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THE NEED FOR ECO-DRIVING TECHNOLOGIES IN URBAN PUBLIC TRANSPORT

Summery. *This article discusses the challenges facing public transport in Ukraine in terms of reducing fuel consumption and emissions. The absence or insufficient development of means and methods for monitoring driver behaviour, as well as high staff turnover, create significant difficulties in controlling drivers and vehicles. A conducted study in Lutsk, the administrative center of the Volyn region, analyzed the driving behavior of passenger buses in the city. Results showed that typical driving modes include idling (40 %), acceleration (18 %), driving at a constant speed (29 %), and braking (13 %). The study also revealed average accelerations and decelerations, and these results do not meet the requirements of ecological driving. The correlation between driver behavior and these dynamic acceleration and braking characteristics has been established. Possible causes for this phenomenon are discussed in the study. The article proposes the introduction of modern solutions to solve these problems. These solutions are Eco-Driving Assistance Systems (EDAS) or integrated systems, such as FleetControl from TRIONA, which can help learning operating conditions and reduce fuel consumption and emissions. These programmes can also serve as effective monitoring tools for individual drivers and transport companies. This paper describes these applications and reviews the research related to their use and development. In addition, the article highlights the importance of training drivers in eco-driving as a cost-effective method of improving fuel efficiency in transport companies. The paper concludes by emphasising the need for further research to fully understand the complexities of public transport in Ukraine and the potential benefits of introducing innovative technologies for a more sustainable and efficient future for the industry.*

Key words: *driver behavior, eco-driving, fuel efficiency, public transport, real-time monitoring, urban transport, vehicle operation, operating costs, sustainable transportation, fleet management, algorithm optimization, environmental impact.*

1. INTRODUCTION

Public transport is an essential part of modern cities, playing a crucial role in connecting people to different areas, promoting social interaction, and enhancing the accessibility and mobility of individuals. The widespread use of public transport reduces traffic congestion and air pollution, contributing to sustainable development and a healthier environment. Moreover, it enables individuals to access employment opportunities, healthcare facilities, and education centers, regardless of their income and social status, promoting social equity and inclusion. Public transport also supports the development of a vibrant and prosperous urban economy, providing efficient and cost-effective transportation services for commuters, tourists, and goods. Therefore, the provision of reliable and high-quality public transport services is critical for creating sustainable, resilient, and livable cities.

The efficient operation of public transport enterprises is essential for achieving the goals of providing affordable, safe, and reliable transportation services to the population while minimizing negative environmental impacts. The efficiency of the public transport system depends not only on the optimization of its technical and technological parameters but also on the quality of the management process. The efficient operation of public transport enterprises is important because it ensures the rational use of resources, minimizes the negative impact on the environment, and improves the population`s quality of life.

2. PROBLEM

Ecological problems in public transport are a serious issue that needs to be addressed. One of the main problems is the high level of air pollution caused by the emissions from public transport vehicles. This pollution not only affects the environment but also has a negative impact on public health, leading to various respiratory and cardiovascular diseases. In addition, public transport is often associated with noise pollution, which can be a major disturbance to urban residents.

Additionally, the most significant cost component for a passenger transport company is the payment of fuel expenses to ensure its fleet operation. According to various studies, this component accounts for 30 % of all expenses, making it crucial and desirable to explore methods of reducing fuel consumption by the company's flee.

The public transportation situation in Ukraine is challenging, especially for urban bus transportation, due to various external organizational factors. These include a compact territory, planned routes with frequent stops and intensive traffic, high daily mileage, peak hour overloads, and inadequate traffic organization. Poor road conditions, low capacity, and environmental pollution add to the difficulties. It is challenging to engage in passenger transportation under such circumstances, particularly from an economic perspective.

When it comes to efficiency, the performance of public transport in Ukraine is not up to par. It is mainly due to the operation of an outdated fleet of vehicles on city roads, which makes it challenging to improve the situation. Replacing old buses with newer ones faces obstacles, such as replacing them with a used vehicle. The current standards used are Euro 3 and Euro 4, but there are still Euro 2 buses in operation. As a result, fuel consumption and harmful emissions into the atmosphere are affected by this outdated fleet.

3. RELEVANCE OF THE STUDY

While innovative methods for improving fuel efficiency are being developed around the world, they have not been widely publicized or implemented in Ukraine properly. Given the significant changes expected in the country in the near future, it is necessary to lay the groundwork for improving the fuel efficiency of public transport. It should be done as part of the country's transport development.

