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DEVELOPMENT OF TROLLEYBUS PUBLIC TRANSPORT IN GDYNIA AS PART OF A SUSTAINABLE MOBILITY STRATEGY

Summary. In many EU cities, trolleybuses are experiencing a period of revitalization. New lines, state-of-the-art designs, the use of auxiliary propulsion batteries, ecological values and other factors offer great opportunities for this kind of public transport as an effective tool to shape transport policy in accordance with the principles of sustainable mobility.

Gdynia is one of three cities in Poland with a trolleybus public transport subsystem. Since the beginning of political and economic transformation, Gdynia's authority consistently implements measures aimed at balancing urban mobility, above all by improving the quality of public transport services and creating conditions for the development of alternatives forms of transport to private car travel.

The experience of the development of trolleybuses in Gdynia as an element of sustainable mobility, the nature of this means of transport in both economic and operation terms, the implementation of original technological solutions in the trolleybuses' construction and the impact on decision-making by marketing research are the areas of interest in this paper.

Keywords: public transport; management; trolleybuses; sustainable mobility.

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1. INTRODUCTION: SUSTAINABLE MOBILITY STRATEGY

The aim of the sustainable urban mobility strategy is to increase the accessibility of urban areas and to ensure the effective processes of movement, such as access, passing through the area and moving within the urban area.

The sustainable mobility strategy sets objectives and priority actions to achieve and perform in the next decade, or even decades to come, taking into account the needs of residents and the local, regional, national and EU strategic objectives of transport policy, as well as socio-economic and spatial development within the framework of the comprehensive policy.

The mobility strategy, in line with the principles of sustainable development, contributes to the balanced development of all modes of transport, while favouring the transition to greener subsystems, in the following ways:

- public transport - by raising the quality of the provided services, increasing their safety and availability and extending the integration of services
- non-motorized transport - by increasing the attractiveness and safety of walking and cycling
- intermodality - through the integration of different transport modes and the facilitation of changes of means of transport during a journey
- road transport infrastructure - optimizing the use of existing road infrastructure, taking into account flowing and slower traffic
- intelligent transportation systems (ITS) - their use supports effective traffic management of all modes of transport and services for the mobility of both people and goods

2. POTENTIAL ROLE OF TROLLEYBUS TRANSPORTATION IN THE SUSTAINABLE MOBILITY POLICY

The trolleybus transport subsystem, with its characteristics, can play an important part in achieving the main goals of sustainable urban transport. The urban public transport system will be one of the pillars of sustainable mobility; however, in many cities, it is still one of the main sources of pollution and exhaust emission. Therefore, the development of technologies using electric power has become the driving force in the change of the fleet structure in recent years. Electric vehicles, compared with diesel-powered vehicles, are more efficient and productive.

It is essential that, within the plans of public transport development (including electric vehicles), a comprehensive approach is adopted, which balances the transport issues in social, economic and environmental aspects. One of the most important global policy objectives of sustainable mobility is to reduce the negative impact of transport on the environment. Trolleybus transportation is part of this policy as a way of eradicating direct pollution from the cities. The development of any trolleybus subsystem is fully compliant with the current goals and environmental commitments, providing an innovative approach to the organization of public transport. Trolleybus transportation fits well into the concept of electromobility, which assumes the use of individual electric vehicles, such as electric bicycles, electric cars, electric scooters, electric motorcycles and public transport systems, including trams, trains, buses and electrobuses. The operation of the electrical subsystems of public transport in the Tri-City area (Gdańsk-Gdynia-Sopot) is a significant facilitation in developing sustainable urban mobility.



An intermediate goal of sustainable mobility is to achieve a balanced representation of the different means of transport used for everyday travel. To achieve this objective, users of the system should be provided with an attractive way of travelling by public transport, which should be as competitive as possible with other means, especially passenger cars. In this respect, the trolleybus subsystem is characterized by good performance properties, including dynamic acceleration, being vibration-free and low noise levels inside the vehicle.

Gdynia is an example of the growing role played by trolleybus transportation in shaping sustainable mobility.

