UDC 656.1:628.4.046.3
DOI: 10.37128/2520-6168-2025-3-14

MODERN TECHNOLOGIES AND TRENDS FOR THE FUTURE USE OF TRACK BIKES FOR TRANSPORTING SOLID HOUSEHOLD WASTE

Mykola MYTKO, Candidate of Technical Sciences, Associate Professor
Vinnytsia National Technical University
Serhii BURLAKA, Ph.D., Associate Professor
Svetlana KRAVETS, Assistant
Vinnytsia National Agrarian University

МИТКО Микола Васильович, к.т.н., доцент
Вінницький національний технічний університет
БУРЛАКА Сергій Андрійович, доктор філософії, доцент
КРАВЕЦЬ Світлана Миколаївна, асистент
Вінницький національний аграрний університет

The article considers modern technologies and innovative approaches to the introduction of cargo bikes - trucks into the system of collection and transportation of solid household waste in urban and suburban conditions. Growing environmental challenges, the need to reduce greenhouse gas emissions and restricting the use of traditional vehicles in densely populated areas encourage the search for alternative solutions in the field of municipal logistics. One of the promising areas is the use of cargo cargo bikes - trucks, in particular electrified models, capable of ensuring transportation efficiency with minimal negative impact on the environment.

The article analyzes in detail the technical capabilities of bikes-trucks, their carrying capacity, energy efficiency and the feasibility of integration into the waste management system. A conceptual model of the use of bikes-trucks in urban infrastructure is proposed, taking into account the factors of population density, route length and road network congestion. A comparative analysis of traditional garbage trucks and bikes-trucks is carried out according to the criteria of economy, environmental friendliness and maneuverability.

The results of the research demonstrate that the use of bikes-trucks for transporting solid household waste can reduce CO_2 emissions by 30–50% compared to diesel cars, as well as contribute to reducing noise pollution in cities. In addition, the system has shown effectiveness in areas with narrow streets and traffic restrictions, where traditional transport is of little use. The article also provides recommendations for the development of the infrastructure necessary for the widespread introduction of bikes-trucks, including specialized sites, charging stations and logistics centers.

The proposed approach may be useful for local governments, municipal services, as well as engineers and entrepreneurs involved in the development and implementation of environmentally friendly transport systems. The results obtained contribute to the formation of new trends in the field of "green" urban logistics and the development of sustainable infrastructure.

Key words: *bikes - trucks, solid household waste, urban logistics, ecological transport, infrastructure, energy efficiency, electrification.*

Eq. 2. Fig. 7. Table. 2. Ref. 18.

1. Problem formulation

Modern cities are facing increasingly acute problems of solid household waste management. The growth of waste volumes, congestion of the street network and increasing environmental requirements require the search for new solutions in the field of municipal logistics. Traditional garbage trucks, although they provide large volumes of transportation, are often inefficient in conditions of dense construction, narrow streets and pedestrian zones. In addition, the use of diesel transport is accompanied by high fuel consumption and significant emissions of harmful substances into the atmosphere.

In this context, the task of transitioning to more environmentally friendly and energy-efficient means of waste collection and transportation becomes particularly relevant. One of the promising areas is the use of bikes - trucks, in particular electrified models, which combine mobility, maneuverability and low environmental

Article received 24.10.2025. Article accepted 08.12.2025. Article published 25.12.2025.

pollution. Such vehicles can operate effectively in conditions of limited traffic, reducing the load on urban infrastructure and reducing operating costs [1, 2, 3].

The aim of this study is to analyze modern technologies and future trends in the use of bikes - trucks for transporting solid household waste in cities and suburban areas. The article examines the technical and organizational aspects of implementing this type of transport, makes a comparison with traditional garbage trucks, and offers recommendations for the development of infrastructure for their effective operation.

Modern trends in the field of urban logistics and waste management are focused on increasing the efficiency of transport systems while simultaneously reducing their negative impact on the environment. Traditional diesel-powered garbage trucks are characterized by high energy consumption, significant emissions of harmful substances and low maneuverability in dense urban areas. This significantly reduces the economic and environmental feasibility of their use, especially in central areas of cities, areas with pedestrian spaces and narrow streets.

