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Cost, Efficiency and Service Quality Effects of Rolling Stock Renewal in Bulgarian Rail Transport

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Abstract

In the long-term perspective, the increased societal sensitivity towards environmental protection requires the promotion of environmentally friendly modes of transport. This implies a shift in the distribution of passenger traffic in favor of rail transport. The development of passenger rail services is determined by the quality of the service offered. The most important indicator of this is the condition of the rolling stock. Investments in new rolling stock and, consequently, in transport infrastructure accelerate economic growth, create prosperity, facilitate mobility, and not least, improve geographical accessibility. A key strategic priority for BDZ Passenger Services is the implementation of an active technological policy to meet the needs of passengers for quality, fast, safe, and comfortable transport. The introduction of new rolling stock into operation will meet these requirements while simultaneously increasing the efficiency of overall transport services.

Keywords: passenger railway, rolling stock, efficiency, quality service, BDZ Passenger Services.

JEL: R42

Introduction

Rail transport plays a key role in the development of any modern society. It is considered a fundamental means of economic development and a prerequisite for achieving social and regional cohesion. The transport sector in Bulgaria is of paramount importance for increasing the competitiveness of the national economy and for serving the population with transport services. At the same time, in recent years, the demand for passenger transport services has increased, despite the negative effects of the pandemic, and with that, societal expectations for their quality have also risen. In this context, the goal of BDZ Passenger Services is to create economic conditions for providing public services and the corresponding infrastructure to support them, meeting consumer expectations. Bulgarian State Railways (BDZ) as a group of companies, have activities in the field of railway transportation and provides the full set of services for passengers

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traveling and goods/freight forwarding, in the national and international railway network. The structure of the group includes Holding BDZ EAD, state-owned company (via the Ministry of Transport, Information Technology and Communications, Bulgaria), and several subsidiaries, as the main activities are being provided through BDZ Passenger Services EOOD and BDZ Cargo EOOD. One of the steps is to develop mechanisms to increase the efficiency of rail transport, adhering to the principles of its sustainable, safe, and reliable development, in line with the needs of passengers. Improving the efficiency is a continuous process, not one-time actions for achieving the goal. The ability to measure efficiency involves specific indicators designed to monitor its improvement. As Lord William Kelvin writes, anything that does not get improved inevitably deteriorates (Kelvin, 2024). This approach allows the activity of carriers to be adapted to the changing demands of passengers, thus ensuring that railway transport will be sustainable and ready for the future. The primary indicators for measuring the efficiency of railway services are the financial results, the costs (operative) for carrying out freights, passenger satisfaction, the impact of railway transport on the environment, the quality of services, security, reliability and safety during transportation. All of these indicators are interconnected – the improvement of one leads to positive results in regards to the others. Improved energy efficiency (which results from the incorporation of new rolling stock) leads to improved financial results and reduce costs for train traffic. Improving the quality of services, passenger satisfaction, as well as safe and secure travel is related to social efficiency, whereas the impact on the environment is directly linked to ecological efficiency. Increasing the efficiency involves maximizing the results of the invested resources, thus creating an optimal combination between key indicators. Efficiency is measured through analysis of time series, which allows for the energy, social and ecological efficiency of the current railway system to be compared to the ones from previous years. Access to quality data poses a challenge to the analysis. The collection and processing of such information for the purposes of internal management is not deemed necessary by the BSR railway company. Railway carriers believe that providing such information allows for public comparisons, which is not in their interest. Detailed information about the association's efficiency could help optimize the staff and replace it with a highly qualified one with a view to modernizing trains and innovative technologies when organizing traffic and ticket sales.

Literature review

Rail travel is essential to how people move around cities and countries. Ensuring a positive experience for passenger at train stations is crucial encouraging more people to use rail services (Wavetec, 2024). The passenger rail is a backbone of mobility networks, efficiently connecting cities, rural areas, and regions. (Shao, 2024) Passenger railway systems often offer a cost-effective, energy-efficient, low-carbon alternative for short- and medium-distance travel, while also reducing urban congestion. Sreelekha (2024) emphasizes through study the significance of transportation network planning as a means to reduce travel. Designing road networks is identified as a key strategy for managing travel demand and addressing mobility challenges. Transport which has fixed routes and services long distances, such as railway

transport, could solve the problem of moving large masses of passengers (Erdei, 2023).

The quality management system for transport services is a set of management measures, methods, and tools aimed at establishing, ensuring, and maintaining a high quality of rail services, based on the principles of international standards (Dragieva, 2021). The inefficiency of the services of railway transport is affected negatively by the revenue per capita, the percentage of electrified lines and their density (Lan, 2006). The efficiency of passenger rail transport poses a significant challenge for governing bodies, such as the Ministry of Transport, the Executive Agency "Railway Administration", the National Railway Infrastructure Company, and the national rail carrier itself. The former struggle to secure funds for maintaining infrastructure due to the low fees for railway use, while the carrier faces pressure to keep operating costs low. For rail transport to be effective, results must be achieved that are measurable by specific indicators, such as the ratio between train-kilometers produced and the resources invested. In this context, as noted in the International Transport Forum (ITF) report, efficiency is a broad term with many potential definitions (Beck, 2013). Emphasis can be placed on energy, social, environmental, technological, and economic efficiency. Reliability, safety, and security can determine the level of efficiency, particularly in Bulgaria. However, Professor Vasilev argues that "to the extent that any achieved effect can be transformed into an economic one to some degree, the primary summary measure is economic efficiency" (Vasilev, 2012). Reports from a roundtable organized by the OECD in 2019 concluded that "railways can be successful if there is political will to change the investment approach – not just investments in new infrastructure and rolling stock, but also in maintaining the existing ones" (OECD, 2019, report 177). One way to improve efficiency in organizing passenger transport is by increasing capital intensity through sound financial justification, changing the main goals and incentives that the management of BDZ Passenger Services typically faces. The main issue deteriorating the quality of rail service is problematic access to information, poor organization and management, delays, and sometimes even a lack of connections with other types of transport (Todorova, 2022). Improving the energy efficiency of rail transport depends not only on the renewal of rolling stock but also on train schedules and their management (Petrov, 2012). Regarding the efficiency of passenger rail transport, many authors believe that these services are not efficient.

