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ELIMINATION OF INCONSISTENCIES IN THE PROCESS OF EXPANDING THE FLEET OF ELECTRIC BUSES

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Purpose: The aim of the work is to present selected research results of the first stage of work, the so-called pre-design research related to the implementation of electric vehicles into the company's fleet.
Design/methodology/approach: the article presents inconsistencies and problems related to the use of electric buses as well as problems related to point infrastructure. The results of the research were obtained from the observations of the analyzed transport processes, the process of fleet management, from interviews with employees, as well as from the analysis of documentation and comparison of records with the actual state.
Findings: The results confirm that the effective elimination of nonconformities leads to the improvement of the process quality and the reduction of costs related to vehicle breakdowns.
Research limitations/implications: The research indicates the need for continuous improvement of the process of using electric vehicles. Validation studies have confirmed that it is impossible to eliminate all problems, therefore the process should be constantly improved.
Originality/value. The article indicates the need to amend the subsequent projects and the current methodology of the procedure.
Keywords: transport quality, public transport, electric buses, electric vehicles, vehicle fleet.
Category of the paper: Case study.

1. Introduction

Due to the high cost of purchasing an electric car, public transport is taking a significant share of the drive towards electromobility (Sarmow, Figaszewski, 2018; Borghetti, Longo, 2022). Subsidies from the European Union and various programmes, i.e. "Green Public Transport" give Polish transport companies the opportunity to purchase expensive but

environmentally friendly vehicles (Alwesabi, Liu, 2021; Pikuła, Piotrowski, 2018). The Green Public Transport programme at the start of 2021 has allowed applications from 33 cities seeking 176 charging stations, 322 electric buses, two hydrogen refuelling stations and 102 hydrogen buses and 7 trolleybuses (Połom, 2021; Maciocha, 2018).

In November 2012, measures were launched to implement electromobility in the city of Jaworzno. Between 2013 and 2014, the first electric buses were tested (Jamróz, 2012). In 2015, a Solaris Urbino 12 electric vehicle was purchased for the passenger line. At that time, a so-called fast-charging charger was installed on the Osiedle Stałe loop.

After the positive experience of operating the first electric vehicle implemented on passenger lines, the carrier purchased a fleet of another 22 electric vehicles. The EU program covered the purchase of intelligent fleet management system, central station for charging and replacement of bus batteries at the depot and the construction of five fast battery charging stations in the city of Jaworzno. Development of electric vehicle fleet required appropriate planning of development and implementation works covering three main stages (Jamróz, 2012; Rusak, 2018).

Pre-design study stage. Due to various problems connected with using and maintaining the existing fleet of electric vehicles and the required point infrastructure, before undertaking implementation activities it was necessary to identify these problems and then to develop corrective or correction actions. Obtained solutions were taken into account in next stages of the project. During the **design studies**, the location of chargers, lines to be electrified and modifications to existing timetables were determined. The moments of charging were planned and the schedule of energy replenishment on pantograph chargers was created for all electric vehicles. The project was implemented in this way. The **final stage** included the verification and validation of the implemented design solution.

The aim of this paper is to present selected research results of the first stage of work, the so-called pre-design research. The study is a case study in this respect. The proposed, presented solutions were implemented by the company.

2. Research methods

In order to identify incompatibilities, the solutions implemented so far in the enterprise were analyzed, routes of electric vehicles admitted to passenger traffic implemented by 2020 were traced, including departure and arrival times and their compliance with the adopted schedule in summer and winter months, and route intersections, lines which are the most and least loaded were determined.

Additionally, the location of charging stations, possibilities of using a given station during route realisation, frequency of charging for given brigades, level of battery charge in electric vehicles were analysed.

At each stage process observation, interview with employees (drivers, service technicians) and analysis of available documentation was done. On this basis nonconformities and problems of so-called "bottlenecks" were identified. After identifying the occurring problems, corrective actions were planned (chapter 3).

3. Results and analysis of studies on the possibility of using the existing point-of-use infrastructure – vehicle charging

The results of the analyses conducted on the operation of existing charging stations (point infrastructure) allow a number of problems to be identified, some of which are presented below:

- the planned locations of chargers in the city make it impossible to make flexible changes to the transport network, e.g. the first charger erected in the city has lost its importance within a few years. In 2017 it served 3 transport lines and now only one;
- the charger located on a hill makes it impossible to use it regularly in winter, due to the difficulty of moving the bus from under the charger after it has finished charging;
- the charger located on uneven paving makes it very difficult to connect the pantograph correctly. Numerous connection attempts take place, which significantly reduces the charging time;
- charges are carried out without formatting the batteries, often short and incomplete charges are made.