One of the main problems is the lack of effective alternatives to traditional vehicles that could adaptively respond to specific operating conditions: traffic intensity, volumes of collected waste, features of urban infrastructure and environmental requirements. The imperfection of existing waste collection and transportation systems leads to overloading of the transport network, excessive fuel consumption and increased environmental pollution.

Thus, the issue of introducing bikes - trucks, in particular electrified models, into the solid household waste transportation system is relevant. This will optimize the collection and transportation processes by reducing CO_2 emissions, increasing mobility, and reducing operating costs [4, 5].

2. Analysis of recent research and publications

In recent years, there has been a growing interest in the development and implementation of environmentally friendly transport solutions for urban logistics and waste management. Current research focuses on the use of cargo bikes - trucks and other small-sized electrified vehicles that can ensure efficient transportation in densely built-up areas of cities.

According to studies [6], the use of cargo bikes allows for fuel consumption reduction and CO_2 emissions reduction in urban transportation by 30–50%, compared to diesel light-duty vehicles. At the same time, the maneuverability of transport increases and the load on the road infrastructure decreases. A similar approach is considered in [7], which studies the experience of using cargo bikes - trucks in Western European countries. The results show that their integration into the household waste collection system allows for optimization of routes and reduction of operating costs by 20–25%.

Researchers [8] emphasize the importance of using electrified bikes - trucks, which have increased load capacity and autonomy. The work emphasizes that the combination of pedal and electric traction provides adaptability to various operating conditions, including climbs and long routes. At the same time, the efficiency of waste collection increases in areas with pedestrian traffic, where the use of traditional garbage trucks is impossible.

The study [9] examined the environmental aspects of introducing bikes - trucks into urban infrastructure. The results show that the use of this type of transport reduces noise pollution, improves air quality and increases the level of comfort of residents. The authors also note that the development of digital platforms for route management and the integration of monitoring systems increases the efficiency of their work.

Despite the positive results, scientific publications draw attention to certain challenges. In particular, the need to create specialized infrastructure for bikes - trucks (parking lots, charging stations, garbage hubs), load capacity limitations, and seasonal operating factors. However, the development of new materials, the use of electric traction, and intelligent control systems open up prospects for overcoming these barriers and the widespread introduction of this type of transport into urban logistics.

3. The purpose of the article

The aim of the article is to study and substantiate the prospects for using bikes - trucks for transporting household waste as a tool for improving urban infrastructure and developing environmentally friendly logistics in cities and suburban areas. The implementation of this approach will contribute to the formation of a new model of urban waste transportation, combining efficiency, environmental friendliness and economic feasibility. Further research should be aimed at developing technical solutions to increase the carrying capacity of bikes - trucks, improving route logistics and creating an appropriate infrastructure for their operation.

4. Results and discussion

In recent years, there has been growing interest in the introduction of bikes - trucks as an innovative type of ecological transport for the collection and transportation of household waste. Studies [10] show that the use of such vehicles in densely populated urban areas allows reducing emissions of harmful substances by 20–30% compared to traditional diesel-powered garbage trucks. In addition, such solutions have a positive effect on the level of noise pollution, which is an important factor in densely built-up areas.

In [9], attention is focused on the possibility of integrating bikes - trucks into the "last mile" system in waste management, when large garbage trucks operate only on main routes, and collection in yards and narrow streets is carried out by compact bicycle vehicles. This allows reducing congestion, optimizing traffic flows, and increasing logistics efficiency.

Studies [9, 11, 12] also note variable challenges: limited load capacity of bikes - trucks (in the range of 120–300 kg), the need for specific infrastructure (cycle paths, parking spaces near delivery points), and reduced productivity during adverse weather conditions. At the same time, the development of modular bodies, battery systems, and digital logistics management services creates the prerequisites for overcoming these limitations [9, 11, 12].

