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ESSENTIAL FUNCTIONALITIES OF ERA-NET ELECTRIC MOBILITY EUROPE PLATON PROJECT

The paper is an extension of the same name plenary report at the conference "Innovations in mechanical engineering-2018", which has been held in Minsk, Belarus, on September 18–19, 2018. Essential functionalities of the project PLATON (Planning Process and Tool for Step-by-Step Conversion of the Conventional or Mixed Bus Fleet to a 100% Electric Bus Fleet) are presented. Paper covers the following topics: 1) Introduction with a brief overview of approaches to assessing the efficiency of urban transport, 2) General information on PLATON project, 3) Motivations and hindering arguments for bus fleet transition, 4) Strategic backgrounds from the public transport operators point of view, 5) Dependences between entities of various domains in the process of electric bus deployment, 6) Basic stages in creating electric buses fleet and initial data problem, 7) Modelling: using different kind of modelling, 8) Optimization problem and 9) Conclusions. The project PLATON has received funding from the ERA-NET COFUND Electric Mobility Europe within the Horizon 2020 program. Project runtime is 01.2018-06.2020.

Keywords: *urban buses, conversion, electric bus fleet, project PLATON, functionalities*

Introduction

The widely-spread type of investigations is the comparison of buses with different propulsion systems. Diesel bus, Trolleybus, Hybrid Electric Bus (HEB), Fuel Cell Electric Bus (FCEB), and Battery Electric Bus (BEB) are among them. A comparison of these vehicles types is made in various aspects. The basic ones are the following: Economics, Pollution, Energy Utility/Consumption, Operation, Infrastructure modification [1].

The main barrier for BEBs wide application is their high initial costs. But if to take into account the total cost of ownership (TCO) then BEBs become competitive. The new Directive 2014/24/EU significantly innovates the process of tenders awarding, through assigning a relevant importance to life cycle costing (LCC). New contract award criteria have been introduced in Article 67: "The most economically advantageous tender from the point of view of the contracting authority shall be identified on the basis of the price or cost, using a cost-effectiveness approach, such as life cycle costing...". Based on its perceived benefits, the European Commission would like to encourage and facilitate the wide use of LCC by making available tools and approaches that could help the application of harmonized LCC methods among public authorities in Europe. LCC complexity and the scope of the tool (i. e. the product categories) impose a number of limitations and require particular caution. A careful selection of input data and precise instructions will allow the user to get solid results. Such results will allow Public Authorities to use the LCC approach according to Public Procurement Directive 2014/24/EU [2].

Another typical approach can be presented by a method that has been developed primarily for public transport authorities and operators to be able to analyze what kind of electric bus and charging system has lowest TCO depending on the route or city specific requirements [3].

Paper [4] presents a holistic design methodology to identify the 'most suitable system solution' under given strategic and operational requirements. The relevant vehicle technologies and charging systems are analyzed and structured using a morphological matrix. The model can be used to determine a feasible electric bus system. The technology selection is based on a detailed economic analysis which is conducted by means of a TCO model. Obtained results indicate that electric bus systems are technically feasible and can become economically competitive from the year 2025 under the conditions examined.

An analysis of the typical approaches to the problem under consideration [3–5] and others, which are summarized in the indicated publications, leads to the following conclusion. All these approaches are focused on certain methods and sets of initial data, and also consider the transition to the electric buses fleet as to certain fixed object. In reality, this is a process with many stages, it is necessary to take into account a wide range of dependencies between interacting objects in this process, as well as different methods should be used at each stage. The solution is reduced to considering the situation with many criteria and alternatives. Therefore, on the basis of existing approaches, it is necessary to create a tool that takes into account the ambiguity of the transition conditions and that it should be accessible to a circle of stakeholders. The PLATON project is devoted to the creation of such a tool. Its essential functionalities are described in this paper.

General information on PLATON project

The project PLATON (Planning Process and Tool for Step-by-Step Conversion of the Conventional or Mixed Bus Fleet to a 100% Electric Bus Fleet) was approved for funding in the Electric Mobility Europe Call 2016.

The main objective of the PLATON project is to define a planning process for the conversion of a given diesel or mixed bus fleet to a 100% electric bus fleet and to implement this process into a web-based software tool. Due to the complexity of this issue, the planning process is based on basic methods (e. g. simulation, charging infrastructure optimization, vehicle scheduling optimization) which contains all the expert knowledge and experience required. At a given investment budget and the defined optimization goal (e. g. replace the maximum passenger x km by electric buses, maximum number of electric buses or minimum CO_2 emission) the planning process delivers a list of recommendations concerning all relevant aspects [6].

Project concept. Firstly, relevant real life cases and requirements will be collected from electric bus manufacturers (including variability of bus models, electrical power storage devices and power charging systems, bus mechanical specificity, etc.) and public transport operators (including characteristics of bus fleets and routes, operating and management cost of buses etc.). Based on the results, input data, constraints and output data for the planning process and the basic methods will be determined. The most complex scientific part of the project concerns the mathematical modelling of the physical devices and the whole transportation system optimal design, as well as the improvement and efficiency increasement of existing basic methods using computer science algorithms.

