A Concept of Conventional or Mixed Bus Fleet Conversion with Electric Vehicles: A Planning Process

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***Abstract*—The challenge of converting the fleet consisted of conventional buses with more modern vehicles is particularly up-to-date nowadays. In this paper, it is assumed that – sooner or later – only battery-electric buses (BEB) will operate the bus routes. The content includes a basic structure of the algorithm supporting the decision process of bus fleet conversion, from the currently operated conventional or mixed fleet to the fleet consisting of electric buses only. In the algorithm, three major paths are derived, which results in the following indications in terms of the conversion process: vital technical parameters of electric buses, a comprehensive schedule for the bus fleet conversion process and the economic assessment of the investment in this technology. An outline of the decision support tool for the deployment of electric buses using the energy consumption model to calculate the total cost of ownership is presented in this paper.**

***Index Terms*—electric mobility, transport system, public transport, road transport, electric bus, conversion process**

I. Introduction

One of the significant aspects of public transport management is to take some strategic decisions on network design. This is related to the continuous conversion of the bus fleet to meet current environmental parameters, which are often enforced by law. Growing environmental awareness in society is the context for these decisions. Hence, there is a vibrant debate on the future of urban bus fleets. Transit agencies and other entities responsible for bus fleet development face the following problem: how to match the bus fleet to the increasing environmental awareness? Conversion of the conventional or mixed fleet, which is currently in service, into an all-electric bus fleet is one of the options they may consider.

Naturally, there are many ways to achieve environmentally-clean bus fleets. The following power sources and technologies should be mentioned here: hybrid engines, compressed or liquefied natural gas or – in the long term fuel-cell buses. In this paper, however, the focus is only put on the problem of converting a conventional bus fleet to electric buses. We do not undertake an analysis of the selection of the most advantageous propulsion type for the specific transport network. Rather, the assumption was made that such an analysis has been done earlier and resulted in the recommendation to invest in electric buses.

The bus fleet conversion problem is widely described in the scientific literature. The process of decision-making requires a thorough assessment of possible solutions from the technical, operational, and economic point of view under the given conditions and constraints [1]. In [2], a few scenarios for bus fleet conversion were given. These strategies differ from one another by the degree of the dynamics of the process to be conducted by a transit company. Mohamed *et al*. [3] simulated electric buses on a full transit network. The focus was put on operational feasibility and grid impact analysis. The results indicated that electric buses charged with the use of flash and opportunity charging are more feasible for full transit operation. However, their main drawback is high and intermittent power demand. Häll *et al*. [4] stated that some modifications in the design of a transit route network, as well as in the timetabling and vehicle scheduling processes, are required. They took into consideration the most popular charging technologies (overnight charging, fast charging, in-motion charging) to adjust the mass transit to make it be operable by electric buses.

There are numerous other papers elaborating the possibility of electric buses deployment in a real transit network. These include, inter alia, the following papers: Li *et al*. [5], Wang *et al*. [6], An *et al*. [7] and Perotta *et al*. [8]. In these papers, the issues of route planning and recharging scheduling are comprised. In [9] and [10], an economic approach to the fleet conversion problem was given.

Herein, we look at the conversion process from a macro perspective, rather than from a technical or economic one (as it was the case in the aforementioned papers). Within a multi-national research project with an acronym PLATON (Planning Process and Tool for Step-by-Step Conversion of the Conventional or Mixed Bus Fleet to a 100 % Electric Bus Fleet'), a bus fleet conversion planning process is being developed. The aim

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of the project is to define the fleet conversion process and implement it as an IT tool, based on open-access Internet technologies involved in the project (mainly: transit agencies, bus manufactures). One may find some functionalities of the PLATON project in Algin *et al*. [11].

II. Structure of the Bus Fleet Conversion Support Algorithm

A. Outline of the Issue

The challenge of bus fleet replacement with electric buses may be considered as quite complex. When a transit company is about to start using electric buses, it needs to consider some technical, operational and organizational issues.