Despite the positive results, scientific works [13] also note certain challenges: limited load capacity of bikes - trucks, the need to create specialized infrastructure for their movement, as well as seasonal factors (in particular, reduced efficiency during adverse weather conditions). At the same time, the active development of battery systems, modular bodies and digital logistics management services opens up prospects for further dissemination of this technology.

In recent years, there has been an increase in interest in the use of cargo electric bicycles and bikes - trucks in urban logistics, especially when performing transport and utility tasks, including:

- According to a report on the CFTS website, DB Schenker [5] has started transporting goods in Germany on "giant electric bicycles" of the "Velogista" brand. This confirms the existence of practical cases of commercial use of such means of transportation in logistics (Fig. 1).
- The website 3kolesa.kiev.ua offers the "Trash Bike" model [1] – a specialized bicycle for transporting waste, which demonstrates that commercial solutions already exist on the market in Ukraine (Fig. 2).
- Rymarbike presents the "Marsel New" model in its portfolio [2] – an example of modern bicycle transport that can be used as a cargo electric bicycle (Fig. 3).
- According to Infocar, a French company has created a cargo electric bicycle train, which serves as an example of the scaling of this type of solution (Fig. 4).
- Staff-Capital.com offers three-wheeled electric cargo bicycles with a chainless Free Drive system - an integrated system of a pedal generator, electric motor, battery and HMI, which provides electric drive to the rear wheel and demonstrates modularity and variability of designs for delivering food, mail, medicines and transporting large-capacity cargo (Fig. 5).

These examples demonstrate that solutions using cargo electric bicycles are already finding practical application in the world and in Ukraine.

In addition, there are the following significant studies in the scientific literature:

- Studies on urban logistics using electric bicycles highlight the benefits in terms of reduced CO_2 emissions, reduced noise and increased route flexibility (for example, in Europe such models are already being used in city centers).
- In last-mile logistics work, electric bicycles solutions are often compared to traditional vehicles, showing the advantages of the former over short routes and in areas with limited traffic.
- Some research is focused on improving batteries, energy recovery systems, and lightweight structures, which could increase the efficiency of electric cargo bicycles in transporting goods.
- Other works focus on route optimization, mixed transport logistics, and adaptive transport state management based on sensors and IoT (Internet of Things).

However, there are certain challenges before widespread implementation:

1. Limited carrying capacity of electric cargo bicycles compared to trucks;
2. The need for appropriate infrastructure: charging stations, passenger/freight hubs, separate lanes or safe routes;
3. Seasonal and climatic restrictions (rain, snow, ice) can reduce efficiency;
4. Difficulties with economic payback: high capital costs for bicycle fleet modernization, support, and maintenance;
5. The need for integration with existing waste collection and processing systems, coordination with large vehicles.

a *b*

c

Fig. 1. DB Schenker's Velogista cargo bike, which is equipped with an electric drive and can transport up to 250 kilograms of cargo with a loading volume of up to 1.6 m2 [5]: a – side view of the bike moving around the city; b – front view of the bike moving around the city; c – general view of the bike, with a length of 6.5 meters and a load capacity of up to half a ton, the Cargo Bike is a real "megaliner" among cargo bikes

Fig. 2. Cargo tricycle with the possibility of installing a garbage can in front for organizing cleaning, tidying and servicing of objects of the Cargo brand "Trash-Bike" [1]

Fig. 3. Rymar Marsel New cargo bike of the "Flower" brand, which can be used by housing and communal services workers, gardeners, hotel and country business owners for transporting heavy, oversized cargo – with a load capacity of up to 200 kg [2].

Fig. 4. French electric cargo bike-train "Pelican eTrain". A modular monster that can be equipped with two electric trailers to transport up to 500 kilograms of cargo, the total volume is 3000 liters [14]

Fig. 5. Electric cargo bicycles with a chainless Free Drive drive system that can be used to deliver food, mail, and medicine in the city center [15]

The review of the main material emphasizes the relevance of the development of ecological transport, in particular, cargo electric bicycles intended for the transportation of solid household waste. This creates a basis for the development of a mathematical model and practical research, taking into account the peculiarities of the urban agglomeration, where the use of such bicycles is appropriate.