The study by Meléndez-Hidalgo, Rietveld, and Verhoef (2007) examines the economic impacts of rail transport investments, highlighting the importance of transport cost reductions on social welfare and user surplus. The research emphasizes how spatially distributed markets benefit from improved rail infrastructure, which in turn enhances overall economic efficiency.

Gatta and Marcucci (2007) discuss the integration of quality requirements in public transport service contracts. Their study uses a choice-based conjoint analysis to evaluate how passengers perceive various service features, ultimately recommending a structured approach to include these quality standards in service contracts to ensure that efficiency is maintained alongside passenger satisfaction. Doumas (2007) explores how passenger railway companies diversify their activities, particularly through the commercialization of land and infrastructure.

This diversification strategy, observed globally, is noted for its potential to generate additional revenue, which can then be reinvested into the rail system, enhancing service efficiency.

Another relevant study by Beria (2007) focuses on the economic feasibility of transport megaprojects in Italy, discussing how increasing capital intensity through investments in infrastructure and rolling stock is vital for improving the efficiency of passenger rail services. This is especially critical in maintaining the competitiveness and reliability of the rail network.

These sources collectively provide a comprehensive view of the factors influencing the efficiency of passenger rail transport, from economic considerations to service quality and infrastructure investments. In our research, we will focus on an analysis of the current state of rail transport in Bulgaria and the state of the rolling stock. On this basis, we will determine the efficiency of rail transport and evaluate the economic, social and energy efficiency of purchasing and deploying new rolling stock.

Methodology

The purpose of this study is to analyze the efficiency of the national carrier BDZ Passenger Services and how this affects the quality of the transport service offered and the behaviour of transport service users when choosing their mode of travel. The main factors influencing people's choice to use passenger rail transport and how they impact consumer attitudes toward using rail transport are analyzed. The focus of this research is the national carrier, with the subject being the efficiency of the service provided. The working hypothesis to be investigated is whether the introduction of new rolling stock will improve the efficiency of transport services and which factors influence the choice of transport mode. Some factors, such as demographics and ecology, which are important for the sustainable development of passenger rail transport, are not considered, as they do not significantly impact consumer choice. The study of consumer preferences regarding the transport service provided gives the railway carrier grounds to change its development policy, directing its capital investments towards new rolling stock and adapting its operational activities to meet customer requirements, ultimately improving the quality of the service offered.

The approach to conducting the analysis includes methods and tools from the methodology and handbook for conducting functional analyses of horizontal and sectoral policies. Several main research methods are used in the study, namely:

- **Analytical** – this method is used to analyze all collected data and to identify the main issues in the provision of the rail service;
- **Statistical** – this method is used to search for and collect the necessary data to examine the various indicators of service quality;
- **Comparative** – this method involves evaluating and comparing the different indicators of the new and existing rolling stock and assessing how its renewal will impact the demand for passenger rail services and the volume of passenger transport.

The collected empirical information has been analyzed, and specific trends in the development of rail transport in Bulgaria have been identified. The results have been analyzed, and consumer preferences and directions for improving the quality of passenger rail services have been identified

based on improving the efficiency of the rail carrier.

Analysis of railway transport in Bulgaria and the state of the rolling stock

Rail transport is a fundamental element of the national transport system, and its development towards integration with the Balkan and European transport systems has a significant impact on the overall development of Bulgaria's economy. It continues to be foundational for economic development, territorial and social cohesion among the population. Rail transport is crucial for the effective functioning of the European economy – the sector had a turnover of over 100 billion euros in 2019 and employed more than 850,000 people (Eurostat, 2021). Over the last five years, more than 9 billion trips have been made annually by rail. It accounts for between 7-8% of total passenger traffic across Europe, with revenues estimated at 7 billion euros (European Commission, 2021). Although rail transport is gaining increasing importance in Europe, it is difficult to conduct an analysis in Bulgaria due to the fact that the available data is not harmonized and correctly reported by the national carrier (EU, 2023).

The importance of rail transport for modern society is evident, especially when people's mobility largely depends on the cost of energy sources. Mobility via rail is crucial for achieving the goals of European transport policy and for enhancing the integrated development of transport systems in the context of the green transition. Transport functions efficiently thanks to well-established connections that have evolved over the years and because science and technology have found innovative solutions within it. Fast communications create opportunities to overcome barriers between different regions and countries (Nowak, 2005). Although communications have developed to a level where connections between individuals and companies can be made virtually, economic life, professional realization, mutual dependence, unity, and coherence can be achieved and largely depend on a well-organized and functioning transport system (Rodrigue, 2017).