3. POLICY OF SUSTAINABLE MOBILITY IN GDYNIA

In common with other cities in Poland, Gdynia has been struggling with the problem of growing individual motorization for many years. In response to the problem of increasing traffic congestion, the city undertook various activities aimed at stopping and reversing the negative trend. The instrument used in the implementation of a sustainable transport policy is the *Sustainable Urban Mobility Plan (SUMP)*, which defines a set of actions that aims to effectively solve transport problems and, in a sustainable way, meets the needs of the movement of people and goods in Gdynia. The main objective of Gdynia's *SUMP* is to achieve a sustainable urban transport system through the implementation of such objectives as:

- increasing road safety (pedestrians, cyclists, drivers/passenger cars) and safety in public transport vehicles
- reducing noise and air pollution, carbon dioxide emission and energy consumption
- improving the effectiveness and efficiency of transporting people and goods
- improving the attractiveness and quality of the urban area
- improving the residents' quality of life
- improving the accessibility of transport services for residents

The priority of public transport development was realized by the modernization of the fleet and investment in energy-efficient and low-emission vehicles: in other words, buses powered by compressed natural gas, modern buses that meet the highest environmental standards and trolleybuses. The role and importance of trolleybuses were confirmed in all the major strategic documents of the Gdynia local authority. Trolleybus transportation is an implementation task included in the *Strategy for Development of the City of Gdynia*, which is regarded as being environmentally friendly and contributing to the unique image of the city. There have also been actions undertaken to promote public transport traffic through the use of designated bus lanes and also priority at traffic lights, which is the result of the implementation of the Tri-Star traffic management system in Gdynia.

4. PUBLIC TRANSPORT IN GDYNIA

At the beginning of the process of economic transformation in Poland (the 1990s), Gdynia's authorities immediately took measures to improve the quality of public transport services. At that time, the objectives of the transport policy of the city were subject to different conditions of transport organization (Table 1), which focused primarily on improving the cost-effectiveness of providing services based on market forces and improving

the quality of these services through competition between operators. Since Poland was not a member of the EU and could not benefit from European funds, the main direction of change in the operation of public transport was set out by the changes in the organization and management of the transport system.

Table 1. Selected characteristics of the transport system in Gdynia in 1996 and 2013

Item	1996	2013
Share of households with a car (%)	48	74
Share of passenger cars in urban journeys (%)	32	54
Share of public transport in urban journeys (%)	68	46
Number of passenger cars per 1,000 residents	190-220	520

Source: own elaboration

Aiming to improve the quality of public transport services and already predicting the role of public transport as an alternative to the fast-growing individual motorization, Gdynia's authorities decided to decouple the functions of the transport organization from the operator, as well as introduce competition into transport services. The Public Transport Authority in Gdynia (ZKM Gdynia), an independent transport organizer, was established. On the one hand, acting on behalf of the passengers as a buyer of the services from the operators, it had to ensure quality of these services. On the other hand, as a representative of the city authorities, it had to rationalize the amount of budget subsidies to public transport in relation to the quantity and quality of services.

These objectives assumed the break-up of transport organization, which was then at the behest of one monopolistic operator. The main tasks of the organizer of public transport became [1]:

- marketing research
- developing timetables
- ticket sales and control
- hiring operators, as well as the quantity and quality control of the services provided
- supervision, regulation and control of the movement of public transport vehicles
- maintenance of stops
- promotion of public transport

The basic advantages of breaking up transport organization among the operators were as follows:

- by functioning as an organizer in terms of a specialized unit, public transport could be managed using marketing techniques
- the conditions for competition could be created in public transport service provision
- the payment for services could be linked with quantity and quality on the basis of specific contracts
- specialized control of quantity and quality of services could be carried out

The action taken by the city authorities and ZKM Gdynia created a foundation for implementation in the following years of the policy of sustainable mobility in light of rapidly growing individual motorization. Changes in the quantity and quality of services in Gdynia between 1992 and 2014 are presented in Table 2.