The use of AI-based applications and machine learning algorithms in the public transport sector has the potential to become a significant area for growth and research. These cutting-edge technologies have been the subject of intensive exploration and application in recent times. However, there seems to be a lack of these technologies in the public transport industry of Ukraine.

4. PURPOSE AND OBJECTIVES OF THE ARTICLE

The purpose of this article is twofold. First, it aims to explore the use of modern machine learning-based systems abroad that improve the fuel efficiency of a company's fleet. Secondly, it provides an overview of the current situation in Ukraine regarding public transport. Through this article, readers will gain a broader understanding of machine learning-based systems, their potential benefits, and the importance of their implementation in the Ukrainian public transport sector.

5. ANALYSIS OF RECENT RESEARCH AND PUBLICATIONS

Machine learning (ML) algorithms have the potential to contribute to the reduction of ecological problems in public transport. By analyzing data on vehicle usage and driver behavior, this system can provide recommendations on the most fuel-efficient driving patterns and identify areas for improvement. It can help reduce fuel consumption, emissions, and operating costs for public transport enterprises while also improving the overall sustainability of public transport [1–3].

Machine learning is a branch of artificial intelligence that involves creating algorithms and statistical models that enable computer systems to learn and enhance their performance from experience without requiring explicit programming. These algorithms utilize input data to automatically identify patterns and relationships, which can be utilized to make predictions or decisions. There are different kinds of machine learning algorithms, such as supervised learning, unsupervised learning, and reinforcement learning. These algorithms have been utilized successfully in various fields, including, among others, speech and image recognition, natural language processing, autonomous driving, and predictive maintenance. Applying machine learning algorithms in public transport companies can potentially result in efficiency, safety, and cost savings [4].

These systems are based on a "philosophy" of eco-driving. In the literature, they are referred to as DAS/EDAS (Driving Assistance System/Eco-Drive Assistance System). It can be illustrated by showing one of the possible rule-based theories of eco-driving in Fig. 1

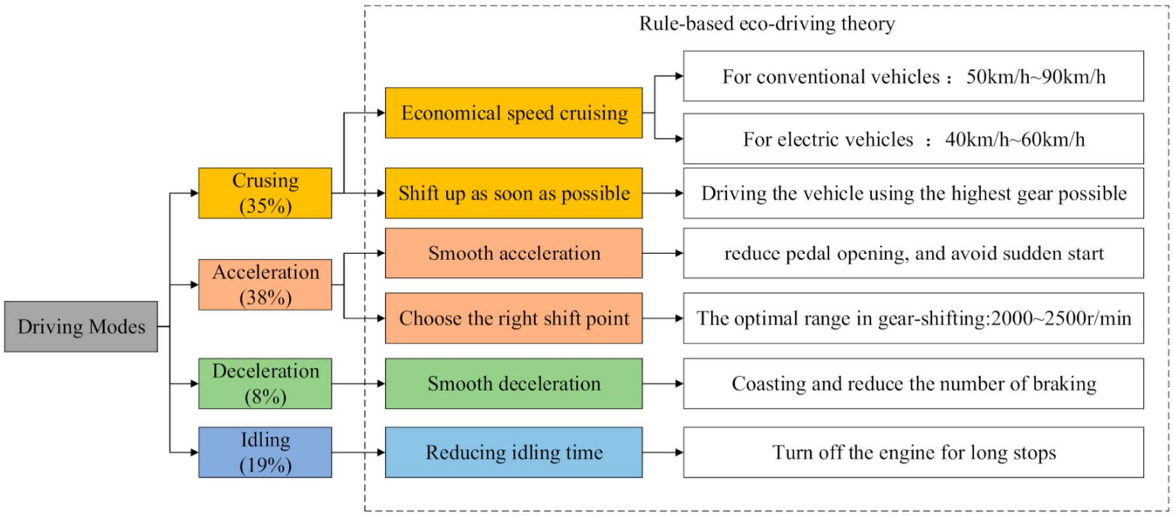


Fig. 1. Rule-based eco-driving theory in the main driving modes [5]

The Eco-Drive system is an intelligent driving behavior stimulator that promotes safer and more fuel-efficient driving. The system provides a unique feature that enables the adjusting the maximum speed, acceleration, and RPM for each gear, resulting in smoother and safer driving. By optimizing the engine power usage, the system ensures that more power is supplied only when necessary. The driving behavior analysis of the Eco-Drive system is aimed at reducing fuel costs and CO2 emissions while increasing safety awareness among drivers. The system encourages the adoption of "Eco-Style Driving", also known as economic driving, which helps employees exhibit calmer and safer road conduct and driving behavior [6]. Kibok Kim et al. has also reported a similar finding [1, 3, 7].