When determining the public significance of rail transport, it is important to consider its main functions and advantages, namely:

- Socio-economic function: Providing affordable transportation for the most vulnerable social groups in the country;
- Environmental function: Rail transport has the lowest relative impact on the environment compared to other types of land transport. In Bulgaria, 75% of the rail network is electrified, resulting in reduced harmful emissions during passenger and freight transport;
- Security and safety: Statistically, rail transport has the fewest accidents and incidents compared to other types of land transport (NSI, 2021).

Over the last 30 years, passenger rail transport in the country has undergone significant transformations, operating under continuous reforms and a decline in the number of passengers served. This has had a substantial impact and necessitates the adaptation of the national rail carrier's activities related to the management, operation, and maintenance of rolling stock. The imbalance in the shares of different types of transport has changed public attitudes towards modes of travel for intercity trips within the country. For example, the share of rail transport in passenger travel from 1990 to 1994 was 28% of all types of transport (NSI, 1998). However,

during the period from 2015 to 2021, its share has fallen to less than 6% (EEA, 2019).

Over the years, large-scale and ambitious programs for investments in infrastructure and rolling stock have been launched in Bulgaria, which are crucial for this type of transport to regain its competitive position (Council of Ministers, 2011). A well-crafted and successfully implemented rail transport policy contributes to improving the quality of life in any developed society (Nikolova, 2017). Given the need to enhance the efficiency and competitiveness of rail transport, restructuring in line with the European Union's policies for the integration of the transport sector within the Community is essential (Committee on Transport and Tourism, 2020).

One of the main EU requirements for Bulgaria in the area of rail transport was to create conditions for integrating the Bulgarian transport system with the European one (Gatovski, 2020). The alarming trend of a sharp decline in the work performed in passenger-kilometers is due to two main reasons (NSI, 2021):

- Unfair competition with road transport, which benefits from not covering the full costs of rail operations, thereby gaining a much more advantageous position compared to the railways; and
- The poor condition of the rail infrastructure and rolling stock.

The decrease in the number of passengers using rail transport is associated with various factors – limited train services with long intervals between them, extended travel times (due to poor infrastructure conditions and an inconvenient schedule for passengers), and extremely low comfort levels when traveling in outdated rolling stock (NSI, 2021).

For this reason, improving the material and technical base should be achieved through the introduction of new rolling stock, the construction of new transport facilities, as well as the reconstruction, modernization, and expansion of the existing rail network (Nikolova, 2021). Given that the railway network in our country is almost fully developed, in the coming years, it will be necessary to construct new railway lines to double certain sections of limited length, as well as lines connecting our country with neighboring countries (e.g., North Macedonia). Therefore, the primary focus should be on the reconstruction, modernization, and renewal of rolling stock, the implementation of automation and telemechanics in train operations, and the mechanization and automation of locomotive shunting work.

Rail transport in Bulgaria has experienced a continuous decline in passenger numbers. Figure 1 shows the number of passengers transported by rail in Bulgaria during the period 2010-2021 (NSI, 2022).

The primary reason for this decline is the deteriorating quality of the transport service offered – low travel speeds, lack of comfort and hygiene in passenger carriages, as well as the absence of additional services such as internet access, electronic ticketing, and food and beverages. Although rail transport has a great potential for development, achieving this requires not only the replacement of rolling stock but also the modernization and reconstruction of railway infrastructure and the improvement of the railway operator's management. The low quality of rail service and the technical limitations of the rolling stock create obstacles to its innovative development, leading to a decline in passenger numbers.

One of the main issues in BDZ Passenger Services is the high number of breakdowns

in the traction rolling stock, a consequence of exceeding the overhaul mileage for locomotives. There are numerous cases where locomotives are in operation with two or even three approved protocols for exceeded mileage, which further deteriorates the overall technical condition of the rolling stock. A significant portion of the rolling stock operating on the national railway infrastructure is obsolete, requiring increased maintenance costs and needing renewal and modernization.

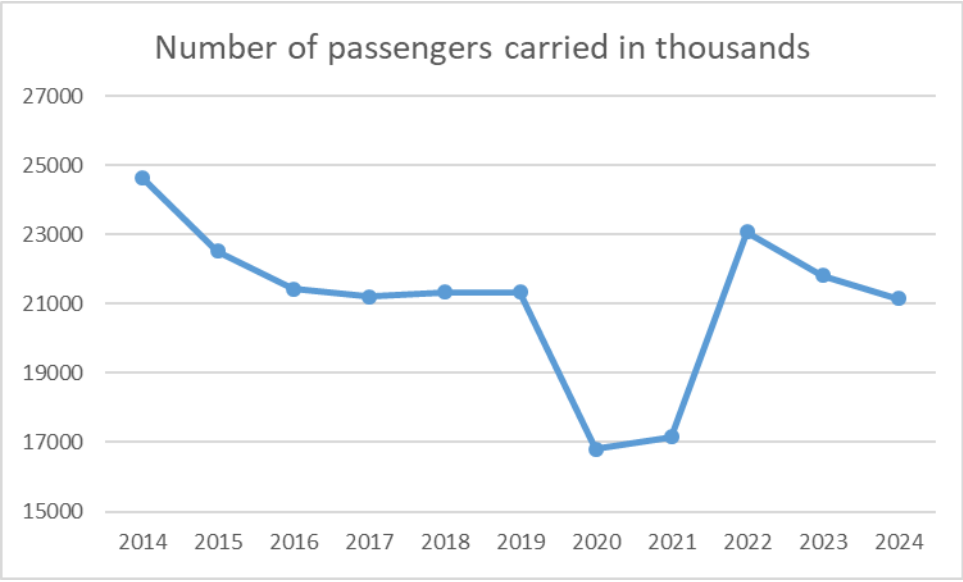

Figure 1. Number of passengers carried
Source: NSI, 2025 (https://infostat.nsi.bg/infostat/pages/reports/result.jsf?x_2=775)