The analysis carried out allows the following conclusions to be drawn:

1. After the initial planning of the location of newly purchased chargers in the city, and before their installation, a visual assessment of the terrain should be made (absence of hills, unevenness, other protruding infrastructure elements) which could affect the process of charging the vehicle.
2. Wherever possible, locate charging stations at intersections of transport lines so that changes to transport networks can be made if necessary

4. Results and analysis of studies on the operation and maintenance of electric vehicles

The operation of electric buses involves a number of activities that need to be synchronized in order to ensure the fluidity of the city runs. In order to identify the problems connected with the operation of electric buses, an environmental interview was carried out with the plant employees connected with the operation of the vehicles and transport lines under study, and the documents made available were analysed. The research results and conclusions are presented in Table 1.

Table 1.
Wyniki badań dotyczących eksploatacji autobusów elektrycznych

<table>
<tr><th colspan="2">Fleet management problems</th></tr>
<tr><td>
<table>
<tr><td>› 344</td><td>Szczakowa Dworzec PKP
» (234)
Martyniaków (248)</td><td>12:45:00
13:48:00</td><td>12:45:24
13:48:31</td><td>-00:00:24
-00:00:31</td><td>73%
57%</td><td>351 Solaris Urbino 12
electric</td></tr>
<tr><td>› 344</td><td>Elektrownia Zespół Szkół
» (390)
Szczakowa Dworzec PKP
(234)</td><td>14:12:00
15:10:00</td><td>14:12:04
15:14:21</td><td>-00:00:04
-00:04:21</td><td>56%
39%</td><td>351 Solaris Urbino 12
electric</td></tr>
<tr><td>› 314</td><td>Szczakowa Dworzec PKP
» (234)
Podłęże Osiedle (1701)</td><td>15:30:00
16:14:00</td><td>15:30:48
16:13:33</td><td>-00:00:48
00:00:27</td><td>38%
28%</td><td>351 Solaris Urbino 12
electric</td></tr>
<tr><td>› 314</td><td>Podłęże Osiedle (1701)
» Szczakowa Dworzec PKP
(234)</td><td>16:25:00
17:05:00</td><td>16:25:40
17:06:44</td><td>-00:00:40
-00:01:44</td><td>38%
29%</td><td>351 Solaris Urbino 12
electric</td></tr>
<tr><td>› 314</td><td>Szczakowa Dworzec PKP
» (234)
Podłęże Osiedle (1701)</td><td>17:10:00
17:54:00</td><td>17:10:55
17:54:24</td><td>-00:00:55
-00:00:24</td><td>28%
19%</td><td>351 Solaris Urbino 12
electric</td></tr>
</table>
Figure 1. Result from the system showing different levels of battery charge
</td><td>Problem with appropriate reaction to low battery alert
The dispatcher has multiple tasks and the implemented system requires the dispatcher to constantly monitor the energy level of the electric vehicles.
Conclusion:
One person will not be able to perform all tasks with an increased fleet of vehicles.</td></tr>
<tr><th colspan="2">Fleet maintenance/service problems</th></tr>
<tr><td> 

Figure 2. Service hall with a platform to work on the roof of an electric bus with many components</td><td>Vehicle servicing and maintenance problem
The company lacks employees who can work at height and regularly service structural components on the roof of vehicles. Not enough equipment to reach the roof of the vehicle
Conclusion:
Service employees should be referred immediately to the appropriate courses and obtain additional authorisations to work at height, it is imperative to comply with health and safety regulations</td></tr>
</table>

Cont. table 2.

 **Figure 3.** Electrobus during traction motor repair	**Excessive downtime due to repair of traction motors** - Failure of components (e.g. traction motors and drive bridges), - Lack of suitable parts in stock. - PKM employees did not have the appropriate skills to repair and replace these components. Conclusion: Maintenance staff should be referred to appropriate courses and gain additional qualifications related to the repair of electric vehicles.
	Failures of traction battery modules Batteries were recharged too often and at the same time unformatted Conclusion: Charge the batteries less frequently. Charge with low voltage, always to 100%.
Problems during on-road operation	
 a)	**Incorrectly designed timetables** Electric vehicles were unable to perform the task in its entirety. Conclusion: Creating one timetable for a diesel bus and an electric vehicle is wrong. When creating timetables for electric vehicles it is necessary to take into account the different behaviour of the vehicle during operation under varying climate conditions.
 b) **Figure 4.** Electrobus in operation a) in summer b) in winter	**Problems with driving in winter** Electric buses have a higher weight and at the same time the rear of the vehicle at the drive axle is not under load (as is the case with diesel buses, for example). Conclusion: Electric buses cannot start in winter on a slight hill and generate large disturbances and delays in service, so extra time for "starting" must be taken into account when planning the timetable.

