connected with a charging and discharging socket, the external power supply device is connected with a power supply plug of the charging connecting device, and the energy conversion control device comprises a three-level bidirectional DC/AC module, the charging and discharging control module and a controller module. PWM (pulse width modulation) signals transmitted and modulated between the energy conversion control device and the external power supply device through the charging connecting device are used for mutual communication, and the three-level DC/AC module and the charging and discharging module are controlled by the controller module so as to enable the external power device to charge the power battery. The charging system is controlled by three levels without DC-DC (direct current) modules, high-power charging is realized, bus voltage is reduced, efficiency is high and charging time is short”.

Among other companies there are (by degree of activity) MAN TRUCK ([14], Forms B1, 5, 6, 8, 15, 16), TOYOTA ([14], Forms B1, 4, 22,10, 29, 30), FORD ([14], Forms B1, 27, 43, 44, 47), as well as ABB, SCANIA, Fathym.

It is advisable to note the invention:

- FORD ([14], Form B1, 43): Vehicle energy consumption optimization system includes a route calculation device and a speed profile generator. The route calculation device combines the path sections into one route from the initial point to the destination. The speed profile generator, located partly outside the vehicle, uses the vehicle energy consumption model together with the road gradient data corresponding to the specified route to calculate the optimum speed profile. The generator is configured to determine the values of the speed at which the passage of the corresponding sections of the route will occur with the optimum level of energy consumption. To determine the optimum speed profile, the speed profile generator is configured to compare the energy consumption for a plurality of possible speed profile trajectories between the maximum and minimum trajectories. Also, the system comprises a device for adjusting the speed based on the current position of the vehicle and the optimum speed profile.

- ABB ([14], Form B1, 24): System contains at least one charging port with interface for energy exchange with at least one electrical vehicle, at least one power converter intended to convert power supplied from the power source such as the supply mains to the format suitable for the vehicle charging, at that the power converted is in remote position from the charging port, for example, in a separate room and/or building. EFFECT: provision of simultaneous charging for several vehicles without increased costs for the charging station.

- Fathym ([9], Form B1, 53): Systems and methods for obtaining data about road conditions as they pertain to an individual vehicle, using this information to build a model of vehicle behavior as a function of its environment, and aggregating information concerning multiple vehicles along with data from other sources in order to predict vehicle behavior in future environments.

Analysis of scientific and technical information allowed us to establish typical variants of the “electric bus charging configuration” system (see [14], Tables 1 and 2). This is important for building models and methods for finding rational solutions when transiting to a fleet of electric buses, taking into account possible options. A feature of electric buses compared to other types of electric vehicles is a variety of charging configurations.

Fig. 31 presents data on the storage capacity depending on the length of the electric buses and the type of charging configuration, which are obtained as a result of data analysis on the electric buses used in the EU.

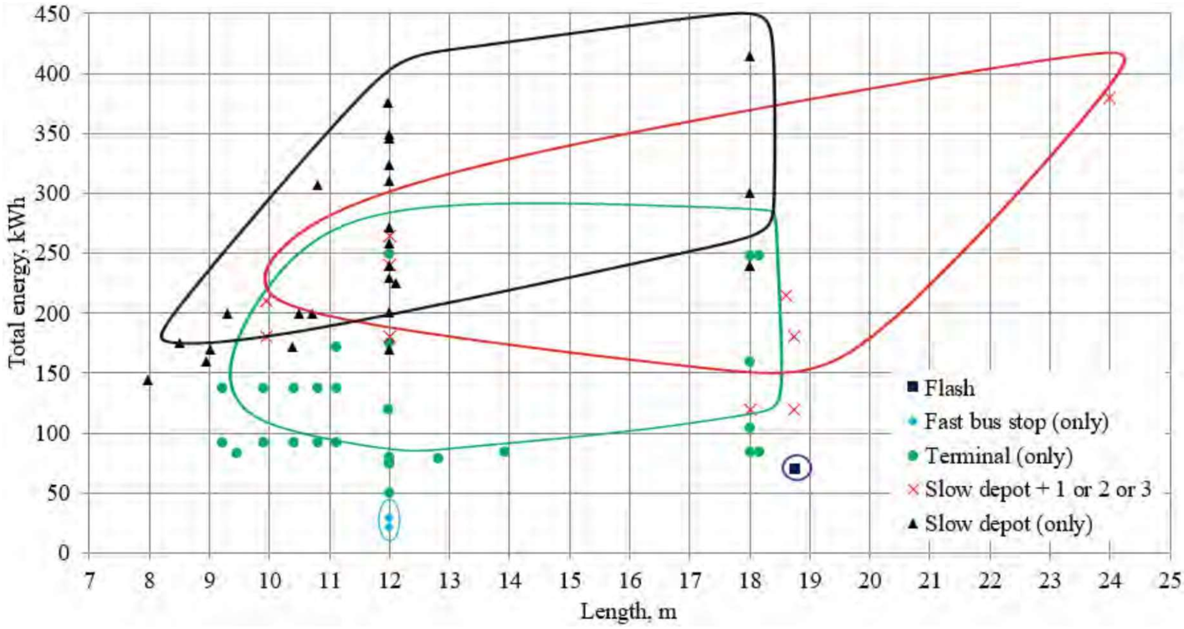


Figure 31 Battery capacity of electric buses (kWh) depending on the length of buses and charging configuration

One of the key problems is the determination of the energy consumption of an electric vehicle en-route and its optimization. Optimization methods are presented both in scientific and patent sources. In the latest inventions, when solving a problem, the capabilities of the diagnostic system are used to obtain the parameters of the workflow. The capabilities of computing devices, including onboard vehicles, are also used.