Table 1. Number and age of locomotives

Type of locomotive	Series	Year of manufacture	Age in years	Number	Number of operation
Diesel	7	1971-1977	45-51	9	4
Electric	40	1970-1983	40-52	82	70
Electric	40M	2004	18	2	2
Electric	46200	1999-2008	18	2	2
Diesel trains (DMT)	10	2005	17	25	17
Electric trains (EMT)	30	2007	15	14	13
Electric trains (EMT)	31	2008	14	10	9
Electric trains (EMT)	32	1971-1979	43-51	17	11
Electric trains	80	2020	2	2	2
Total				174	134

Source: BDZ Passenger Service.

Table 2. Number and age of wagons

Type of wagons	Year of manufacture	Age in years	Number	In operation
First class (purchased and non-purchased)	1972-1999	23-40	72	46
Second class (purchased and non-purchased)	1976-2020	2-46	358	258
First and second class	1978-1983	40-44	24	16
Couches wagons	1986	36	5	4
Sleeping wagons	1985-2012	10-42	52	27
Bistro	1989-1996	26-33	5	4
Total			516	355

Source: BDZ Passenger Service.

BDZ Passenger Services possesses traction rolling stock and carriages that are both morally and physically outdated, with an unfavourable age structure. Table 1 shows the types of locomotives and their ages.

As seen in the table, BDZ has a total of 174 units of traction rolling stock (locomotives and multiple units), of which only 134 are in operation (77%). The average age of the locomotives is over 30 years (Bulgarian Parliament, 2021). The condition of the carriage fleet is similar, and the next table shows the types of carriages and their age structure.

The table shows that the total number of carriages is only 516, of which 355 are in operation, with an average age of 30 years. Another notable aspect from the tables is the variety of traction rolling stock series, which complicates the servicing of passenger trains.

The public function of BDZ Passenger Services is strongly oriented towards maintaining the number of passengers served by improving the quality of the service provided. This is achieved by anticipating the population's transportation needs and exceeding their expectations in fulfilling the transport task. A quality transport service requires the provision of accessible comfort, reduced travel time, and additional services. To achieve these goals, transport must be carried out with technically sound locomotives and carriages. Ensuring technically sound rolling stock for daily operations requires timely and high-quality ongoing and scheduled maintenance of the company's locomotive and carriage fleet, as well as their daily upkeep. This, in turn, necessitates adherence to the Public Procurement Act procedures for the supply of necessary spare parts and materials, as well as the contracting of external contractors for major scheduled repairs. This significantly complicates the entire process of rolling stock maintenance, prolongs repair timelines, and creates problematic situations with shortages of locomotives and carriages for current operations. These issues lead to a decline in passenger numbers and a loss of market share to road transport.

The implementation of necessary supplies and services under the Public Procurement Act places BDZ Passenger Services in a disadvantaged position, making it uncompetitive compared to road transport operators, who are not required to comply with the same legal requirements.

Another problem is the lack of ETCS equipment in the locomotives, which hinders

the commissioning and normal operation of the railway infrastructure in sections equipped with ERTMS. The changes being made to the railway network are also related to capacity management, and currently, these are low-tech solutions. Despite the large reserve, it is necessary to technologically upgrade the methods for managing network capacity, which would have both economic and technological effects.

Efficiency of rail transport

Improving the efficiency and competitiveness of passenger rail transport in Bulgaria requires continuous development and enhancement of the material and technical base, primarily through the implementation of innovations. Over the past twenty years, rail transport has been systematically neglected and not modernized, which is the main reason for the shift of passengers to alternative modes of transportation. The important role that passenger rail transport plays as a connecting link in Bulgaria's economy and for the mobility of the population necessitates thorough economic and social studies when analyzing the need for new rolling stock. The close connection and interdependence between economic and social efficiency are particularly significant, as they are the two main forms of any efficiency. The introduction of new rolling stock will improve not only the economic parameters of the state enterprise but also the social function performed by rail transport. Thus, higher economic efficiency serves as a foundation for increasing social efficiency, which in turn further enhances economic efficiency (Vasilev, 2012).