Battery electric buses have different technological and operational parameters than conventional ones. They have undisputed advantages, such as good electric drive efficiency, practically none local emissions of harmful substances, slight noise emission and more beneficial operating costs resulting from lower, although rising, prices of electric energy in relation to diesel oil. However, these vehicles have some disadvantages as well. These include the greater purchase costs, limited operational range (often insufficient to run all-day vehicle cycles), power grid limitations and the need for purchasing and operating additional technical infrastructure (charging stations in a depot and located on the network)

In terms of organizational issues, bus schedule may be investigated in two various ways:

- From the passengers' viewpoint for whom it is a basic element of the public transport offer.
- From the transit agencies' viewpoint for whom it is a vehicle work plan.

In this paper, we use transit agencies approach that operate a specific number of buses. These may include conventional diesel buses or mixed fleet (consisted of, among other types of buses, hybrid buses, CNG buses, LNG buses, electric buses). These buses operate the network of stops in a convenient manner for passengers. Bus schedule (timetable for passengers) is defined for bus lines as well as the departure times of services from each bus stop of these lines. Each of the bus lines has at least one terminus (but in most cases two). Between the timetable for passengers and the buses, a link is provided, which is a schedule for the use of individual buses for the operation of subsequent bus lines. The schedule of bus operations on bus routes is essential to carry out the timetable for passengers, taking into account organizational and economic constraints. As long as the timetable containing departure times of services from each bus stop is the most important from the passenger's viewpoint, for transit companies the most important issue is to route the buses in such a way to ensure the realization of the timetable. The instrument and effect of such scheduling for an individual bus is a vehicle cycle being the operating schedule of each bus during the day. The vehicle cycle may be defined as the operation of a vehicle (bus) through the course of a day of transit service (including pull-out and pull-in) which consists of handling a sequence of bus stops (including depots) under handling one or more bus routes.

Fig. 1. GPS file of one of the vehicle cycles operated by PKM Sosnowiec (Map background © OpenStreetMap contributors).

It should be noted that the number of vehicle cycles card(VC) must not be less than the number of buses owned or leased by the company card(BUS). This relationship was presented as

$$\mathrm{card}(VC) \leq \mathrm{card}(BUS) \quad (1)$$

Excess of the minimum required number of buses to operate the vehicle cycles planned, on the one hand, increases the operational reserve, on the other, however, increases the costs. Modeling the policy of the enterprise in this regard is the subject of the day-to-day business activities of the transit agency. Hence, we do not deal with this problem, focusing solely on the required number of vehicle cycles which are to be operated with the use of electric buses.

Vehicle cycles are often denoted with the use of graph theory. They may be then defined as a finite sequence of the arcs in the directed graph of the structure of a transit network. By using the global positioning system (GPS) technology, we can gain vehicle cycles more easily. It would be optimal to collect them from the onboard equipment, being a part of some automatic vehicle location system. In Fig. 1 a vehicle cycle operated by 'PKM Sosnowiec' transport agency is presented in the form of GPS file.

In the event that a public transport company does not have such a system, one can collect these files with the use of personal GPS loggers. It should be noted, however, that in case of extensive and complex transport networks, such a solution is not really time-efficient.

B. Basic Algorithm

Outline of the structure of an IT support tool for bus fleet conversion towards an all-electric fleet is presented in Fig. 2 (next page). The key components of the structure are the following:

- Model for energy consumption;
- Decision-support system for electric bus deployment;
- Scheduling and optimization
- Economic models for the calculation of the total cost of ownership.

These components are marked bold in the figure.

We understand an object as a transit agency operating buses and the necessary infrastructure, operating on a specific transport network equipped with essential infrastructure.