The expected impact of the project is a more reliable and therefore faster conversion of conventional buses to electric buses and therefore an acceleration of environment and climate protection. The bus manufacturer can offer the tool to increase the level of sales of electric buses, however, operators and consultants of public transportation can easily analyse different ways to conduct the conversion to 100% electric fleet by using the tool.

The consortium of Partners consists of three research institutions (Institut f. Automation und Kommunikation, ifak e.V. Magdeburg, acting as co-ordinator, United Institute of Informatics Problems of the NAS of Belarus, UIIP-NASB, and Joint Institute of Mechanical Engineering of the NAS of Belarus, JIME-NASB), one research-educational institution (Silesian University of Technology, SUT), one research consultancy micro company (Effiziente.st Energie- und Umweltconsulting e.U., EUC), two bus manufacturers (Belkommunmash, BKM, and VOLVO), one rail company aiming at the production of electric buses (Stadler-Minsk) and two associated public transport operators (PKM Jaworzno and PKM Sosnowiec). They represent five countries — Germany, Poland, Belarus, Sweden and Austria.

Project mission. The intention and goals of the project are reflected in the project's mission. First of all, it is intended to design and develop tools for planners of the conversion process in public transport companies or consultancies. These tools should enable the planners to support themselves in decision making, assessment of feasibility and provision of founded recommendations of steps towards bus fleet electrification. Basic methods are exemplary: simulation of energy consumption, optimal use of charging infrastructure and solving of vehicle scheduling problems. In this respect important requirements are the definition of use cases and properties of the bus vehicles, their battery characteristics, charging methods and mechanical specifics. Further subjects of analysis are the varieties of transport operations with respect to route characteristics and bus fleets under consideration of economic conditions such as total cost of ownership.

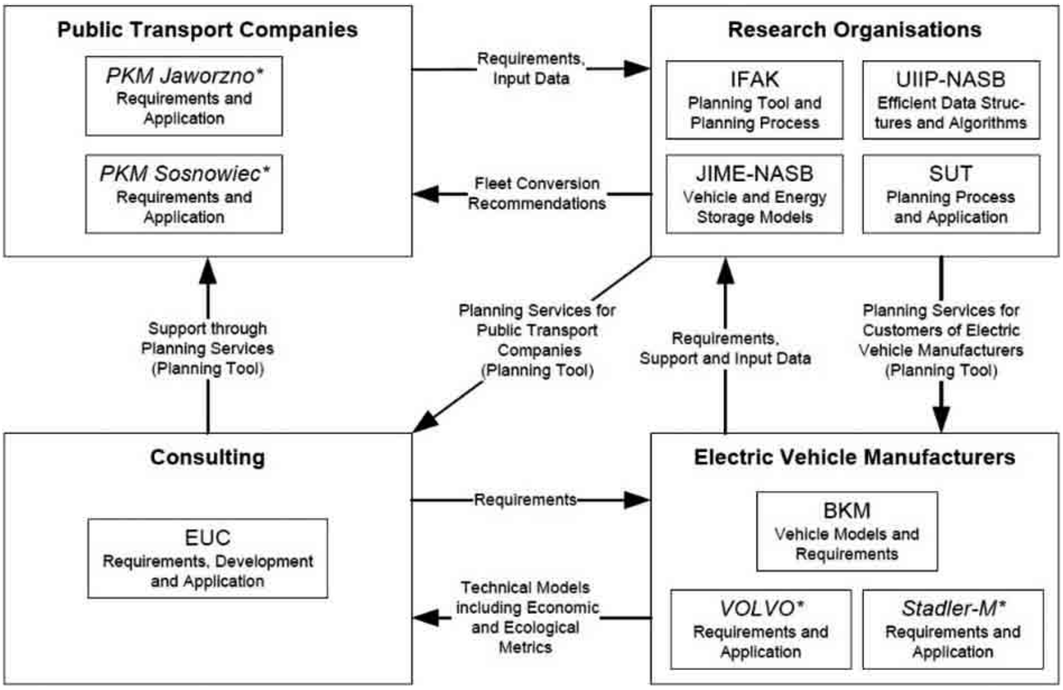


Figure 1 — Project collaboration

So, project mission can be formulated as follows:
- given budget and optimization goals (replacement share, number of e-buses, CO_2 emissions) provide recommendations;
- mathematical modeling of physical vehicle properties and the transportation system;
- basic methods: simulation, charging infrastructure optimization, vehicle scheduling;
- definition of use cases and requirements of vehicle: bus models, batteries, charging systems, mechanical specifics;
- varieties of transport operations: characteristics of routes, bus fleets, cost of ownership.

Collaboration at the project. Figure 1 depicts partners' collaboration at the project. The project collaboration and cooperation between partners is constructed as follows. Research organizations collect requirements and input data from public transport companies and Electric bus manufacturers. The composition of the research partner team is carefully selected with partners from academic research for the tasks of mathematical modeling for vehicle, network and energy related problems (JIME) as well as to develop efficient data structures and algorithms (UIIP). Beside academic research partners, we have partners of application oriented research such as ifak and SUT for design and development planning tools that support the planning process. The partner structure is completed by the transport and energy consultancy EUC providing a profound support through services regarding requirement analysis, development of real time data processing applications.