Most studies centered around the efficiency of railway transport are focused on the technical efficiency of costs. The successful management of operating costs and making passenger freights more profitable pose a fundamental challenge to passenger railway transport. The lack of visibility of costs, and sometimes the lack of structured information about the various activities realized by the national carrier makes it difficult to calculate related costs. In order to solve this problem, key efficiency indicators that have a connection to transport costs need to be determined. It is necessary to make a distinction between expected costs, actual costs and additional costs. Expected costs are bound on the basis of the Contract for Public Services between the carrier and the state, the expected volume of transported passengers on the basis of previous years, the state of the wagons and the various routes (traffic schedule) of trains along Bulgaria's railway network. Actual costs are based on how much the transportation actually costs after it has been carried out. Additional costs are all costs which have not been planned, such as accidents, fines, etc. In order to optimize profitability when carrying out passenger freights, it is important to have real-time visibility and monitor transport operations, as well as the costs said operations involve. The key indicators which are used to determine energy, social and ecological efficiency include:

- Safety and security – number of cancelled trains due to shortage of wagons and locomotives; frequency and types of accidents;
- Quality of services and passenger satisfaction – train delays measured in minutes; observation of schedules; cancelled trips; train sanitation and maintenance; maximum capacity of the rolling stock in regards to available seats;
- Financial results – reduced energy consumption; investments in infrastructure

and rolling stock; generating profit; optimizing traffic costs;
- Impact on the environment – electrifying the railway network; encouraging ecological practices through reduced emissions and waste;

These indicators show the degree of effectiveness. Their detailed study is important for clarifying the overall effectiveness, but this article is limited to examining only the first two indicators mentioned above.

When planning these measures, ways to achieve the highest possible added value should be sought. The efficiency of rail transport has several main directions:

- Increasing the efficiency of the use of transport infrastructure through: modernization of infrastructure, creating a modern traffic management system, increasing revenue from own activities, and ensuring the necessary investments for future transport projects;
- Increasing labour productivity and staff efficiency in the railways (Tzvetkova, 2020);
- Efficient spending of financial resources for the maintenance and operation of railway infrastructure (Yordanov, 2019);
- Efficient use of state-provided funds for public transport service obligations;
- Efficient absorption of European funds for the development of railway infrastructure (Gatovski, 2017);
- Developing and implementing high-tech systems for effective train traffic management, ensuring a high level of safety and interoperability according to EU rules and standards (Nikolova, 2024);
- Achieving efficient management of the railway network and analyzing flows to make better business decisions and maximize the return on investments;
- Enhancing the competitiveness and sustainable development of the rail sector by ensuring conditions for fair competition between and within different modes of transport.

To significantly improve the overall efficiency of rail transport, specific actions must be taken related to:

- Optimize the network to a scope that can be operated and maintained with the necessary quality;
- Focus services on main corridors and efficient internal lines with optimal use;

Build rail links that connect industrial zones with the national railway network;

- Introduce a new unified Republican transport scheme that aligns train and bus schedules to direct passenger flow towards rail transport;
- Modernize railway infrastructure through the implementation of modern traffic management systems, ensuring high traffic safety, particularly the effective implementation of the Strategy and National Plan for ERTMS deployment (NRIC, 2021);
- Introduce high-tech innovative transport systems.

The implementation of the above-mentioned complex of measures will contribute to improving the overall efficiency and financial stability of rail transport.

Assessment of the economic, social and energy efficiency of purchasing and implementing new rolling stock

Economic, social, and environmental sustainability are interdependent and cannot exist without each other. A rail transport system in poor condition due to economic unsustainability cannot meet the demands

of the population and often generates various negative environmental effects. To address these issues, there is a need to purchase new rolling stock that can impact all aspects of sustainable development and generate benefits for all stakeholders. This also involves improving the maintenance of other assets of the national carrier, as well as the infrastructure, incorporating external costs for each mode of transport into infrastructure charges, ensuring technical efficiency and transport safety, improving contract procedures, and implementing other administrative measures.

The effective functioning of rail transport is impossible without the regulatory and supportive role of the state. The experience of other European countries shows that there is no passenger rail transport that is not subsidized by the national budget (EEA, 2007). Several developed countries, such as France, Germany, Belgium, and Italy, regulate rail transport through incentives aimed at optimizing the economic condition of national carriers (DVV Media Group GmbH, 2020). Increasing efficiency and expanding the range of transport service options while adhering to social standards is the main task facing the national rail carrier.

The methodology used includes basic principles and algorithms for evaluating the effectiveness of purchasing new rolling stock for BDZ Passenger Services. It is based on determining costs associated with:

- The current rolling stock;
- New rolling stock that could potentially replace the existing one.

The principles for accounting for the annual costs of the current and newly purchased rail rolling stock are identical. The costs (C) for each train in the Train Schedule (TS) are determined individually, and the total costs $C\sum$ for BDZ Passenger Services are the sum of the costs of all trains, with each train's costs represented by the formula (Velkov, 2018):

$$C = (C1 + C2 + C3 + C4) * n * k, \quad (1)$$

where:

C1 - energy costs (electricity or diesel fuel) in BGN/gross tonne-km;

C2 - costs for locomotive and train crews for servicing a particular train set, BGN;

C3 - costs for maintenance of traction rolling stock, BGN;

C4 - infrastructure fees for train movement, BGN;

n - the number of days a particular train operates according to the TS;

k - correction coefficient that adjusts the costs from the other multipliers in equation (1) to the actual costs reported in the accounting records of BDZ Passenger Services. This coefficient is introduced because some of the real operating costs (not dependent on operational work) are not included in formula (1).

Energy costs C1 are determined by the following formula:

$$C1 = Wj * V, \quad (2)$$

where:

Wj is the work performed by the train in tonne-kilometers, determined by multiplying the gross mass of the train by the transport distance;

V - the value of the energy source in BGN/tkm.