Table 2. Selected characteristics of public transport in Gdynia in 1992 and 2014

Item	1992	2014
Absence of service (%)	4	0.02
Early departure above 3 min (%)*	6	0.42
Late departure above 3 min (%)**	10	17
Vehicle kilometre (vkm) (m)	15.2	19.1
Share of low-floor vehicles (%)	0	100

* the early departure of the bus or trolleybus is a departure that is at least 1 min ahead of schedule

** the increase in delays is a result of congestion

Source: own elaboration

Significant improvements to the quality of services and their adaptation to residents' preferences and behaviour were reflected in the service assessments with passengers. The results of comprehensive marketing research, carried out every two years in Gdynia, showed that the assessment of public transport services by residents (on a scale from 2, i.e., the lowest, to 5, i.e., the highest) increased from 3.39 in 1994 to 4.21 in 2013.

Gdynia's public transport system currently consists of a bus subsystem, a trolleybus subsystem and an urban railway transport subsystem, namely, the Fast Urban Railway (SKM) and the Pomeranian Metropolitan Railway (PKM). ZKM Gdynia organizes bus and trolleybus transportation. The Marshal of the Pomeranian Voivodeship is the organizer of the railway transportation (SKM and PKM), which is operated by Fast Urban Railway in Tri-City Ltd. The integration of ZKM and railway subsystems is executed through the ticket tariff system (metropolitan ticket) and the coordination of timetables.

ZKM Gdynia uses 336 low-floor vehicles, including 230 buses (including 98 articulated), 86 trolleybuses and 20 minibuses on the public transport system. The share of trolleybus transportation in vkm and carriage of passengers is respectively 26 and 29%. The higher share of trolleybus transportation in passenger carriages stems from the fact that trolleybus routes go through downtown Gdynia. The location of trolleybuses routes has become one of the determining factors of the trolleybus transportation's role in executing the policy of sustainable mobility.

The problem of rapidly increasing congestion made it necessary to take action in the field of sustainable mobility, including the development of the trolleybus network. The main activities, which determined the effective use of trolleybuses as an instrument of sustainable mobility policy in Gdynia, became:

- the reorganization of the trolleybus transportation operator
- the policy of renewing the fleet and building the infrastructure, with the following objectives:
 - improvement in the quality of trolleybus services, especially reliability, punctuality and comfort
 - technical and technological development, enabling the use of batteries as an alternative to the supply from overhead cables (catenary wire)
 - the use of expertise in vehicle construction by the trolleybus transportation operator
- the operational, economical, financial and ecological conditions of the development of trolleybus transportation in Gdynia



4. USE OF TROLLEYBUSES AS AN INSTRUMENT OF SUSTAINABLE MOBILITY IN GDYNIA

The following are the features of the trolleybus, which are used to promote it as an instrument of sustainable mobility [2]:

- it is environmentally friendly (it does not emit exhaust fumes at the site of use, while it emits low-level noise in comparison with other modes of transport)
- it is cost-effective in using renewable energy sources
- it does not require large and long-term investments due to very good technical solutions in the field of fleet and infrastructure
- the price of the fleet and the running costs will decrease, while its quality will increase with the rapid development of trolleybus subsystems
- it has a longer service life and is more convenient for passengers in comparison with the bus, as it offers more passenger space in the vehicle and uses power, which is generated outside the vehicle
- it shows good traction qualities and dynamics in motion, regardless of the topography and the occupancy of the vehicle
- it is flexible on all types of routes, with the option of an auxiliary drive
- it has the ability to store and recover energy
- it ensures high productivity at high capacity and operates in separate traffic corridors, which can produce a high operating speed
- it is suitable from the point of view of the requirements of the local community, as it ensures a balance between transport capacity and the impact on the environment

These features determine the potential of trolleybuses as part of a policy of sustainable mobility. The specific conditions of its operation in a particular area will always determine its final performance.

In Gdynia, the starting point for action in the use of trolleybuses, as an instrument of sustainable mobility, was the establishment of the trolleybus service operator as a separate and independent economic entity. Provision of bus and trolleybus services within a single company encouraged the operators to shift the burden of costs related to inefficient economic decisions onto the trolleybus transportation operation, which was characterized by a high proportion of fixed costs³. The new operator, established in 1998, as the Trolleybus Transport Company (PKT), owned by the Municipality of Gdynia (the city has a 100% share in the company), undertook actions in order to improve the quality of services.