Motivations and hindering arguments for bus fleet transition

Currently significant majority of city buses on European streets are diesel-powered. As they are the source of toxic substances, the improvements in scope of air quality is necessary. What is more, electric buses might be promoted as 'a means of transport in the future cities' and their production can contribute to the development of electric vehicles market.

What hinders the process of bus fleet transition is the necessity of financing the purchase and operation of electric buses. Other problems that are still unsolved

Table 1 — Transition to Electric bus fleet: pro and con

Motivations (pro)	Hindering arguments (con)
Vast majority city bus fleets are diesel powered being a source of toxic substances	The necessity of financing the purchase and operation of electric buses
The need for air quality improvement	Battery and charging related issues
Independence from fossil fuels	Power grid related issues
Promotion of electric buses as a means of transport in the cities of future	Unwillingness to unproven technologies
Electric vehicles market development	Non-adaptation of traditional automotive industry to produce electric vehicles (including electric buses)

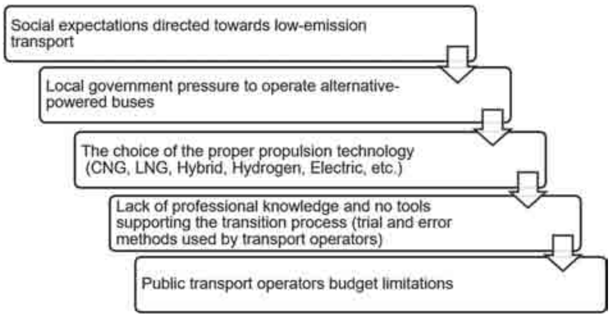


Figure 2 — Problems of public transport operators

are: battery electric bus battery charging and power grid related issues. We must also take into account the adaptation of traditional automotive industry to manufacture electric buses. In addition to economic and technological issues we also have social resistance associated with unwillingness to new, unproven technology. Arguments 'pro' and 'con' are represented in Table 1.

Strategic backgrounds from the public transport operators point of view

People across Europe and beyond expect actions towards lowering harmful emissions in the transportation sector. The pressure for operating alternative-fueled buses on local governments is thus growing. The consequence of this is propulsion type choice — whether we'd like to operate CNG, LNG, hybrid or pure electric buses.

If we choose electric buses, we will face a transition process issue: 'how can they be deployed in our transportation system?' From the point of view of public transport operators, there is a strong need for a tool that could help them with conducting the transition process, taking into account their budget limitations.

In a generalized form, problems of public transport operators are depicted in Figure 2.

Dependences between entities of various domains in the process of electric bus deployment

The diagram, presented in Figure 3, illustrates the dependencies between entities of various domains in the process of electric bus deployment. The dependencies describe the basic relationships between these entities in the form of edges, connecting nodes of the dependency network. Neighboring nodes of the directed edges constitute a dependency. The input node of an edge has influence on the output node, or the output node is dependent on the input node.

The domains of the entities are the legislative and governmental domain, economic domain, public transport domain, the vehicle and fleet related domain and the domain of electric power generation and distribution grid. The purpose of the dependency network lies in the identification of input and output variables, which can be numbers in the simplest form but also vectors of variables of various types, planning documents, procurement decisions and even also legal positions. Therefore, it is of great value for the analysis of requirements for modelling and the design of the planning process. For different models developed to describe the relations and dependencies it must be assured, that interoperability is ensured in terms of data models and interfaces for input/output data exchange.

The interconnection and dependencies between entities of the denoted domains is to be explained in more detail by the following example. The numbers in brackets denote the numbers of edges that represent the dependencies in the diagram.

The structure of zoning and housing has a strong influence (18) on transit demand that is to be met by public transit services (31). The planning process of public transit services comprises transit operations (33) and the design of the transit network (32). The latter one leads to a planning of transit stops (24) with locations that ensure a comfortable reachability and accessibility for the population of the residential areas as passengers of public transport services that influences the ridership (30) as occupation of buses in revenue service. A transit route is reasonable connection of bus stops by a route (24) that is directly dependent on the location of bus stops.

The higher the ridership, the higher the frequency (57) of transport vehicles to be planned, which constitutes a direct dependency. A higher frequency of vehicle in connection with a shorter headway (36) requires more vehicles to be scheduled in the timetable, resulting in the need for a higher required quantity of electric buses (3).