The Eco-Drive Connected functionality offers a comprehensive insight into fuel consumption, CO_2 emissions, and driving behavior on a driver and vehicle level. The system calculates fuel consumption and CO_2 emissions by analyzing fuel injection in the engine, providing journey-specific data. The system allows identifying the trends or irregularities within fuel consumption and comparing the fuel and CO_2 emissions performance of different vehicles and drivers [7].

The Eco-Drive system offers a comprehensive analysis of driving style, using a combination of various parameters to create a map of each driver's behavior. The analysis includes parameters such as cornering and braking behavior, gas pedal movements, coasting behavior, gear changes, acceleration rate, average driving speed, (preliminary) idling, and adherence to speed limits. The system provides a detailed overview of how closely drivers follow maximum speed limits for each road section.

In addition, the system can identify and report any instances of unlawful driving behavior during trips, and these incidents are projected accurately onto the road map for each journey. It allows for a traceable record of the actual driving behavior of each driver [8].

According to a study carried out by ROBERT AKENA p'OJOK, training drivers in economic mode driving is an effective and cost-efficient way to enhance fuel efficiency in vehicles. The research emphasizes that compared to other techniques to improve fuel efficiency, driver training proves to be the most profitable in terms of capital investment and profit. Hence, investing in driver training programs focused on economic mode driving can bring about substantial advantages for the environment and the financial stability of the transport company [9].

Studying the impact of driving behavior on fuel consumption provides insights into the factors contributing to higher energy costs for some drivers. This knowledge can be used to promote fuel-efficient driving styles among drivers who consume more energy. Additionally, effective driving behavior-energy consumption models can serve as fundamental technologies for ADAS systems that aim to reduce commercial vehicle fuel costs [10].

Recent research in this area has been focused primarily on developing accurate and functional algorithms for data processing.

The usage of ML for developing assistant systems and data processing algorithms is currently an active area of research. The effectiveness of such systems critically depends on the analysis of the received data, which requires accurate and reliable algorithms. Therefore, understanding the relationships between collected parameters and their impact on fuel consumption is essential. In this context, the research paper [2] presents a machine learning algorithm that has been developed and validated for use on manual transmission buses.

The present study focuses on investigating the impact of the driver's behavior on fuel consumption with particular emphasis on the accelerator pedal, brake pedal, and gearbox operation as primary parameters. Based on these parameters, an algorithm has been developed to accelerate the system's response to the driver's current behavior, evaluate it and provide specific advice. Efficient fuel consumption during vehicle operation requires a balanced using these parameters by the driver, which is essential to obtain the necessary energy to drive in constantly changing driving conditions. However, it is noteworthy that attaining such a balance is a challenging task in urban public transport, as observed by Jose Almeida, Hongji Ma, et al. [2, 8].

As noted by the author José Almeida, the main objective is to design an algorithm that can effectively process data received from the vehicle to provide drivers with accurate and prompt advice and feedback. In order to achieve this goal, the algorithm will need to consider and process various significant components such as the vehicle's driving characteristics, driver behavior, information related to the operating environment, including traffic speed and volume, as well as route conditions, such as the number of stops and traffic signals [2].

The study conducted by Kibok Kim et al. showcases the successful implementation of an Eco-Drive Assistance System.

The eco-drive monitoring system was designed to increase the score as the driving behavior improves in terms of fuel economy. The score obtained from the fuel economy prediction model can be utilized to evaluate the eco-friendliness of driving practices in urban bus operations, resulting in reduced fuel costs.