As a typical example, it is possible to mention the claimed system for modeling the drive cycle and energy use of a vehicle (for example, [14], Form B.1, 57); the system contains the computing device configured to:

- receive motion cycle data collected during the actual movement of the vehicle;
- receive information about the torque of the engine associated with the actual movement of the vehicle;
- estimate the mass of the vehicle payload based on the corresponding received information about the engine torque;
- assess energy use based on relevant driving cycle data, engine torque and estimated vehicle payload.

The similar systems, according to their basic principles, meet the ideology of Industry 4.0, including a model approach, building and setting up models using individual operating data, using on-board diagnostics, various ways of accessing data, including Web technologies, working with data, including analytics, and access for interested parties.

The systems have a wide range of possible applications: determining fuel consumption and building on this basis estimates of the driving style of individual drivers, monitoring the condition of batteries of electric vehicles and predicting their service life, and economic evaluations, including the total cost of ownership of the vehicle.

The presented results of the patent-information search are the basis for the database, which is periodically updated with new sources according headings presented in the search regulations. This will allow us to quickly track new results and keep the database up to date, which is planned during the PLATON project.

8 Summary

1. The Deliverable 3.1 contains a description of the transport system (input data and data models) for solving the problems of its conversion to 100% electric bus fleet (JIME). For the first time, the problem of rational formalized presentation of input data and the possibility of their formation by the interested parties themselves (transport companies, manufacturers, managers for the development of urban infrastructure, etc.) was set and solved as the basis for the subsequent solution of various tasks, including optimization with the use of economic and other criteria.

The transport system is presented in formalized shape by the following components:

- Infrastructural and operational part
- Electric buses
- Charging configurations
- Operation conditions: traffic obstacles and interference, passenger loading

To form the “Infrastructural and operational data”, the capabilities of Internet navigation services are shown.

To describe the road components of the transport system, the "routes cycle" concept is introduced. This allows to formalize the diverse work cycles of urban vehicles, including work on routes and auxiliary trips.

A multi-level description of the transport system (levels: 1-route cycle, 2-route, 3-segment from stop to stop, 4-zone segment) has been developed, with which the infrastructural and operational components are connected, including the change in schedules of the intervals between routes and inside routes, passenger traffic, speed limits. Data on operating conditions for the first time contain a description of the actual interference and obstacles on the considered routes. The presented description of the transport system allows to solve various tasks related to the energy consumption of electric buses, to select the battery capacity for a specific set of routes, to obtain the characteristics of routes based on the energy consumption of buses operated on them.

2. The problem of energy consumption is highlighted as a basic for the transport system. To solve this problem, a probabilistic approach has been developed, covering a multitude of possible situations and allowing the user (interested party) to choose the calculated value of energy consumption with a certain probability that the user himself can set. Thus, already at the stage of analyzing the transport system, it becomes possible to solve a number of practically significant tasks and make decisions on this basis without attracting additional special information (economic, financial, etc.).

3. As one of the applications for data and data models of the transport system, it has been proposed to evaluate the rigidity of the operation modes of buses on complicated routes using a parameter “Kinetic intensity”, certify routes according to this parameter and make recommendations on the predominant use of electric buses (ifak).

4. For the correct calculation of energy consumption, models of the electric bus operating cycle are developed. In contrast to the well-known approaches that use abstract and artificial driving cycles, an approach is developed based on reproducing the characteristic features of the route and its operational environment, including traffic obstacles and interferences, variable bus payload and driving styles (JIME).

5. The Deliverable also includes a description of the input data for solving high-level tasks: the activities of transport companies (SUT), the integrated optimization problem (UIIP).

6. The Deliverable reflects the results of experimental studies of electric buses conducted jointly by Belkommunmash and JIME on the study of driving styles, passenger load, traffic interferences and their relationships with energy consumption. Also, data on the energy consumption of electric buses in ordinary operation (Belkommunmash) are presented and their analysis is performed. The effect of the seasonal factor (ambient temperature) is shown.

6. Patent information research conducted by JIME provided a basis for developing models, choosing a list of source data and their values for the user to accept by default in the absence of the necessary information. The report on patent information research was registered by National Intellectual Property Center of Belarus and also presented in the project cloud.

7. Subsequent research in WP 3 involves the uniform interpretation and use of input data, the coordination of formats for input and intermediate data in tasks at different levels and the refinement of computational procedures. From this point of view, the

procedures of high level, containing cyclical references to the tasks of determining energy consumption on individual routes and their segments, are particularly difficult.

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