As part of its strategy, the PKT proceeded with the modernization of overhead cables and vehicles. Overhead cables were flawed by outdated technical solutions (emergency substations, switches and crossings, an exploited network, the poor condition of catenary poles, some of which were from the 1940s). The vehicles (Gdynia's trolleybus transportation fleet in the early 1990s was based on the Soviet trolleybus ZIU and the Polish Jelcz-Berliet) were also characterized by a high breakdown rate and very low comfort, including the lack of low-floor spaces.

Outdated catenaries and fleet contributed to a lower quality of service compared to that of bus transport (see 1998, Table 3).

³ This was possible, since the operator did not conduct any comparisons of costs for diesel- and electricity-powered options

Table 3. Comparison of the quality of trolleybus and bus transport services in Gdynia in 1998 and 2014

Year	1998		2014	
	Trolley	Bus	Trolley	Bus
Share of absence of service (%)	0.35	0.18	0.03	0.01
Share of late departures, less than 3 min (%)	18.5	21.96	28.11	28.82
Share of late departures, more than 3 min (%)	6.8	10.66	19.71	15.21
Share of early departures (%)	2.14	2.24	0.37	0.45
Share of mismarked/incomplete marked vehicles (%)	0.06	0.03	0.05	0.12

Source: own elaboration

Furthermore, in the opinion of the residents, the quality of trolleybus transportation differed from that of the bus service. The lower quality perceived by passengers and, consequently, the lower competitiveness of trolleybus transportation limited the possibility of its use as an instrument in sustainable mobility policy, and to some extent challenged the offer of ZKM Gdynia in terms of public transport. In this situation, the organizer of transport, ZKM Gdynia, developed a variant strategy jointly with the PKT for trolleybus development, pointing to a variant of investment development as appropriate from the point of view of achieving the objectives of sustainable mobility.

The EU-funded measures, implemented from 2004 to 2014, helped to improve the perceived quality of trolleybus transportation services in Gdynia (Fig. 1). They also enabled greater use of its potential in preparing the strategy of sustainable mobility.

The investments significantly improved the assessment of trolleybus speed and convenience. The fact that the trolleybuses in Gdynia are still perceived by the people as slower than buses stems from the fact that trolleybus routes run through the downtown area, which is much more vulnerable to congestion. At the same time, the results of the study indicate that the inconvenience of congestion in Gdynia has increased. This is indicated by a decrease in the assessment of bus punctuality in 2013 compared to 1998, as well as a clear increase in the share of delays in 2014 compared with 1998 (Table 3).

From the point of view of the promotion of trolleybuses as an element of sustainable mobility, the residents' attitude towards this means of transport is important. Gdynia residents support the authorities' actions regarding trolleybuses and the adopted strategy of sustainable mobility. The results show that 63% of the population want at least to maintain the present role of trolleybuses in the city, while an additional 27% want spatial expansion (17% in favour of creating new trolleybus lines and 10% in favour of replacing bus lines with trolleybuses).