The LightGBM-based analysis demonstrated that shift indicator, rapid acceleration, coasting rate, average engine speed, rapid take-off, accelerator pedal gradient, gear shifting under low-end engine speed, rapid deceleration, and over speed had a decreasing impact on fuel economy in descending order. Based on these findings, the score allocation rate was adjusted to 100 points, with the coefficient and offset set to achieve a sum of 100 adjusted points for each item. If a particular item has no violation, the coefficient and offset can set from zero, and points can be deducted accordingly. Equation (1) presents the method used to convert the index of each item into a score, which is then summed up to obtain the eco-drive score [1].

$$Score_{Item} = Coefficient_{Item} \cdot Index_{Item} + Offset_{Item}$$
$$Eco - Driver\ score = \Sigma Score_{Item} \tag{1}$$
$$Item: research\ parameters\ taken\ from\ the\ vehicle`s\ sensors$$

Machine learning can be utilized to simplify the allocation of points for each monitoring item, especially when identifying a complex relationship with a target value is difficult [1].

By monitoring the eco-drive, drivers can avoid behaviors such as aggressive driving and unnecessary braking, which have a negative impact on fuel economy and can determine their eco-drive level. Implementation of the eco-drive scoring algorithm resulted in an average annual improvement of 12.1 % in fuel economy for urban buses. Fig. 2 provides more detailed results.

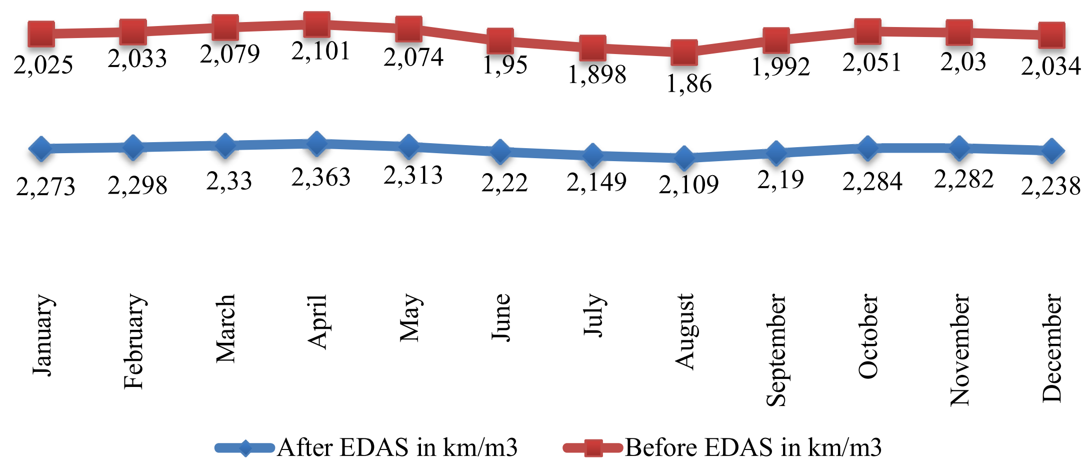


Fig. 2. Improvement in fuel efficiency through the use of an eco-drive system [1]

The findings indicate that modifying driving behaviors can enhance fuel economy without requiring hardware development. Earlier studies have also reported that eco-drive information devices in commercial vehicles have resulted in an 8.8 % improvement in fuel economy [11].

Another example could be Scania which has developed a driving assistance system called Scania Driver Support (SDS). It is aimed at reducing fuel consumption by optimizing driver behavior. SDS uses data from various sensors on the vehicle to analyze the driver's behavior, providing real-time feedback and guidance on how to drive more efficiently. The system considers different factors such as speed, acceleration, gear selection, and road conditions to provide recommendations to the driver on how to optimize fuel consumption. By improving driver behavior, SDS has been shown to reduce fuel consumption significantly and lower overall operating costs [12].

After conducting extensive simulations and road tests, the production code for the target ECU was generated using an Embedded Coder. The ECU has been installed in Scania R-Series trucks, and early tests indicate that drivers using the system have reduced fuel consumption by up to 11 %. The Scania Driver Support system has been highly praised, with the International Truck of the Year award recognizes it as an innovative learning tool capable of continuously and proactively assessing drivers on the road [12].

A prime illustration of an integrated system is the FleetControl system proposed by Triona, which addresses the challenging tasks of collecting and analyzing data on fleet operations to account for the efficiency of the transport enterprise. Moreover, this system employs the same data to offer real-time advice and feedback to drivers during vehicle operation [13].

This integrated system is designed to capture various data points, including driver behavior, vehicle performance, route conditions, traffic information, and other relevant parameters. The collected data is then analyzed to optimize the vehicle's performance, reduce fuel consumption, and minimize maintenance costs.