The corporate management of a transit company will draw decisions on procurement of electric buses based on entrustment of transit services (16) and provisions of funding (17) both provided by local government policies, (53) and (52) respectively, that are being executed on the basis of parliamentary resolutions. Furtherly, the corporate management takes into consideration strategical alternatives and decisions on tram extension or e-bus transition that have been drawn on a long-term basis. The procurement decision for e-buses is based on economic feasibility studies that include the procurement cost (12) and operational costs to be determined by costs of ownership (13) and cost of charging infrastructure (14). Costs of ownership depend on depreciation determined by bus life span (46) maintenance cost (11), determined by workshop costs (45) and personnel costs that are determined by the wage level (44) in the respective country. The corporate operational costs accounting process taking into account municipal subsidies results in fare calculations (15). The amount of fares has an indirect proportional impact on the transit share within the model split breakdown of transport mode choices of the traffic and transport user. High fares will lead to lower transit share; low fares will lead to higher transit share. A lower transit share itself will decrease the transit demand (19) and vice versa.

Not to be underestimated are the energy costs that are determined by costs of power generation (39) that are composed of power generation sources of lower

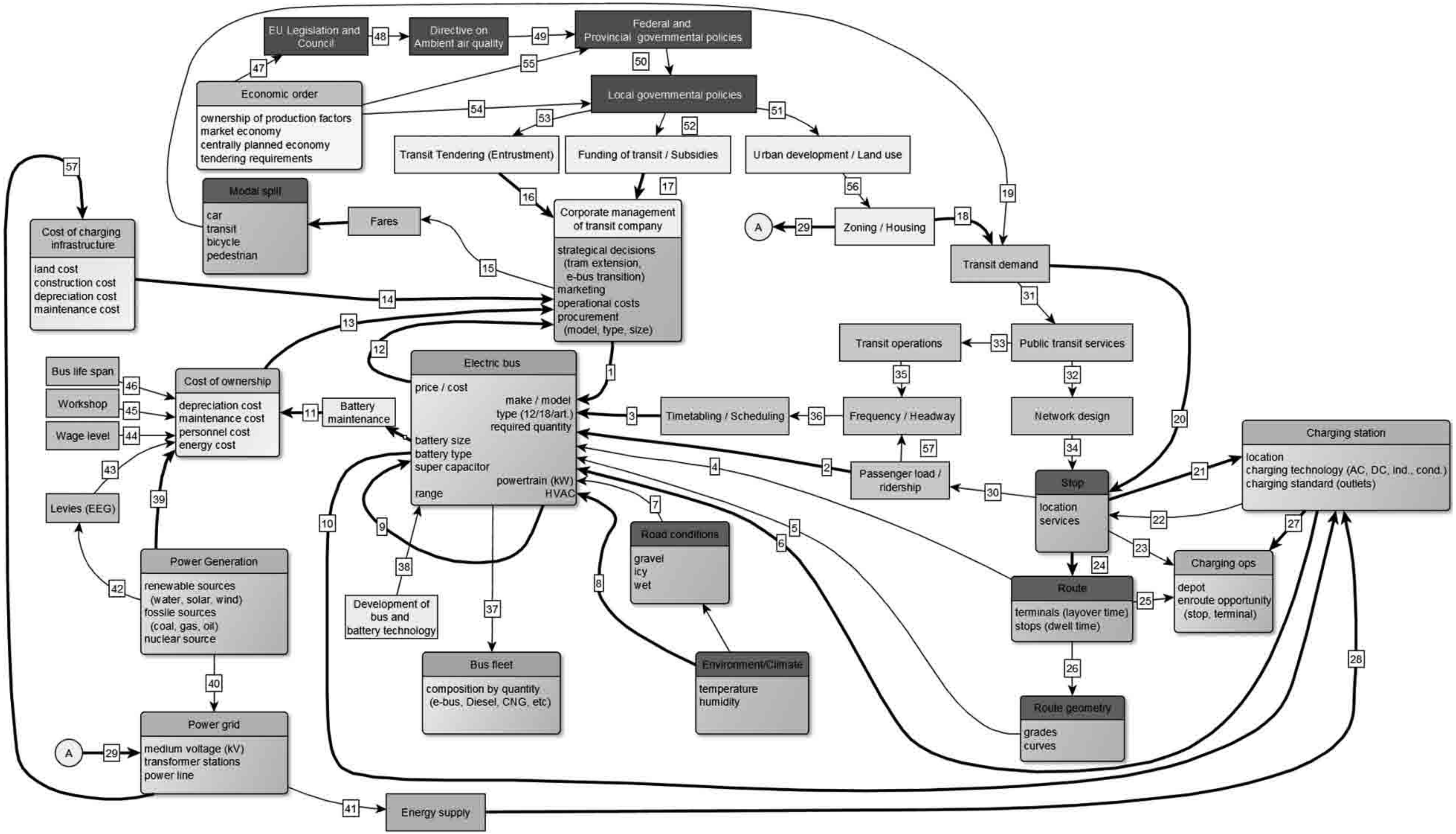


Figure 3 — Dependencies of electric bus deployment process

cost categories (water, coal, nuclear) and higher cost categories (solar, wind, gas, oil) and levies (43) charged for the allocation of significant costs for renewable energy production (42).