When calculating the electricity costs, average values are used for electric traction rolling stock, while for diesel, they are differentiated by series.

Table 3. Energy costs for different types of traction rolling stock

Types of Traction Rolling Stock	Costs in BGN/tkm
Electric	0.01000
Locomotive Series 07	0.04649
Multiple Unit Series 10	0.01962
Locomotive Series 55	0.06587
Locomotive Series 75	0.05840
Locomotive Series 55	0.06056

Source: BDZ Passenger Service.

All data used is provided by BDZ Passenger Services as of September 2021 and are as follows:

The costs for the locomotive and train crew to service a specific train set, R_{2j}, are determined by the following formula:

$$R_{2j} = H_j * \sum_{i=1}^{5} n_i * S_i \quad \text{C=H} \tag{3}$$

where:

H_j is the working time for servicing the train, equal to the travel time plus 1 hour for pre-departure preparation and 0.5 hours after scheduled arrival;

n_i is the number of personnel involved in the train's operation (engine driver, assistant engine driver, train manager, conductor, sleeping car attendant if applicable);

S_i is the hourly rate for the personnel, as per data from BDZ Passenger Services for September 2021: engine driver – BGN 11.28/hour, assistant engine driver – BGN 8.14/hour, train manager – BGN 7.46/hour, conductor – BGN 6.43/hour, sleeping car attendant – BGN 6.67/hour.

The maintenance costs R_{3j} are determined by the following formula:

$$R_{3j} = L_j * S_r \quad \text{C=L×S} \tag{4}$$

where:

L_j is the distance between the departure and destination stations, in km;

S_r is the maintenance cost per kilometer for traction rolling stock, BGN/km.

The infrastructure fee costs for each train C_{4j} are determined according to the methodology of NRIC (National Railway Infrastructure Company, 2019), with the formula:

$$R_{4j} = L_j * S_v + M_j * L_j * S_b = \\ = L_j * (S_v + M_j * S_b) \tag{5}$$

where:

L_j is the distance between the departure and destination stations, in km;

S_v is the cost rate per train-kilometer (S_v=BGN0.7902/train–km);

M_j is the gross mass of the train, in tons;

S_b is the cost rate per gross tonne-kilometer (Sb=BGN0.0025/grosstonne–km).

The total operational costs for BDZ Passenger Services are the sum of the costs C_j of all trains:

$$R_{\Sigma} = \sum_{j=1}^{n} R_j \tag{6}$$

where n is the number of all trains.

Efficiency from replacing the traction rolling stock fleet, excluding multiple unit trains from Series 10, 30, and 31

The efficiency of replacing the entire fleet of traction rolling stock (excluding the existing multiple unit trains from Series 10, 30, and 31) has been assessed in a differentiated manner by type of trains, with the aim of:

- Evaluating the overall efficiency of replacing the traction rolling stock;
- Proposing a strategy for the prioritized replacement of train types to meet the current schedule.

The same methodology was used for the evaluation of the currently used rolling stock, along with the following data:

- Value of the energy source (BGN/tkm);
- Hourly rates for train personnel (BGN/hour);
- Maintenance costs for traction rolling stock (BGN/km);
- Infrastructure usage fees, as provided by the accounting reports of BDZ Passenger Services for 2021.

For the equivalent data on new rolling stock, the following were used:

- Value of the energy source (BGN/tkm) – average catalogue data from leading manufacturers of similar traction rolling stock. These values are on average 20% lower than those provided by BDZ Passenger Services for Series 07, 32, 44, 45, 46, 55, 61, 75, and 77, and are approximately equal to those for Series 10, 30, and 31;
- Hourly rates for train personnel (BGN/hour) – the current rates have been maintained. The only change is in the number of personnel in line with the specific requirements for train operation (usually without an assistant driver);
- Maintenance costs for traction rolling stock (BGN/km) – these have been aligned with the currently operated multiple unit trains from Series 10, 30, and 31;
- Infrastructure usage fees - current NRIC methodology has been retained.

Summary data from the calculations are presented in Table 4.

The energy costs of fast trains along the main lines of Bulgaria's railway network (specifically along the longer sections – Sofia – Varna and Sofia – Burgas) experience a 44% drop when freights are carried out with new wagons (from 13 500 BGN to 7560 BGN). The costs for locomotive brigades experience a 23% drop (from 3700 BGN to 2850 BGN), the use of new wagons helps reduce repair costs by 46%, and the costs for infrastructure fees are reduced by 26%. The total cost of running one train on the main rail lines results in an average 32 % reduction, or approximately 500 000 BGN on an annual basis. Similar calculations are observed in regards to passenger trains where the average drop in costs is 43%, or 28 million BGN, due to the fact that the majority of the train compositions in the BSR Passenger Freight schedule are passenger ones, and therefore make more frequent stops along their routes.