European practice in recent years demonstrates a growing interest in the introduction of cargo bikes - trucks as an environmentally friendly transport for waste collection and transportation. Scientific studies and practical cases show that electrified cargo bikes can reduce CO_2 emissions by 20–50%, reduce noise pollution and increase maneuverability in densely populated areas where traditional transport is inefficient [6 – 15]. Examples of such solutions include Velogista (DB Schenker), Trash Bike (3kolesa.kiev.ua), Marsel New (Rymarbike), Pelican eTrain (France) and Free Drive (Staff-Capital.com), which demonstrate different approaches to modularity, load capacity and integration of digital control systems.

A review of current research and practical implementations highlights key trends and challenges: electrification and modular designs to increase load capacity, the development of intelligent route management systems, the need for specialized infrastructure (charging stations, parking lots, garbage hubs), seasonal restrictions, and economic feasibility. These factors emphasize the need to quantify the effectiveness of bikes- trucks and compare them with traditional garbage trucks in terms of economy, environmental friendliness, and maneuverability.

Based on this, modeling of the efficiency of using bikes - trucks, comparison of economic and environmental indicators with traditional means of transport, assessment of the impact of infrastructure, and recommendations for optimizing routes and developing the logistics system will be presented.

The algorithm for mathematical modeling of the efficiency of using bikes - trucks for transporting solid household waste is depicted in formula 1, which takes into account key parameters of routes, carrying capacity, energy consumption, and features of urban infrastructure. This allows us to assess the economic and environmental feasibility of introducing such vehicles into household waste collection systems.

Mathematical modeling of the efficiency of using bikes - trucks.

To assess the effectiveness of using bikes - trucks, the following formula can be used to calculate the potential CO_2 emission reduction compared to traditional garbage trucks:

$$\Delta CO_2(\%) = \frac{E_{truck} - E_{bikes}}{E_{truck}} \cdot 100 \quad (1)$$

where: E_{truck} – average annual CO_2 emissions of a traditional garbage truck, kg/year; E_{bikes} – average annual CO_2 emissions from the use of bikes - trucks, kg/year;

Based on data [6, 10], we can assume = 12000 kg/year; = 6000 kg/year, which gives = 50%.

As can be seen from the data in Table 1, electric bikes - trucks have significantly lower energy consumption, increased maneuverability, and low noise levels, which makes them suitable for operation in densely populated areas of the city.

Table. 1

Comparison of main characteristics of vehicles

Parameter	Garbage truck (diesel)	Bikes - trucks (electric)
Load capacity, kg	3 000 – 5 000	120 – 300
Energy consumption, kWh/100 km	35	1,2 – 3,5
CO_2 emissions, kg/year	12 000	6 000
Maneuverability	low	high
Suitability for narrow streets	low	high
Noise level, dB	75	55

To quantitatively assess efficiency, it is advisable to compare economic and environmental indicators based on the calculated data given in Table 2.

Table. 2

Comparison of economic and environmental indicators of a traditional garbage truck and a bikes-trucks for solid household waste collection in the Vyshenka district (Vinnytsia city)

Indicator	Unit of measurement	Diesel garbage truck	*Bikes-trucks*	Relative savings, %
Energy/fuel consumption	l/100 km or kWh/100 km	35 liters of diesel	6 kW·h	≈ 75
CO_2 emissions	kg/km	0,9	0,05	≈ 94
Operating cost	UAH/km	40	9	≈ 78
Noise level	dB	85	45	–
Cost of collection 1 ton of solid household waste	UAH/t	950	720	≈ 24
Maximum load capacity	kg	4000	250	–

As can be seen from the data in Table 2, the use of an electric bikes - trucks for solid household waste collection in the Vyshenka district of Vinnytsia allows for a significant reduction in energy consumption and CO_2 emissions several times compared to a traditional diesel garbage truck. The average fuel economy is 70-80%, and the emission reduction is over 90%, which confirms the high environmental efficiency and economic feasibility of introducing such vehicles into the city infrastructure.