An important precondition for the construction of charging infrastructure is the spatial proximity to power lines of medium voltage (40) 1 kV up to 30 kV to supply enough energy (41) for charging stations. So, the location of charging stations is influenced by both the location of bus stops (21) and by the proximity to energy supply (28). The availability of transformer stations from medium voltage to low voltage is essential for the cost of charging infrastructure (57). Eventually new transformer stations and additional cabling to charging stations have to be build adding up to anyway-cost-figures.

Basic stages in creating electric buses fleet and initial data problem

The paper [7] introduces requirements for data and documents reflecting the main factors and stages of creating a fleet of electric buses. These stages are the following: 1 — analysis of possible variants of "electric bus — charging configuration" for the routes under consideration and ensuring their technical feasibility; 2 — economic analysis of the total cost of ownership for the fleet; 3 — development of a business plan; 4 — support for the transition process on basis of the concept of an "open system" [8]. The composition of the initial data and their formats with corresponding examples are given in the framework of the first stage. The key procedure of the first stage is to determine the electric power consumption of an electric bus, taking into account the parameters of its design, charging configuration and route features.

There is a firm belief that one of the key problems for the development of electric vehicles is the available charging infrastructure. However, for personal electric vehicles in Europe, it will cease to be a problem.

A new analysis by Transportation & Environment (T&E) finds that in the UK and Europe, 95% of all EV charging events occur at home or work. Only 5% take place along highways. In fact, says T&E, when it comes to what is delaying the electric car revolution, 'it is a lack of choice and availability of electric cars that is the principal barrier.' T&E points to Norway, which has the highest percentage of new EV sales in Europe. In 2014, 10% of all charging events took place at public chargers. By 2017, that number had dropped to just 2%. T&E suggests the fact that newer electric cars have larger batteries and longer range may explain the decreased use of fast chargers [9].

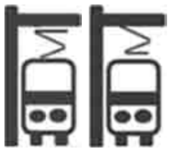
The situation is different for urban electric transport. Morphological matrix of available technology options in electric bus systems is depicted in Figure 4 [4]. There are various charging configurations. They should be presented in more detail and studied in the light of experience

Charging configurations. One of the typical tasks is choosing the rational capacity of the electric bus battery under different bus charging configurations. Some popular solutions relevant to this problem are presented in Table 2.

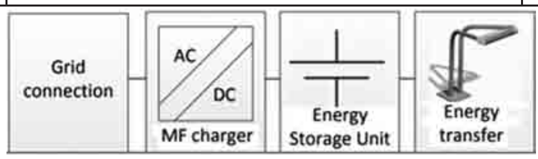
Function	Options					
energy source	grid				local storage	
	low voltage	medium voltage	high voltage	rail	stationary battery	H_2 tank
charging/ refueling strategy	opportunity	in motion	depot			
charging/ refueling interface	manual (plug, pump nozzle)	pantograph	induction	trolleybus current collector	battery swapping	
on-board energy source	battery			capacitor	H_2 tank (+ fuel cell)	none
	NMC	LFP	LTO			
drive motor	permanent magnet synchronous	electrically excited synchronous	asynchronous	switched reluctance		
drive topology	central motor	wheel hub motor				
body type	12 m single-deck	18 m articulated	24 m bi-articulated	double-deck		
cooling	electric air-conditioning	none				
heating	electric resistance heating	electric heat pump	fuel heating			

Figure 4 — Available technology options in electric bus systems [4]

Table 2 — Electric bus charging configurations in EU (based on data from [10])




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
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 + SlowTerminal	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 + Flach	1	0.86
16	In-Motion Charging + Fast Terminal/Depot	4	3.45
17	Fast Depot + SlowTerminal	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



It may be noticed that 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. Currently 20 buses are used in Minsk on two routes with travel distance till 15 km and time of charging 6–7 min. Detailed data on the design and the first route of an electric bus are presented in Figure 5 and Table 3.

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 [11]. 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 [12].

Detailed data on the design and route of mentioned Belkommunmash buses are presented in Figure 6 and Table 4.

Estimating data on energy consumption in the system 'Bus — Route'. Battery capacity and operational conditions (as well as some others additional factors) determine bus energy consumption and as consequence the places on route for chargers.

Options determining bus energy consumption:

- data from manufacturers,
- statistics from transportation companies,

Type of the energy storage	supercapacitor
Length of autonomous run, km	15*
Maximum charging time (from 30% capacity), min	6
Passenger capacity, persons	153
Seats	38
Unladen electric bus weight, kg	17 200
Total weight, kg	28 000
Length, mm	18 735
Maximum speed, km/h	70
Technical characteristics of supercapacitor system	
Rated voltage range, V	420-600
Functional energy storage, kWh	34
Standard charging current, A	400
Weight, kg	1350
Service life, cycles	90 000

* It depends on terms and conditions of order.