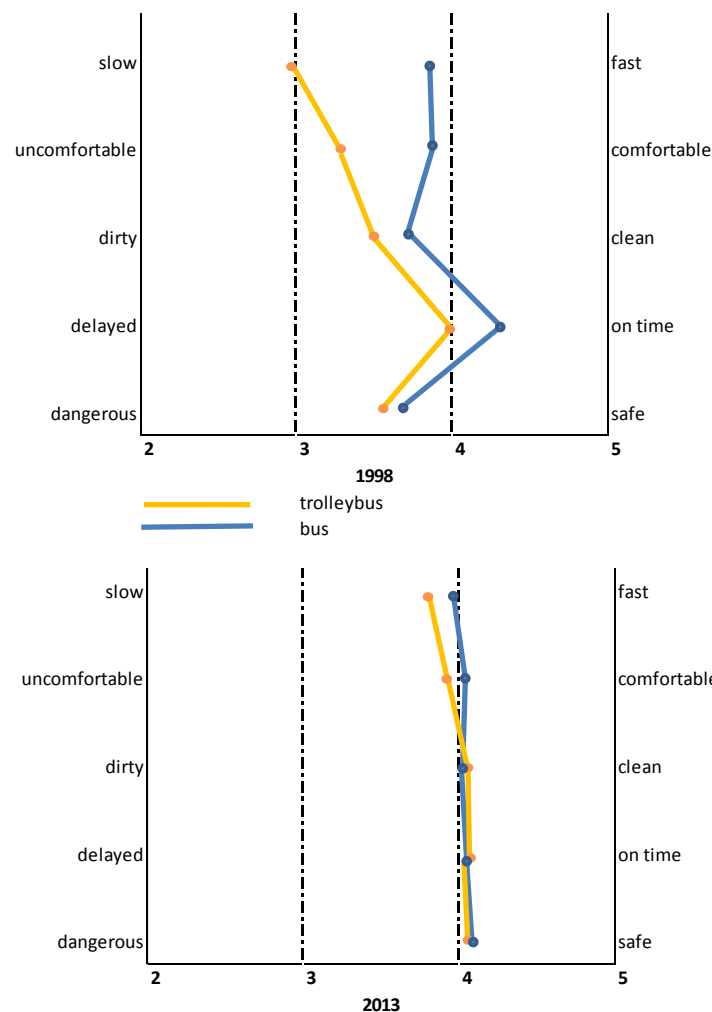


Fig. 1. Quality ratings of trolleybus and bus services by the residents of Gdynia in 1998 and 2013

Technological advances in the field of new energy sources present new opportunities for trolleybus growth, including expansion plans. To a certain degree, the use of the latest solutions of lithium-ion batteries frees trolleybuses from catenaries by allowing more flexibility in planning trolleybus routes and lines. In Gdynia, 47 trolleybuses are equipped with a battery drive (treated initially as an emergency drive). An efficiency test of the battery drive on one of the trolleybus lines (connecting the centre of Gdynia with the resort of Sopot) was completed at the end of 2015. Its results will determine the use of trolleybuses with a battery drive in serving Gdynia's districts and other cities in the future.

The cost of new vehicles for the many cities considering the introduction or development of trolleybus transportation, especially outside the EU, is a reason why they abandon the idea to implement any policy of sustainable mobility using this mode of transport. The cost of a new rigid trolleybus with a battery drive on the Polish market is about PLN 1.2-1.5 million (EUR 280-350,000). The price of a comparable bus is PLN 0.8-0.9 million (EUR 185-210,000). Before Poland joined the EU, in seeking alternative economic and technical solutions, the PKT developed and implemented the original technology of converting buses (especially used ones) into trolleybuses. The process of reconstruction of the buses into trolleys involves a number of steps, such as the removal of unnecessary components

(i.e., the internal combustion engine, gearbox, fuel tank etc.), the adaptation of the engine compartment for electrical equipment, interior restoration and strengthening of the vehicle roof, mounting of a pantograph and electrical equipment on the vehicle roof and in the engine compartment, electrical installation, and start-up and technical trials. The entire process of reconstruction, depending on the vehicle type, takes between two and four months. From the operational and functional point of view, trolleybuses acquired through conversion do not differ significantly from purpose-built vehicles. Between 2003 and 2013, the PKT acquired 32 vehicles from conversions, the cost of which was about 50% lower than for a new vehicle. Currently, the PKT focuses on the purchase of new vehicles, but the method developed in Gdynia can be successfully used in other cities, which cannot, for various reasons, buy new trolleybuses.

The development of trolleybus transportation in Gdynia and its use as part of a strategy of sustainable mobility are also affected by economic calculation, which takes into account the cost of the trolleybus transportation subsystem and external costs. The prime costs of trolleybus transportation in Gdynia are relatively easy to analyse, due to the public transport market organization in the city, where the organizer buys services from different operators, which allows for easy identification on the basis of unit costs (rates paid to carriers). In 2013, the cost of 1 vkm of services from the PKT was higher than the average for bus transport by 28 to 48%, depending on the contract with the bus operator. The higher cost of trolleybuses in Gdynia results from:

- higher fixed costs than for bus transportation (catenaries and substations)
- greater cost of a trolleybus

The analyses of the effectiveness of trolleybus transportation as an instrument for a sustainable development policy should also take into account the external costs. In the manual (an e-book), compiled in 2013, which was devoted to the problems of operating and developing trolleybus transportation, it states that a model of operational efficiency and the development of trolleybus transportation ought to take into account the varying “clean” quality levels when producing electricity, diesel prices and the number of departures. Figure 2 shows the break-event point for trolleybuses when over 90% of their electricity is generated from coal, as it is in most Polish cities.