In addition, reduced noise pollution and better maneuverability make bikes – trucks suitable for operation in densely built-up areas, where traditional garbage trucks operate with technical limitations.

To evaluate the graph of the dependence of route efficiency on population density, it can be represented as a dependence of delivery time on population density ρ (persons/km^2):

$$T_{route} = \frac{L \cdot f(\rho)}{V_{avg}} \quad (2)$$

where: L – route length, km; V_{avg} – average speed, km/h; $f(\rho)$ – traffic complication coefficient due to population density (determined empirically).

For example, for narrow urban areas $f(\rho) = 1 + 0{,}005 \cdot \rho$, which takes into account the slowdown of traditional transport.

Here is a graph (Fig. 6) showing how delivery times vary with population density for a diesel garbage truck and a bikes – trucks.

The graph illustrates the relationship between population density ρ (persons/km^2) and freight delivery time. This approach allows us to assess the efficiency of using different modes of transport in urban areas with different building densities.

As can be seen, with increasing population density, delivery times for traditional transport (garbage trucks) increase dramatically, while for bikes – trucks this increase is much slower. This confirms their higher efficiency and suitability for operation in densely populated urban areas.

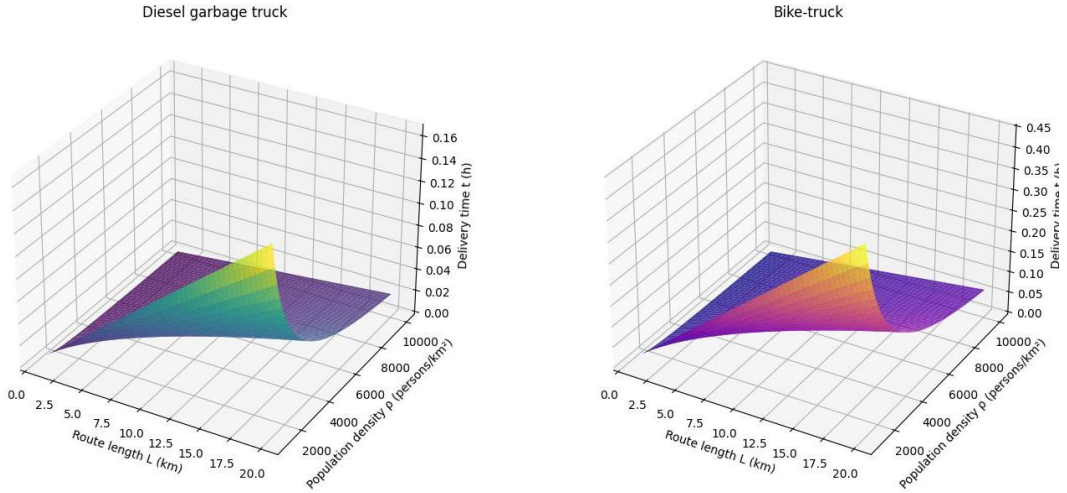
For the effective integration of bikes – trucks into the urban logistics system for transporting solid household waste, it is advisable to develop and implement a number of infrastructure measures, including:

1. Creation of specialized waste hubs within neighborhoods for intermediate reloading, sorting and further disposal of waste. Such points can serve as logistics nodes between bike-tracks and centralized SHW processing stations;

2. Placing charging stations on key routes with high traffic intensity, which will ensure stable operation of electric bicycles and minimize downtime during tasks;

3. Organization of dedicated lanes or bike paths for cargo bikes – trucks, which will increase transportation safety and reduce travel time;

4. Implementation of digital monitoring platforms that will provide control over the technical condition of vehicles, battery charge level, real-time route tracking, and container loading optimization.



ig. 6. Dependence of delivery time on population density for different types of vehicles

Figure 7 presents a schematic model of modern technologies and trends in the use of bikes – trucks intended for the transportation of solid household waste. The model demonstrates the design features of the vehicle and the logic of its functioning within the urban SHW collection system.