Figure 5 — Parameters for Belkommunmash model E433 VITOVT of 18-m electric buses

Table 3 — Experience of electric bus operation with fast terminal charging in Minsk city since 2017

Route description		Result of operation	
Electric bus route № 59el “d/o Serova — Dolgobrodkaya”		Average run of an electric bus during a month, km	2,700
Round trip on route / one way, km	24.6 / 12.4	The remaining charge of supercapacitor after passing a route in one direction, %	30
		Maximum speed, km/h	55
Daily run of one electric bus, km	200.3	Charging time, min	5
Number of charging stations on route	2	Electrical energy saving in comparison with a trolleybus model 333 %	14
Number of charging station in park	1	Electric bus operating costs for 1 km of run in comparison with a trolleybus model 333 are 6 % lower	
Number of daily operated electric buses on route, unit	10–14	ELECTRIC BUS MODEL E433	

- data from test runs by researchers,
- cost distance analysis,
- modelling:
  - methods in which the speed profile on a route is pre-determined,
  - methods that reproduce the actions of the driver along the route.

About rational calculated level of energy consumption on the route. The problem of estimating energy consumption is a key issue when choosing the characteristics of the battery or the placement of chargers on the route of the electric bus. An analysis of typical works on this topic [13–16] shows that the problem needs additional research. This reflects paper [16]: ‘Taken together, operational feasibility simulation and grid impact models generate contradictory recommendations for the selection of a suitable BEB configuration. This outcome in itself is significant, as it highlights the need to consider both operational constraints and grid impacts simultaneously. Therefore, additional research efforts are required to optimize BEBs configuration on a multitude of energy, utility and operational aspects.’

The concepts of “Worst case” and “Calculated case” should be introduced and scientifically justify to solve the problem. **“The worst case”** is a possible combination of all the unfavorable factors that affect the operation of the battery (vehicle efficiency, weight/number of passengers, weather conditions, route characteristics, driving style, etc.). For example, aggressive driving style with high acceleration can increase energy consumption up to two times. **“Calculated case”** of energy consumption must reflect hard but real operation conditions. Therefore, the additional problem is to choose a *rational calculated level of energy consumption* on the route using the data obtained by various method, tools, sources.

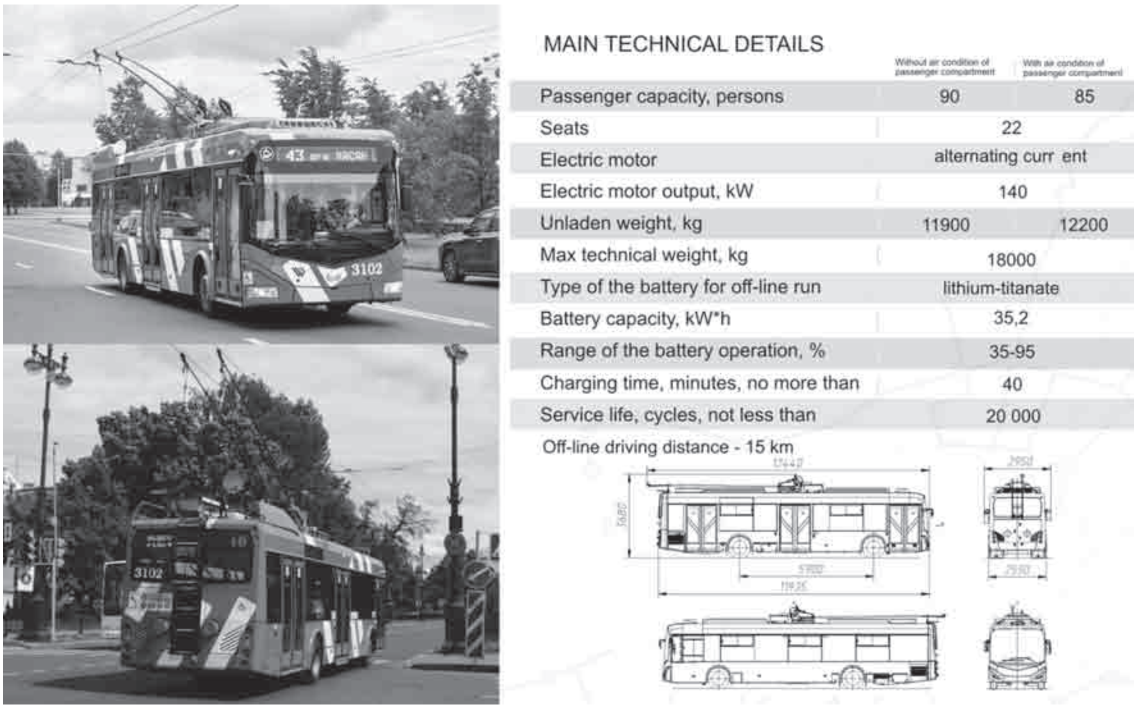


Figure 6 — Parameters of Belkommunmash model 32100D buses operated in Grodno city

Table 4 — Grodno city route description

Route Details	
In the forward direction:	
- power from the contact network, km	1.3
- autonomous run, km	4.3
- power from the contact network, km	3.6
- autonomous run, km	3.2
In the opposite direction:	
- autonomous run, km	2.4
- power from the contact network, km	4.9
- autonomous run, km	3.9
- power from the contact network, km	1.5
Route Characteristics	
The length of the route, km	25.1
The presence of the contact network, km	11.3
No contact network, km	13.8
Maximum slope of the road, %	4.2
Daily mileage, km	1,136
Belkommunmash e-buses, units	4

Modelling: using different kind of modelling

Based on different domains of dependencies in the deployment process there are specialized modelling approaches needed (Figure 7):

The Polish Partner University of Silesia is working on "Economic models" and their application in the "Planning process" of bus fleet electrification.