Additionally, FleetControl provides drivers with actionable advice and comments, such as suggestions to adjust speed or route to avoid traffic congestion, enhance their driving behavior and ultimately increase the fleet's efficiency [14].

Overall, FleetControl represents an innovative approach to fleet management that leverages data analysis and real-time feedback to optimize fleet performance and reduce operating costs.

In conclusion, research has extensively explored the correlation between fuel consumption and specific operational parameters, such as driving behavior. It has been demonstrated that improving driver training and culture is the most effective way to improve fuel efficiency, positively impacting the company's capital investment. However, this method becomes less effective when high driver turnover is prevalent within the transport company, a problem many Ukrainian trucking firms face.

ML-based systems based on the eco-driving philosophy, either as an addition or alternative to driver training, are a potential solution to the problem of fuel efficiency. These systems rely on well-designed algorithms that are continuously studied, developed, and improved by modern science. Unlike driver training, these programs are linked to the vehicle and can adapt to the characteristics of various drivers over time. The quality of the algorithm influences the speed of this adaptation.

EDAS systems can also be integrated into other systems that collect and analyze data crucial to the effective operation of a transport company. The usage of EDAS systems in Ukraine presents significant potential for application. However, to ensure effective implementation, it is imperative to investigate the compatibility of existing software in Ukraine road transport companies with EDAS. In addition, comprehensive studies must be conducted to define the precise operating conditions, enabling the development of technical specifications for EDAS. It will determine the specific functions the program should perform beyond its original design. These studies may identify the need for unique machine learning algorithms, borrowed ones, or modified existing algorithms to suit the Ukrainian public transport environment.

It is noteworthy that the learning capability of EDAS programs is one of their primary advantages; however, this means that they require training before usage. For this purpose, a comprehensive database where the program can be trained must be established. It poses a challenge, as technical requirements need to be developed to understand what data should be collected for training. While similar databases exist in countries where these systems are already in use, it is essential to consider that public transport and infrastructure in Ukraine possess differences, which may impact the use of these databases.

6. THE COMPLEXITY OF UKRAINE'S PUBLIC TRANSPORT

In Ukraine, monitoring the behavior and condition of drivers while operating vehicles is challenging due to the lack of developed methods and tools, as well as high turnover rates among drivers resulting in a shortage of highly skilled personnel; the implications of these issues can be illustrated by examining the driving patterns in Lutsk, the administrative center of the Volyn region. A study was conducted to determine the specific driving modes of passenger buses in the city, revealing that the most common driving modes were idling (40 %), acceleration (18 %), driving at a constant speed (29 %), and braking (13 %). The visualised results are shown in the diagram in Fig. 3.

The driving cycle derived from the experimental data in this study is as follows in Fig. 4.

Based on this graph, it can be established that an average of eight acceleration-deceleration cycles occur during the bus's movement.

The average acceleration during acceleration and braking was 1.4 m/s^2 for 0–25 km/h, 0.83–1.0 m/s^2 for 25–40 km/h, and the average deceleration from a speed of 25–30 km/h was 1.4–1.6 m/s^2. The average operating velocity of public transport in the city ranged from 20 km/h to 11.4 km/h, depending on the city district [15].

In this study, attention should be paid to the value of accelerations during acceleration and braking. According to the results of this study, these operations account for 31 % of the total, which is typical for the public transport operation in the urban cycle. It is important because these operations account for a large amount of the energy required to perform them. With the right approach, the driver can maintain a balance so that energy consumption is rational.

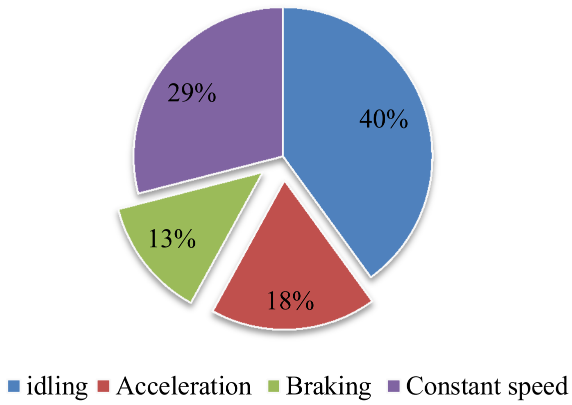


Fig. 3. The probability of a vehicle being in a certain driving mode [15]