The analysis of the data from the table allows the following important conclusions to be drawn:

- Replacing the entire fleet of rolling stock is expected to reduce the company's costs by nearly BGN 33 million annually.
- The most significant reduction is in energy costs - 56%, followed by maintenance costs - 44%, infrastructure fees - 25%, and train personnel costs - 24%.
- The new trains will reduce the overall weight of train compositions by 30%, leading to

Table 4. Summary Data from the Calculations

Energy value, BGN		Cost for locomotive crew, BGN		Repair costs, BGN		Infrastructure fee, BGN		Total costs, BGN		Reduction
Old rolling stock	New rolling stock	Old	New	Old New	New	Old	New	Old	New	Amount
Fast trains in main directions										
13500	7560	3700	2850	9600	5200	7800	5800	12630000	7815000	481500
44%		23%		46%		26%		38%		
Passenger trains in other direction										
72000	30300	22860	17380	45800	26100	39500	29600	65758400	37733700	28024700
58%		24%		43%		25%		43%		
Total										
85500	37860	26560	20230	55400	31300	47300	35400	78388400	45548700	32839700
56%		24%		44%		25%		42%		

Source: BDZ Passenger Services.

a decrease in the energy consumed for movement.

- Thanks to the new aerodynamic designs of the trains, energy consumption will decrease by up to 25%.
- The new traction equipment will also reduce energy consumption by 5-8%.

It should be noted that over the years, the existing rolling stock has been subjected to accelerated depreciation due to the postponement of repairs. Additionally, the lack of working capital to purchase spare parts forces the national carrier to cannibalize other damaged machines to provide parts for those still in operation. In conclusion, based on the data analysis, replacing the old rolling stock with new equipment can be identified as a key priority in the coming years.

Benefits of implementing new rolling stock

In 2021, BDZ Passenger Services executed its investment plans to renew the existing rolling stock to enhance the quality of service offered. In this regard, the company's operational program includes the gradual standardization of traction rolling stock series to reduce the required technological resources for repair, maintenance, and operation. Currently, 15 new Smartron mainline locomotives are in operation, running on routes such as:

- Sofia-Burgas-Sofia;
- Sofia-Varna-Sofia;
- Sofia-Svilengrad-Sofia; and
- Sofia-Kulata-Sofia.

Additionally, it is planned to purchase 20 high-comfort multiple unit trains for long distances and 25 for short to medium distances. Having a sufficient number of traction rolling stock will improve the quality of service by reducing delays and cancellations. Under contracts with domestic wagon repair plants, 15 passenger carriages have been refurbished and are now in operation. They are

included in the composition of express trains on the Sofia-Burgas-Sofia and Sofia-Varna-Sofia routes. The repair program includes the series of traction rolling stock and carriages subject to repairs and modernization, which will ensure and extend their service life by another 15 years.

Achieving sustainable development of passenger rail transport is associated with continuous and stable financing. In this sense, investments of adequate scale are necessary to secure the purchase of sufficient rolling stock. Developing a long-term strategy for sustainable rail transport is a significant challenge, as the trains and carriages purchased today will still be in use 30 years from now, and other assets will be used even longer. The challenges in this context are related to the difficulty in accurately predicting transport demand so far into the future. Some cities and regions will grow more than others, and people and businesses will likely respond to the challenges of global warming by changing how they move and work.

The overall efficiency of replacing traction rolling stock during the period 2022-2028 is the sum of the efficiencies achieved. The expected forecast values indicate a reduction in costs for BDZ Passenger Services by approximately BGN 70 million annually, or 30% compared to 2019 expenses. This allows for the recovery of invested funds within a relatively short period - 12-15 years, while significantly improving the quality of the transport service.

In conclusion, it can be summarized that the new vehicles are equipped with modern control systems, enabling a more efficient form of electrodynamic braking, due to the ability of electric motors to function as reversible machines. Specifically, they can operate both as motors (producing torque when electrical energy is supplied) and as generators (producing electrical energy when torque is applied). Because of these properties, they are often used not only for acceleration and maintaining speed regimes but also for slowing down or stopping the vehicles. In all cases, this involves switching the traction motors to generator mode.

Vehicles with older control systems are unable to convert the generated electrical energy into a form suitable for return to the contact network, which necessitates its dissipation as heat in braking resistors installed for this purpose. In the BDZ Passenger Services fleet, this type of electrodynamic braking is performed by locomotives from Series 44, 45, and even the modernized 46.200, as well as the remaining Series 32 multiple unit trains in operation. Vehicles equipped with more modern control systems (such as Series 80 locomotives and Series 30 and 31 electric multiple unit trains in the BDZ Passenger Services fleet) can convert the produced braking energy into a form suitable for return to the contact network, allowing it to be utilized by other electric rail vehicles in the same traction section.

This type of electrodynamic braking is called 'regenerative braking.' The energy generated from regenerative braking is recorded by the onboard electricity meter and generates savings for the carrier, in this case, BDZ Passenger Services. For this reason, all new electric rolling stock units should be equipped with this type of regenerative electrodynamic brake to improve the energy efficiency of passenger rail transport.