The Belarus Academy Institute UIIP is about to develop models for the "Charging Infrastructure" and their interdependencies with the electrical power grid as well as special problems of "Scheduling" of vehicles in a mixed fleet of conventional and electric buses under consideration of "Optimization" of route characteristics. These problems are mainly related to the infrastructural side.

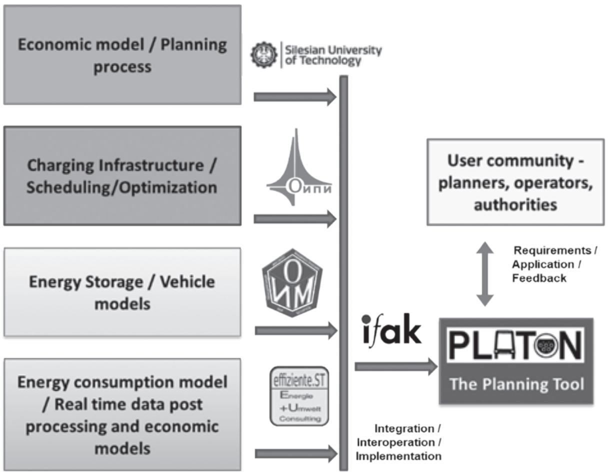


Figure 7 — Different modelling approaches for PLATON

Problems related to the bus vehicle and fleet specific side are worked out by Belarus Academy Institute JIME. The models cover those of "Energy Storage" like battery models under consideration of energy consumption during bus operational revenue cycles and temperatures, battery type etc., as well as "Vehicle models" covering different types of bus vehicles including their modelling parameters and capabilities.

The Austrian consultancy EUC has developed a model of "Energy consumption" and tested under conditions of real time data that are collected during conventional bus operation cycles that are post processed by algorithms in order to assess energy consumption of electric bus vehicles.

The main responsibilities beside project coordination of German institute ifak e.V. Magdeburg are the tasks of “Integration” of these different model approaches and ensure the “Interoperation” of the various tools to be developed. Further ifak e.V. Magdeburg will help to implement these approaches into an -easy to use- toolset for practitioners of public transport operating companies in order to support the decision and planning process of bus fleet conversion.

The functionality of the PLATON planning tool will include the capabilities of the models that are developed under the lead of responsive partners of the project. Therefore, the models must be implemented in a way that allows for their integration or interoperation using well defined interfaces for data exchange. For example, the economic model should take into consideration the Total Cost of Ownership (TCO) of electric bus operation, including the deprecated procurement costs, maintenance costs, personnel and energy costs and their influence on fares with respect to different countries. The model of charging infrastructure, scheduling and optimization of electric bus operation should enable the user of the tool to vary the vehicle allocation for a given set of boundary conditions and constraints such as passenger capacity and energy storage capacity of the buses as well as existing charging infrastructure taking the available energy grid into account.

For the model of Energy storage and Bus vehicles it is important to keep the data updated considering a very dynamic market of bus vehicles. It should allow to select various parameters of batteries and vehicles that are required for simulations of a single bus and the entire bus fleet as well as the energy consumption of single vehicles and the bus fleet under consideration of different variants of charging strategy such as opportunity charging, depot charging or in-motion charging.

From the planners point of view it is rarely the case, that all parameters are at hand which are necessary to describe the electrification of an urban bus fleet for a given public transport network and its services. Therefore it is not only valuable but essential to reprocess field data in form of real time datasets that have been measured by means of GNSS devices. By reprocessing these datasets it is feasible to obtain a highly reliable assessment of energy consumption under real conditions that take into e. g. terrain data, velocity profiles depending on traffic conditions and the road network. In result of analysis of these re-processed dataset it is created a feedback loop for parameters of the models that can be validated in this way.

The integration of all base models into one toolset will be achieved by implementing the algorithms and dataset of each model into one implementation whenever it seems appropriate. However, if the usability of the toolchain requires a decentral approach there can also be implemented a distributed solution that communicates over IP based protocols.

Optimization problem

Approaches to optimization include: 1) the approaches, which include modeling the working processes of the electric buses; 2) the approaches based on the use of possible combinations for the “Electric Bus — Route — Charging Infrastructure” from the technical feasibility phase.