Fig. 7. A current example of technologies and trends for the future use of track bikes, which would be designed for transporting solid household waste: 1 – tank for SHW (solid household waste); 2 – additional compartment for other types of materials; 3 – platform of the bikes – trucks, on which the SHW tank is placed; 4 – battery; 5 – bikes – trucks; 6 – mechanism for driving the pedals of the bikes – trucks wheels.

5. Conclusion

The development and implementation of environmentally friendly transport systems is one of the key areas of sustainable development of urban logistics. The analysis of current trends shows the growing interest in the use of electric cargo bicycles (bikes – trucks) as an alternative to traditional diesel garbage trucks. These vehicles are characterized by high maneuverability, low noise level and complete absence of local emissions, which makes them especially effective for operation in densely built-up residential areas.

European experience, in particular the examples of Copenhagen, Amsterdam and Paris, demonstrates that the use of bikes-tracks in the “last mile” system allows to reduce the number of trips of traditional garbage trucks by 15-30%, reduce CO_2 emissions by 40-50% and significantly optimize the operating costs of municipal enterprises. Modeling of the solid household waste collection route in the Vyshenka microdistrict of Vinnytsia confirmed the feasibility of using bikes-tracks for short urban distances (up to 5 km) with 5-7

container sites. The obtained calculations showed that energy consumption is only 0.4-0.6 kWh/km, which is equivalent to saving about 0.25-0.3 l of diesel fuel per kilometer compared to traditional garbage trucks.

The economic analysis has shown that the cost of collecting one ton of waste using bikes-tracks can be reduced by 20-25%, and the payback of the initial investment is achieved in 1.5-2 years. At the same time, certain barriers to implementation have been identified: limited carrying capacity, lack of specialized infrastructure (charging stations, waste hubs) and seasonal dependence of operation. However, the development of modular structures, powerful battery systems and digital platforms for route management creates the basis for the widespread distribution of such solutions.

Thus, the proposed model for assessing the effectiveness of the use of bikes-tracks confirms their prospects for Ukrainian cities. It can become the basis for further scientific research aimed at forming a comprehensive system of environmentally friendly urban logistics. It is advisable to continue developing models for optimizing routes, integrating monitoring systems and creating a regulatory and technical framework that will ensure the effective and safe implementation of such vehicles in urban infrastructure.