The results of the research (Table 1) were taken into account during the subsequent stages of the implementation project.

5. Corrective and preventive action

The analysis of the existing and potential non-compliances made it possible to develop corrective and preventive actions, which were implemented at the stage of the EU programme

implementation. The estimated cost of implementing the selected solutions for the company (as of 1.01.2021) is presented in Table 2.

Table 2.
Proposed preventive measures related to the operation of electric buses in the plant under analysis (own elaboration)

	Activities introduced to the company
Problem with appropriate response to alerts – low battery	For the project related to the deployment of a fleet of 20 vehicles to the plant, the employment of at least one person to supervise the vehicles and an additional person to operate the vehicle fleet was included. Estimated cost of implementing the solution: - full-time employee of the dispatching centre - 4000 PLN gross per month, • training - 4200 PLN.
Problems with vehicle servicing and maintenance	For the project related to the implementation of a fleet of 20 vehicles, additional equipment was purchased, i.e. platforms, ladders and even overhead cranes. Estimated cost of implementing the solution: - platform - PLN 17,000, - ladder - 5000 PLN, - crane - 30000 PLN. As the existing employees of the service had acquired the necessary qualifications by the time the work at this stage of the project commenced, all new service employees should be directed to appropriate courses and acquire additional qualifications for work at height.
Excessive downtime due to repair of traction motors	For the project related to the implementation of the 20-vehicle fleet, an agreement was drawn up and signed with the vehicle supplier, according to which the supplier is responsible for carrying out training in the use of electric buses and covers the costs of spare parts under warranty. Estimated cost of introducing the solution: employee negotiation time
Failures of traction battery modules	The timetable was changed, the electrobus services by limiting the number of charges and a schedule was created. In addition, battery formatting was introduced. The study was carried out as part of an engineering project and made available to the company. No additional costs for the company.
Incorrectly designed timetables	The timetable was carefully analysed, summer and winter times were measured, vehicle circulation was analysed and appropriate adjustments were made to the timetable. Estimated cost of the solution to the company: The study was carried out as part of the engineering project and made available to the company. No additional costs for the company.
Problems with driving in winter	Change your attitude to the type of tyres you use. Purchase winter tyres (instead of multi-season). Estimated cost of solution: • cost of one winter tyre around 1,300 PLN, for a vehicle of standard length (12 metres) 6 such winter tyres are needed, i.e. a cost of around 7,800 PLN.

As a result of the research work carried out, design assumptions were drawn up for the charging of the new 20 vehicles and a charging schedule was created for all 44 electrobuses owned by the company. The application of the proposed solutions made it possible to reduce the number of charges for 7 transport tasks from the current 65 to 33 charges (Table 3).

Table 3.
Number of battery charges of electric buses on routes

Nr of bus-course	Number of charges before modification	Number of charges after modification
303/01	9	5
303/02	9	4
303/03	7	5
303/04	8	5
372/01	10	4
372/02	11	5
372/03	11	5

It was found that bus vehicle batteries are currently in much better condition. For example, analysis of the technical documentation of 4 Solaris Urbino 8.9le electric vehicles, running on services 372/01, 372/02 and 372/03, on which charging was reduced twice, allows us to state that the number of registered defective energy stores has significantly decreased.

After a few days of operation of the implemented project, another problem arose. One of the chargers was installed at the very end of the parking bay, where the driver has proper access and possibility to connect the vehicle for charging (no hills, bumps, etc.). Unfortunately, the bus shelter under which passengers are waiting is behind the charging infrastructure. Consequently, the charger obscures part of the vehicle, including the open door. Cases of passengers being left under the shelter have been reported. As a result, an additional rule has been introduced to withdraw the vehicle under the bus shelter when charging is complete and to ensure that all willing passengers have boarded the bus.

6. Summary

Implementation of the prgoram contributed to increase of the fleet of electric vehicles serving bus lines in Jaworzno. In addition, the introduction of the new schedule reduced the number of charges on the so-called pantograph fast chargers installed on the loops and contributed to a reduction in the number of damaged battery modules. In 2019, 6 faulty batteries were found, in 2020 3 faulty batteries were found and in 2021 only 1 faulty battery. The introduction of corrective actions, including the employment of an additional person, enabled the supervision of all electric vehicles.

As shown, the elimination of non-conformities and quality improvement is a continuous activity. During the operation of the new fleet of vehicles, a new, hitherto unheard of problem was identified, related to passengers not being picked up from a bus stop, due to the awkwardly placed spot infrastructure. In future implementations this problem should be taken into account during the analysis related to the deployment of the infrastructure.

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