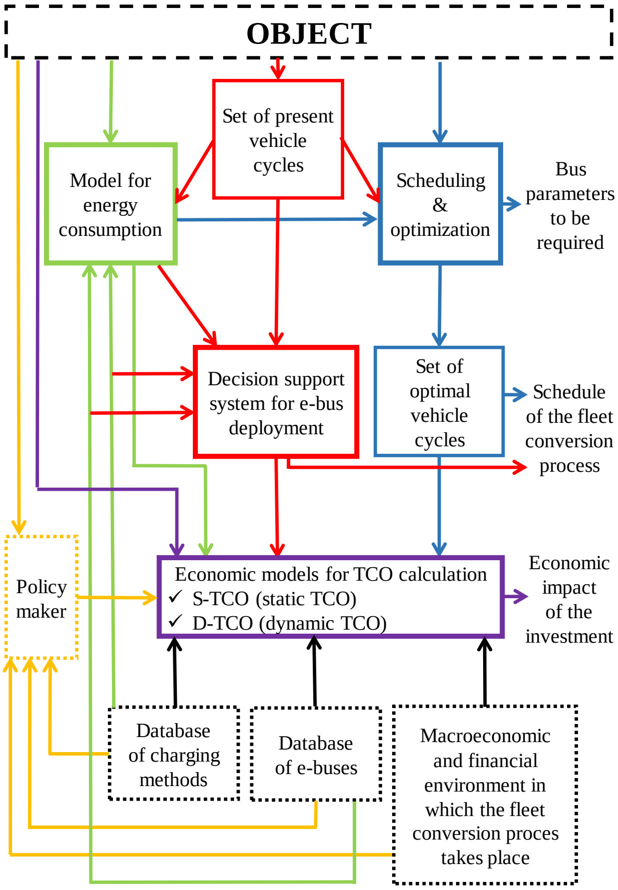

Fig. 2. Overview of the process.

One of the starting points for the calculation is a set of present vehicle cycles (as defined above). In the next step, one can use a decision-support tool for electric bus deployment on a transit network, based on the present bus schedule. The functionality of this component is to adjust the operational limits of electric buses to the present timetable, based on energy demand calculations. We use a model for energy consumption for this purpose. As an alternative, we may calculate the demand for energy more easily either linearly or by taking a constant. By using this component, we have the opportunity to:

- Devise a detailed schedule for the bus conversion process – as a kind of a roadmap for various stakeholders towards a fleet consisting solely of electric buses;
- Formulate a static or dynamic model for a total cost of ownership (TCO) calculation – which aims to show the global cost of investment, including additional technical infrastructure (primarily charging infrastructure).

The idea of the functioning of the decision-support system is presented in next section in more details.

An alternative to the decision support tool based on the set of current vehicle cycles is to calculate the set of optimal vehicle cycles with the use of scheduling and optimization methods. The latter is optimal from the viewpoint of charging requirements of electric buses in a way not to allow discharging of the bus. The result of this approach is the formulation of required bus parameters. This path may also lead to the economic model.