The introduction of new rolling stock will have a direct positive impact on operational and energy efficiency. This, in turn, will affect the key indicators of the quality of the rail service offered, including:

- Increased reliability - related to reduced train failures and breakdowns due to the fact that new vehicles are controlled by electronic components - thyristors and transistors. Increasing the number of vehicles with electronic control, devoid of the numerous moving parts of electromechanical systems, significantly reduces instances of stalled or delayed trains due to traction equipment failures, thereby enhancing reliability and overall operational efficiency;
- Enhanced comfort - the interior of the new carriages offers conveniences and additional services such as wireless internet;
- Improved speeds - the new locomotives and carriages allow for speeds aligned with the parameters of the railway track. The maximum permissible speed of much of the existing carriage fleet does not match the optimal track parameters, or at least not in some sections;
- Optimized use of track parameters - The geography and condition of the railway infrastructure in Bulgaria are characterized by alternating light and heavy track profiles and relatively frequent transitions between high and low-speed sections. This necessitates frequent changes in speed and traction parameters during train operation, especially on long routes that pass through sections with different profiles, technical conditions, and design and permissible speeds. An example is the Sofia-Varna route, where sections with sharp curves, slopes, and low speeds alternate with flat sections, gentle curves, and significantly higher permissible speeds. Vehicles (locomotives and multiple unit trains) with more precise, computerized control of their traction and braking modes, compared to much of the current fleet, would allow for more efficient use of track parameters, with lower energy consumption and shorter travel times.

The social efficiency of any transport service, including rail, is closely related to two key parameters - connectivity and accessibility. Since the new rolling stock will not result in the introduction of new destinations or the connection of new settlements to the railway network, it can be assumed that there will be no changes in terms of connectivity. However, it is important to consider how the delivery of new rolling stock will affect the accessibility factor, i.e., the ability to utilize the existing transport connectivity. Regarding this factor, the purchase of new traction-only rolling stock (locomotives) primarily impacts travel time, as excessively long travel times between two points can effectively negate the transport connection between them, greatly reducing accessibility regardless of the actual existence of connectivity. However, the significance of vehicles whose primary function is to carry passengers - namely passenger carriages and multiple unit trains - is much greater.

From an accessibility standpoint, important factors include the comfort that must match the serviced destination and an environment adapted to the needs of all social groups. In this regard, the existing BDZ Passenger Services fleet has significant deficits that can only be overcome through the purchase of new rolling stock. Much of the carriage fleet does not offer the necessary level of comfort for the long destinations it serves – the carriages lack air conditioning, seat ergonomics are unsatisfactory, and the technical and hygienic condition of the vehicles is often compromised. Most of the used compositions lack internet and additional amenities such as a buffet, children's area, or space for bicycles

and bulky luggage. Conditions in passenger carriages are sometimes inaccessible to people with reduced or limited mobility. The combination of all these deficiencies makes the current rolling stock effectively unsuitable for fulfilling the social function expected of it. This, in turn, severely impacts the accessibility parameter, making the service accessible only to those who can and are willing to endure the inconvenience of using the transport service. Some of the mentioned problems can be overcome through major repairs and modernization of the existing fleet, but others require serious structural changes, leaving the purchase of new passenger rolling stock as the only viable alternative. Modern trends in passenger transportation show that the operation of multiple unit trains is more efficient (and therefore preferred) compared to the traditional locomotive and carriage scheme (with Rail Jet compositions operated by Austrian and Czech Railways being a notable exception) (ÖBB, 2021). The relatively modern multiple unit trains in the BDZ Passenger Services fleet, Series 10, 30, and 31, are designed exclusively for short-distance travel and are therefore unsuitable for long-distance service, once again pointing to the need to purchase new rolling stock designed primarily for long routes, with construction and equipment that meet the requirements for their service, making them accessible and attractive to the maximum number of passengers, with broad representation of all social groups.

Conclusion

The present article utilizes analytical, comparative and statistical methods to measure and explain the efficiency of BSR Passenger Freights Ltd. The study is focused more specifically on energy efficiency while simultaneously examining the influence of social factors on efficiency levels. The study, which is supported by a database for the energy efficiency of new trains, reveals that the efficiency levels in fast trains are improved by 44% along the longer sections and by an average of 58% along other destinations. The costs for maintenance and repair of the rolling stock are reduced by 46% and 43% respectively. The improved energy efficiency has a positive effect on the fees for using the infrastructure, showcasing a 25% drop. This means that trains along the main lines of Bulgaria's railway network can improve the technical efficiency as soon as the BSR manages to incorporate new rolling stock in its railway fleet.

Additionally, it shows how the productivity of the national carrier, in its monopoly position, depends on a multitude of factors, some of which are external to the operator, which makes the process of achieving improved efficiency long and complicated. With a view to improving the management of transport processes, the results show that the BSR should collect more detailed, in-depth and comprehensive data on costs, systematizing them by the reasons for their occurrence.

In regards to the methodology for measuring efficiency, by using the analytical method, it can be noted that factors related to technical efficiency, such as the state of the railway infrastructure, the number of train stations, and the number of wagons and locomotives in good working order, are crucial.

The renewal of the rolling stock of the national carrier BDZ Passenger Services Ltd. is crucial for the overall improvement of the transport service offered. The activities carried out so far in introducing new rolling stock, although steps in the right direction, are on a

scale that is woefully insufficient to significantly improve the rail service, especially on the main routes in the country. The necessary large-scale renewal of passenger rolling stock must be synergized with a reorganization of the railway transport scheme in Bulgaria. This will lead to a qualitative improvement in the service, as well as its efficiency - first by reducing direct maintenance and operation costs, and second by increasing direct revenue from attracting new passengers. Increasing the public benefit of attracting more passengers to environmentally friendly and highly efficient rail transport will improve the financial condition of the national carrier and contribute to improving energy, social and ecological efficiency. In this context, renewing the rolling stock intended for passenger transport, combined with improving overall service, is an important step toward modern trends in the development and modernization not only of Bulgarian rail transport but also of the transport system as a whole.

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