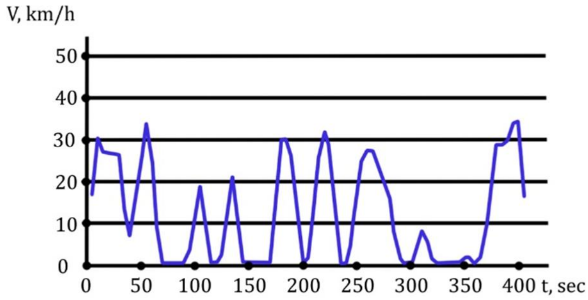
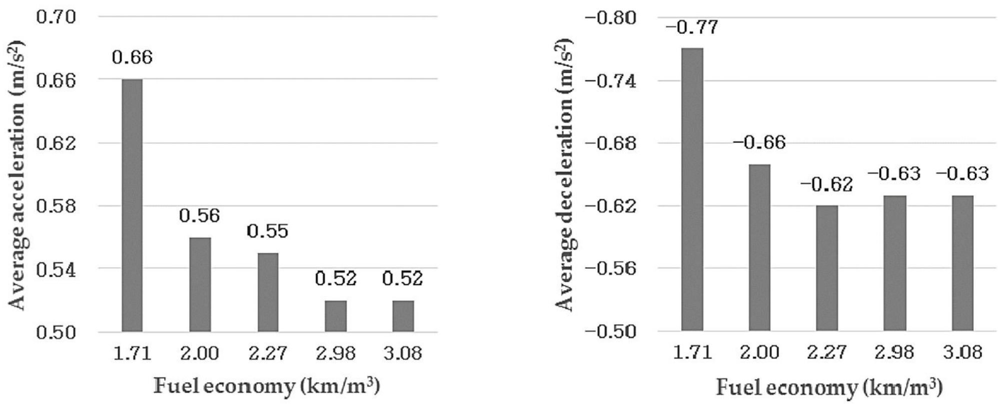


Fig. 4. Average urban driving cycle schedule based on experimental data for a 2.2 km route segment

Comparing this data, for example, with the acceleration and braking data from the study conducted in Seoul (Fig. 5), it becomes clear that such acceleration modes do not meet the basics of economical driving.



a *б*

Fig. 5. Average vehicle speed gradient:
a – average acceleration according to fuel economy;
b – average deceleration according to fuel economy [1]

The findings obtained from the investigation of travel cycles in the urban setting of Lutsk can be deemed representative of public transport systems in cities with comparable architectural features and populations of approximately 150.000–250.000. It should be noted that a contributing factor to the observed outcomes may be attributed to the lack of specific knowledge and training among drivers, leading to significant impacts on the efficient operation of public transportation. The development of a proficient driver workforce necessitates suitable training programs, which may prove impractical in light of the high employee turnover rates commonly experienced within the industry.

The situation is complicated because bus passenger transportation is a private enterprise, which leads to competition between carriers for the number of passengers carried, which is expressed on the roads in bus “races”.

The Ministry of Transport and Communications, which is responsible for organising passenger transport through private entrepreneurs, has no tools to control driver behaviour, and the same situation exists with entrepreneurs.

These results indicate a problem of qualified drivers in the public transport sector at enterprises. It leads to irrational use of entrusted transport by drivers and entails unnecessary fuel costs, thereby increasing the volume of harmful substances emitted into the atmosphere. There is also a problem with monitoring the quality of drivers' work in the car-driver link. The simplest method auto-transport companies use to determine the quality of vehicle operation by a driver is to determine the fuel consumption by this driver on the assigned transport. However, this method does not allow the evaluation of the potential for possible improvements in the driver's work by identifying driver habits that increase fuel consumption.

Implementing modern solutions, such as EDAS or FleetControl by TRIONA, can help studying this issue. Moreover, these programs can serve as efficient monitoring tools for individual drivers and transport companies, depending on the level of implementation. By implementing such innovative technologies, the public transport sector in Ukraine can solve the following tasks:

– obtain comprehensive data on the use of the vehicle by the driver (control of driving quality, determination of driver's professional suitability, determination of systematic violations of operating norms, more accurate calculation of technical maintenance regimes, changes in the operation of the vehicle indicating possible breakdowns)
– study operating conditions and driving cycles with greater accuracy (can help in developing new or correcting existing routes, accumulating data that can be used for research in this area)
– help enterprises create a more qualified team of drivers in conditions of high staff turnover when the classical training method is ineffective.
– determine operational fuel consumption with greater accuracy.