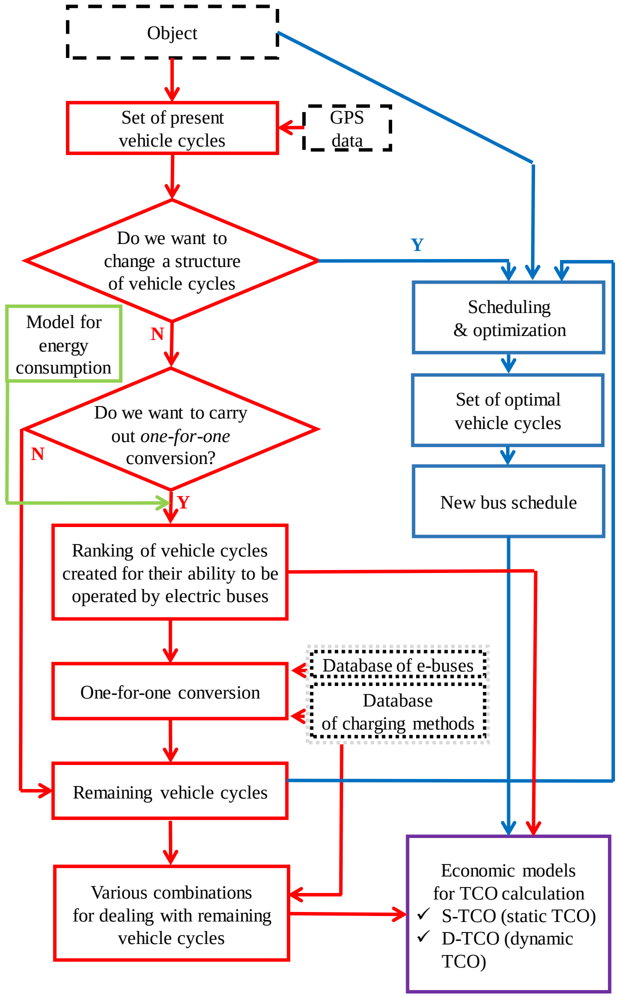

Fig. 3. Basic decision-support algorithm for bus fleet conversion towards a 100% electric fleet.

In the model, we take into account the existence of a policy-maker (e.g. a local authority, supervisory board). This actor may have some influence on the decisions related to the bus fleet conversion process. It is expected that the policy-maker may influence especially these economic issues which are depended on the macroeconomic and financial environment. It is possible for the system to support him or her in looking for other variants of the bus fleet conversion and analyze them.

C. Decision-Support Algorithm for Bus Fleet Conversion Process

The basic algorithm for the decision-support system for bus electric bus deployment is presented in Fig. 3. This figure is a more detailed description of the central part of the section colored red that was already presented in Fig. 2. Here, we expand the process of inducting electric buses to the corresponding vehicle cycles and – in consequence – to bus routes.

Firstly, we should consider whether there is a will to change the structure of vehicle cycles at all. If the answer is negative, one can develop a brand-new structure of vehicle cycles. This variant is colored blue in the scheme. The structure discussed, may be based on the frequencies assigned to subsequent bus lines. In this variant the focus is put on such a re-modeling of the structure of vehicle cycles, to get such a structure that meet all the charging-related limitations (including time slots for charging). In view of the fact that some buses will be busy during charging it may happen that either might we need more buses to sustain the public transport offer (for passengers), or we need to limit the supply of transport services. Both seem unfavorably especially since they are to happen because of the technical limitations of electric buses technology (insufficient range).

As long as there is no will for the modification of the vehicle structure, one may carry out the one-for-one conversion. The latter is understood as an attempt to operate as many vehicle cycles with the use of electric buses, as possible (having regard to the limited bus range).

To calculate the energy demand we may use the model for energy consumption, which is marked green in the schemes. Energy consumption model may have various degrees of detail. The simplest way to calculate the forecasted energy consumption is to use a linear function to the distance traveled. The values of energy consumption of electric buses in the unit of distance may be taken from the scientific sources [12]-[14], or be determined based on the basis of measurements in local conditions. To obtain more detailed results, one should use more advanced models for the calculation of forecasted energy consumption of the vehicle. These models should involve such important factors as energy recuperation, temperature, the load of passengers, terrain circumstances and the energy demand of the on-board systems (including air-condition). One may find other factors that may influence the energy consumption of the vehicle in [15].

The calculation of energy demand of the vehicle is strictly related to the charging technologies which are planned to be used in the transit network we analyze. The characteristics of discharge will look dissimilarly whether the transit agency will be operating terminal plug-in charging scheme, and otherwise, when they will be operating fast pantograph or in-motion charging. The choice of the charging technology is strictly related to the investment budget, a company has at its disposal.

The next step of the basic decision-support algorithm for bus fleet conversion towards a 100% electric fleet is the ranking (hierarchy) of the vehicle cycles. This ranking is created for the ability of vehicle cycles to be served with the use of electric buses. The ranking discussed is ordered from vehicle cycle which is the most suitable from the viewpoint of electric bus operation, to the least vehicle cycles which is the least suitable, but still possible to be operated with the use of electric buses. Capable (according to the ranking) vehicle cycles are the subject of the one-for-one conversion. This means that these vehicle cycles may be operated with the use of electric buses without disturbing any operational issues.

In many cases, however, such vehicle cycles will remain which are not possible to be operated by electric buses at this stage of technological development of batteries. The variants of dealing with such situations is described in the subsequent part of the paper.