References

1. TM 3Kolesa – production of tricycles for adults and children. (n.d.). URL: https://www.3kolesa.kiev.ua/product-page/trash-bike?lang=uk (accessed 01.10.2025). [in Ukrainian].
2. Tricycle “Marseille”. (n.d.). URL: https://www.rymarbike.com/uk/portfolio/marsel-new (accessed 01.10.2025). [in Ukrainian].
3. What is a cargo bike? A comprehensive guide to cargo bicycles. (n.d.). URL: https://www.motrike.com/what-is-a-cargo-bike/ (accessed 01.10.2025). [in English].
4. File: Modern cargo trike in London.jpg. (n.d.). URL: https://tr.m.wikipedia.org/wiki/Dosya:Modern_Cargo_Trike_In_London.jpg (accessed 01.10.2025). [in English].
5. DB Schenker has begun transporting goods in Germany using giant e-bikes (photo). (n.d.). URL: https://cfts.org.ua/news/2020/11/10/db_schenker_nachal_perevozit_gruzy_v_germanii_na_gigantskikh_elektrovelosipedakh_foto_61777 (accessed 01.10.2025). [in Ukrainian].
6. Vasiutina, H., Naumov, V., Szarata, A., & Rybicki, S. (2022). Estimating the emissions reduction due to the use of cargo bikes: Case studies for selected European cities. *Energies*, *15*(14), 5264. DOI: https://doi.org/10.3390/en15145264 [in English].
7. Rudolph, C. (2018). *Reverse logistics introducing cargo cycles: A case study of the municipal city cleaning management of Hamburg City*. Transportation Research Board Annual Meeting. URL: https://trid.trb.org/View/1494526 [in English].
8. Zimmermann, K., & Palgan, Y. V. (2024). Upscaling cargo bike sharing in cities: A comparative case study. *Journal of Cleaner Production*, *477*, 143774. DOI: https://doi.org/10.1016/j.jclepro.2024.143774 [in English].
9. Vasiutina, H., Szarata, A., & Rybicki, S. (2021). Evaluating the environmental impact of using cargo bikes in cities: A comprehensive review of existing approaches. *Energies*, *14*, 6462. DOI: https://doi.org/10.3390/en14206462 [in English].
10. Narayanan, S., & Antoniou, C. (2022). Electric cargo cycles – A comprehensive review. *Transport Policy, 116*, 278–303. DOI: https://doi.org/10.1016/j.tranpol.2021.12.011 [in English].
11. Large-scale introduction of cargo bikes – A game changer for European cities. (n.d.). URL: https://www.rymarbike.com/uk/portfolio/marsel-new (accessed October 13, 2025). [in English].
12. Dutch Cycling Embassy. (2024). *Space for cargo bikes*. URL: https://dutchcycling.nl/wp-content/uploads/2024/06/Space-for-Cargo-Bikes-EN.pdf (accessed October 13, 2025). [in English].
13. Roche-Cerasi, I., & van Duin, J. H. R. (2023). Challenges and potentials of cargo bike logistics in urban freight transport: A literature review. *Transportation Research Procedia, 72*, 473–482. DOI: https://doi.org/10.1016/j.trpro.2023.02.045 [in English].
14. French company creates electric cargo bike train “Pelican eTrain”. (2023). URL: https://news.infocar.ua/frantsuzka_kompaniya_stvoryla_vantazhnyy_elektrovelosyped-poyizd_164889.html (accessed October 13, 2025). [in Ukrainian].
15. Fleet start for Schaeffler’s chainless drive for e-cargo bikes. (2023). URL: https://www.schaeffler.com/en/media/press-releases/press-releases-detail.jsp?id=87897088 (accessed October 14, 2025). [in English].
16. Mytko, M. V., Burlaka, S. A., & Bondar, A. V. (2025). Current state and prospects of the development of transport vehicles and connection roads in the urban infrastructure of Vinnytsia with recommendations on loading. *Naukovi pratsi VNTU, 3*. [in Ukrainian].

17. Mytko, M., Burlaka, S., & Yaroshchuk, R. (2025). Analysis of technical and technological forms of interaction between various types of transport. *Herald of Khmelnytskyi National University. Technical Sciences, 349*(2), 77–82. DOI: https://doi.org/10.31891/2307-5732-2025-349-10 [in Ukrainian].
18. Savin, Y., et al. (2025). The impact of fuel costs on the feasibility of cooperation-based operations at auto transport enterprises. *Scientific Journal of Silesian University of Technology. Series Transport, 126*, 205–220. DOI: https://doi.org/10.20858/sjsutst.2025.126.13 [in English].

СУЧАСНІ ТЕХНОЛОГІЇ ТА ТЕНДЕНЦІЇ ДЛЯ МАЙБУТНЬОГО ВИКОРИСТАННЯ ВЕЛОСИПЕДІВ-ТРАКІВ ДЛЯ ПЕРЕВЕЗЕННЯ ТВЕРДИХ ПОБУТОВИХ ВІДХОДІВ

У статті розглядаються сучасні технології та інноваційні підходи до впровадження велосипедів-траків у систему збору та перевезення твердих побутових відходів у міських і приміських умовах. Зростання екологічних викликів, необхідність зниження викидів парникових газів та обмеження використання традиційних автотранспортних засобів у густонаселених районах спонукають до пошуку альтернативних рішень у сфері муніципальної логістики. Одним із перспективних напрямів є застосування вантажних велосипедів-траків, зокрема електрифікованих моделей, здатних забезпечити ефективність перевезень при мінімальному негативному впливі на довкілля.