The model of the trolleybus break-event point for Polish cities, taking into account the alternative operation of the buses on a particular route, is 250 departures per workday for trolleybus transportation. This figure should be treated with caution, however, because the trolleybus transportation network must be adapted to the distribution of demand sources, as well as meet the transport needs in line with the transport preferences to which the carrier offer must be subordinated. This means that some sections of routes, especially those connecting residential areas or other sources of traffic with the main streets in the city, can be characterized by lower values of the model. Therefore, treating the break-event point, as shown in the model, as a rigid boundary, delineating the routes of trolleybus transportation, would be a misunderstanding. This would require ending trolleybus lines on main streets, thereby forcing passengers to change to trains and buses to continue their journey. Such an action would conflict with the marketing management of the transport offer, along with the objectives of the policy of sustainable mobility.

On a workday in Gdynia, at a cross-section along each main street, trolleybuses perform between 240 (Wielkopolska St.) and 440 (Morska St.) departures in each direction. Between the access streets and the main streets in Gdynia, the number of departures in each direction varies from 70 to 230, while there are 47 departures on the section from Sopot to Gdynia.



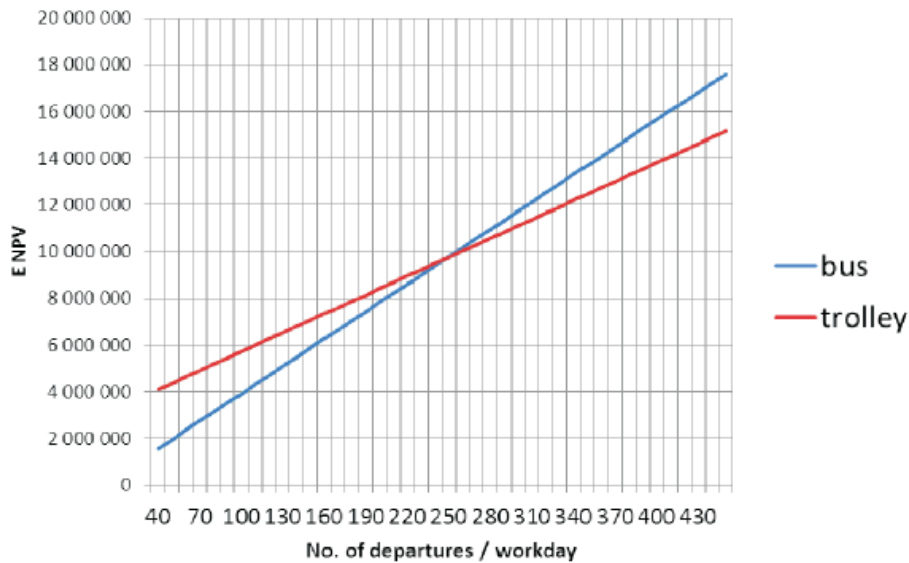


Fig. 2. Trolleybus break-event point (compared with buses) [7]

4. CONCLUSION

In drawing a conclusion from the analysis presented in the paper, it can be stated that an environmentally friendly urban public transport system is one of the main ways in which to support sustainable urban development. The example of Gdynia indicates that including trolleybus transportation in the policy of sustainable mobility should involve comprehensive actions of investment and organization, as well as management and marketing activities. The implementation of new, “clean” and environmentally sound technologies, through investment activities and the purchase of modern vehicles, is vital. Creating conditions for the smooth and cost-effective operation of overhead cables, including itemizing their costs, providing the desired image to residents, and offering high-quality transport services, which identifying specific transport demands, are also of equal importance.

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