Some formulations of optimization problem are developed. Typical set of assumptions is given below:

1. Problem is solved repeatedly for each year of several planning years.
2. No new route or bus stop appears. For each old route, the depot, the bus stops and the order of their visiting by e-buses are given.
3. Fleet of conventional buses can be replaced partly.
4. Available e-bus types are given.
5. Each route is associated with a single depot. The same depot can serve several routes, in which case they share depot charging stations.
6. There are two terminal stops for each route.
7. Routes can intersect at terminal stops and en route stops, in which case their e-buses of the same type share appropriate charging stations at these stops.
8. Passenger flow intensity in the peak block of cycles is the same in each year.
9. Any e-bus is charged to the recommended SOC level. This level and the corresponding charging time depend both on the charging station type and the location type (depot, terminal stop, en route stop).
10. Each charging station location (depot or bus stop) is connected to exactly m transformers.
11. All charging stations at the same location are connected to the same transformers.
12. Some e-buses, charging stations and links of their locations with the transformers can already be in operation.
13. Duration of one cyclic run of any bus in the peak block of cycles is the same for the same route.

Input data. The input data can be categorized into four layers: charging station layer, bus layer, network layer and route layer. An example of a network is given in Figure 8. There is a transportation and electrical network $G = (NN, J, A)$, which is a weighted mixed multigraph with set of nodes NN, set of arcs (directed pairs of nodes) J and set of edges (undirected pairs of nodes) A, see the Figure for an illustration. There, Route 1 is (Depot 1, T_1, 1, 2, T_2, T_1, Depot 1), Route 2 is (Depot 2, T_3, 1, 2, T_4, T_3, Depot 2) and Route 3 is (Depot 3, T_5, 3, T_2, 2, T_5, Depot 3).

Conclusions

1. There are many studies, publications and approaches in which the advantages of electric buses and the inevitability of the transition to them are considered from the general standpoint. Statistics shows the growth of electric buses in the cities of the world. However, the process and progress in electrification are determined by the specific conditions and actions of local authorities

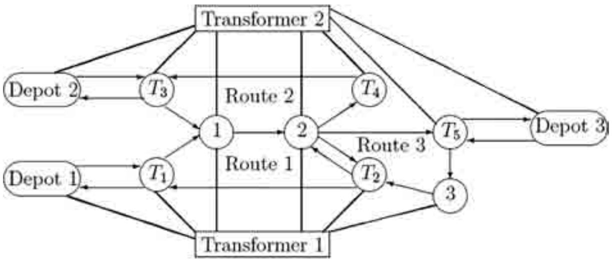


Figure 8 — Network of three routes

and public transport operators. In this case, each situation is individual. Local authorities and public transport operators are faced with the question: how can electric buses be deployed in their particular transport system? There is a strong need for a tool that could help them with the transition process, taking into account their budget constraints. When conducting tenders, this tool is needed to evaluate bids and select a supplier. The PLATON project is aimed at creating such a tool [17].

2. The main goal of the PLATON project is to create a tool embedded into a web application (with free access by interested parties) that will contain the most required expert knowledge and experience to support the planning process for electric bus deployment.

3. The transition process is considered within the framework of the behavior of the system, in which technical, economic and social factors interact. This reflects the developed dependency graph with various forces of connections between the basic entities involved in the process. The graph serves to construct models of different levels for the reproduction of the process.

4. In the process under consideration, characteristic stages are identified, each of which is supposed to use a set of methods that are mutually complementary to each other and apply them depending on the available initial data and technologies. The key problem of the first stage is the construction of technically feasible "Electric bus — Charging configuration" variants for a specific route, taking into account possible types of charging technologies and electric buses. In this case, the basic task is finding the rational rated power consumption by the electric bus in terms of a combination of the main factors (passenger traffic, road conditions, climate, driving style).

5. The openness of the transition process implies its supply with tools for escorting during the life cycle and adaptation to the action of the emerging factors.

6. The problem under consideration implies solving optimization tasks, taking into account a number of criteria covering various aspects of the problem (including positive ecological or social-ecological effect expressed quantitatively, total cost and power consumption).

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ОСНОВНЫЕ ФУНКЦИИ ПРОЕКТА PLATON ИНИЦИАТИВЫ ERA-NET ELECTRIC MOBILITY EUROPE

Данная статья является расширенной версией одноименного пленарного доклада конференции «Инновации в машиностроении-2018», которая состоялась 18–19 сентября 2018 года в г. Минске, Беларусь. Представлены основные функциональные возможности проекта PLATON (Планирование процесса и инструментарий для пошагового преобразования обычного и смешанного автобусного парка в 100%-ный парк электробусов). Статья включает следующие разделы: 1) введение с кратким обзором подходов к оценке эффективности городского транспорта; 2) общие сведения о проекте PLATON; 3) побудительные причины и сдерживающие факторы для преобразования автобусного парка; 4) стратегические предпосылки с точки зрения операторов общественного транспорта; 5) зависимости между субъектами различных сфер в процессе внедрения электробусов; 6) основные этапы в создании парка электробусов и проблема исходных данных; 7) моделирование: использование различных видов моделирования; 8) проблема оптимизации; 9) заключение. Проект PLATON одобрен для финансирования в рамках инициативы ERA-NET Electric Mobility Europe, программа Horizon 2020. Срок реализации проекта: 01.2018–06.2020.

Ключевые слова: *городские автобусы, преобразование, парк электробусов, проект PLATON, функциональные возможности*