The most important task that can be achieved by implementing these systems in public transport in Ukraine is to provide the opportunity to identify gaps in the functioning of transport in the driver-car-road link, which in turn can open up the potential for improvement.

7. CONCLUSION AND DISSCUSION

In this article, we have explored the problems in the public transport sector of Ukraine and discussed possible solutions. We found that driver behaviour plays a significant role in fuel consumption and that driver training can effectively improve fuel efficiency. However, the high staff turnover in Ukrainian public transport companies makes this approach less effective, and alternative solutions should be sought.

One potential solution is machine learning-based systems based on eco-driving philosophies that can be integrated into existing fleet management systems to optimise vehicle performance, reduce fuel consumption and minimise maintenance costs. Such systems are tied to the vehicle and can adapt to the characteristics of different drivers over time, making them a promising solution for transport companies with high driver turnover.

Further research is necessary to investigate the feasibility of integrating EDAS into the insuring systems used by public transport in Ukraine, studying the operational conditions of public transport to develop the terms of reference for these systems. It will also provide an understanding of the feasibility of using foreign databases for EDAS training or, conversely, will require the creation of these databases from scratch.

One of the primary studies that must be conducted is to determine the feasibility and economic impact of implementing an EDAS and decide whether to develop a system from scratch or purchase a ready-made one. In theory, the development of a system is a viable solution since the necessary component systems are readily available and compatible with cars produced since 2001, as the OBD-II diagnostic connector standard is used in these vehicles. Ukraine also has sufficient number of specialists in artificial intelligence and machine learning who can create the necessary algorithm based on the task.

However, the possibility of purchasing a system raises questions about the feasibility of developing a system from scratch, given that existing options on the market already have extensive experience in implementing these systems in public transport.

Nonetheless, this theory requires substantiated confirmation. Further research is necessary to evaluate the economic feasibility of implementing an EDAS and determine the most rational course of action, whether it will be developing a system from scratch or purchasing an existing one.

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ПОТРЕБА ВПРОВАДЖЕННЯ ТЕХНОЛОГІЙ ЕКОЛОГІЧНОГО ВОДІННЯ В МІСЬКОМУ ГРОМАДСЬКОМУ ТРАНСПОРТІ

Анотація. *Розглянуто виклики, що стоять перед громадським транспортом в Україні з точки зору скорочення споживання палива та викидів шкідливих речовин. Відсутність або недостатній розвиток засобів і методів моніторингу поведінки водіїв, а також висока плинність кадрів створюють значні труднощі в контролі за водіям та транспортними засобами. Проведене дослідження в Луцьку дало змогу проаналізувати поведінку водіїв пасажирських автобусів у місті. Результати показали, що типовими режимами водіння є холостий хід (40 %), прискорення (18 %), рух з постійною швидкістю (29 %) та гальмування*

(13 %). Дослідження також виявило середні значення прискорень і гальмувань, і ці результати не відповідають вимогам економного водіння. Встановлено кореляцію між поведінкою водія та цими динамічними характеристиками розгону і гальмування. Для вирішення зазначиних проблем запропоновано впровадження сучасних рішень, таких як системи допомоги за економного водіння (EDAS) або інтегровані системи, такі як FleetControl від TRIONA, які можуть допомогти проаналізувати умови експлуатації та зменшити витрату палива і викиди шкідливих речовин. Ці програми також можуть слугувати ефективними інструментами моніторингу як для окремих водіїв, так і для транспортних компаній. Описано ці програми та зроблено огляд досліджень, пов'язаних із їх використанням і розвитком. Крім того, наголошено на важливості навчання водіїв екологічному водінню як ефективного методу підвищення економічності використання палива в транспортних компаніях. Наголошено на необхідності подальших досліджень для повного розуміння складнощів функціонування громадського транспорту в Україні та потенційних переваг впровадження інноваційних технологій для сталого та ефективного майбутнього галузі.

Ключові слова: *поведінка водія, екологічне водіння, паливна ефективність, громадський транспорт, моніторинг в реальному часі, міський транспорт, експлуатація транспортних засобів, експлуатаційні витрати, сталий транспорт, управління автопарком, оптимізація алгоритмів, вплив на навколишнє середовище.*