У статті детально аналізуються технічні можливості велосипедів-траків, їх вантажопідйомність, енергоефективність та доцільність інтеграції у систему управління відходами. Запропоновано концептуальну модель використання велосипедів-траків у міській інфраструктурі з урахуванням факторів щільності населення, протяжності маршрутів та рівня завантаженості дорожньої мережі. Проведено порівняльний аналіз традиційних сміттєвозів і велосипедів-траків за критеріями економічності, екологічності та маневровості.

Результати досліджень демонструють, що використання велосипедів-траків для перевезення твердих побутових відходів може знизити викиди CO_2 на 30–50% у порівнянні з дизельними автомобілями, а також сприяти зменшенню шумового навантаження в містах. Крім того, система виявила ефективність у районах із вузькими вулицями та обмеженнями руху, де традиційний транспорт є малопридатним. У статті також наведено рекомендації щодо розвитку інфраструктури, необхідної для широкого впровадження велосипедів-траків, включаючи спеціалізовані майданчики, зарядні станції та логістичні центри.

Запропонований підхід може бути корисним для органів місцевого самоврядування, муніципальних служб, а також інженерів і підприємців, які займаються розробкою та впровадженням екологічно безпечних транспортних систем. Отримані результати сприяють формуванню нових тенденцій у сфері «зеленої» міської логістики та розвитку сталої інфраструктури.

Ключові слова: *велосипед-трак, тверді побутові відходи, міська логістика, екологічний транспорт, інфраструктура, енергоефективність, електрифікація.*

Ф. 2. Рис. 7. Табл. 2. Літ. 18.

INFORMATION ABOUT THE AUTHORS

Mykola MYTKO – Candidate of Technical Sciences, Associate Professor of the Department of Automobiles and Transport Management, Vinnytsia National Technical University, (95 Khmelnytske Shose St., Vinnytsia, Ukraine. e- mail : mytko_83@ukr.net., ORCID: https://orcid.org/0000-0002-5484-0510).
Serhiy BURLAKA – Doctor of Philosophy in Industrial Mechanical Engineering, Associate Professor of the Department of Engineering Mechanics and Technological Processes in the Agricultural and Industrial Complex of Vinnytsia National Agrarian University (3 Sonyachna St., Vinnytsia, Ukraine, 21008, e- mail : ipserhiy@gmail.com, https://orcid.org/0000-0002-4079-4867).
Svetlana KRAVETS – Assistant of the Department of Engineering Mechanics and Technological Processes in the Agricultural Industry, Faculty of Engineering and Technology of Vinnytsia National Agrarian University (3 Sunny Street , Vinnytsia , 21008, Ukraine, email: swkravec2017@gmail.com, https://orcid.org/0000-0001- 8296-1929).

МИТКО Микола Васильович – кандидат технічних наук, доцент кафедри автомобілів та транспортного менеджменту, Вінницького національного технічного університету, (вул. Хмельницьке шосе, 95, м. Вінниця, Україна. e-mail: mytko_83@ukr.net, ORCID: https://orcid.org/0000-0002-5484-0510).
БУРЛАКА Сергій Андрійович – доктор філософії з галузевого машинобудування, доцент кафедри Інженерної механіки та технологічних процесів в АПК Вінницького національного аграрного університету (вул. Сонячна, 3, м. Вінниця, Україна, 21008, e-mail: ipserhiy@gmail.com, ORCID: https://orcid.org/ 0000-0002-4079-4867).
КРАВЕЦЬ Світлана Миколаївна – асистент, кафедри Інженерної механіки та технологічних процесів в АПК Вінницького національного аграрного університету (вул. Сонячна, 3, м. Вінниця, Україна, 21008, e-mail: swkravec2017@gmail.com, ORCID: https://orcid.org/0000-0002-1778-9111).