D. Variants of the Bus Fleet Conversion Process in a Transit Company

If, as a result of the application of the abovementioned methods, or as a result of the omission of a one-for-one conversion stage, no serviceability by electric buses will be achieved the following possibilities are to be considered by a public transport company:

- Keeping the current timetable without changing the structure of vehicle cycles.
- Keeping the current timetable allowing changes in the structure of vehicle cycles.
- Keeping the current number of vehicle cycles allowing changes in the timetable.
- Partial or total re-schedule of the timetable and the structure of vehicle cycles
- Amendment to take account of the political nature of the decision to require electric buses on certain lines.
- Keeping the current timetable without changing the structure of vehicle cycles, awaiting for better technical parameters of electric buses to try the one-for-one conversion again.

One variant from another is different in the degree of interruption in the bus schedule, transit offer for passengers as well as in the time horizon of the investment. Graphic representation of these variants is presented in Fig. 4.

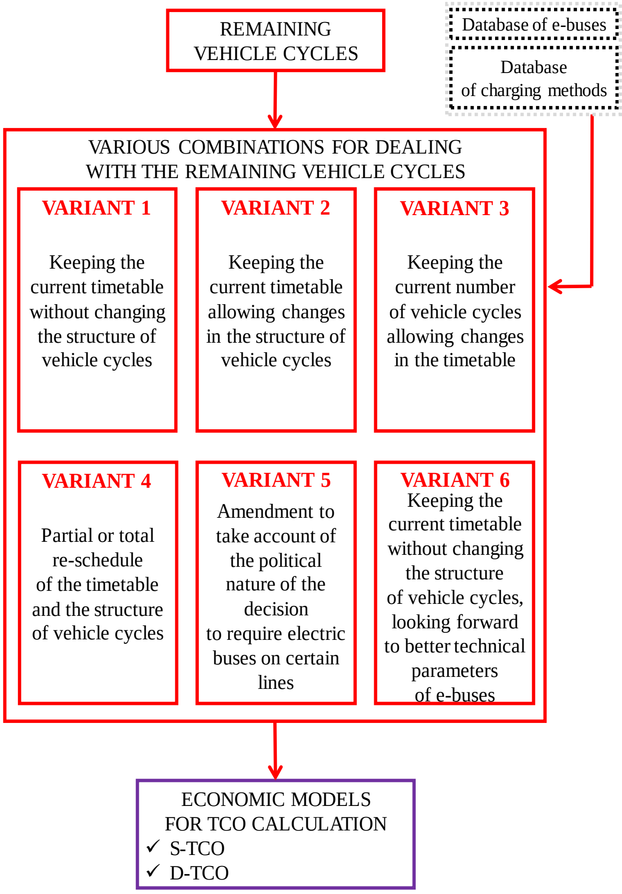

Fig. 4. The variants of the bus fleet conversion process in a transit company.

Fig. 4 is a development of the ‘various combinations for dealing with the remaining vehicle cycles’ box, presented previously in the lower part of Fig. 3.

E. Economic Models

We can evaluate the costs of the bus fleet conversion using the model for the calculation of the total cost of ownership (TCO). This feature is to help the decision-makers to take up an appropriate strategy of the fleet renewal.

The model for the TCO calculation is divided into static TCO model and dynamic TCO model. The static one we may calculate the total cost of the investment in the electric buses if only they are to be purchased in one go. This model uses the following basic components: bus acquisition costs, operating costs, infrastructure costs, external costs and the proceeds of liquidation.

In the dynamic TCO model, however, the successive purchases of electric buses are taken into account.

The economic evaluation of the bus fleet conversion in the transit company results in the detailed report of the economic impact of the investment.

III. Summary

The conversion of conventional or mixed bus fleets of transit agencies in Europe and beyond, to more modern powertrain technologies (including battery-electric buses) is a vital issue. The approach presented in this paper allows a methodological approach to the achievement of a fully-electric bus fleet in a transit company.

The decisions on fleet conversion process may be supported by the tools based on information technologies that use the data from transit companies. Under the PLATON international research project, such a tool is being developed. It can help the stakeholders involved in the process to take methodologically-justified decision related to the fleet renewal process.

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