

Weigh-in-Motion (WIM) System Introduction for Sustainable Transport

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Abstract

The aim of this study is to assess the role of the Weigh-in-Motion (WIM) system in promoting sustainable road transport in Poland. Research conducted as part of the GOSPOSTRATEG project enabled the assessment of the strategic, economic, and social aspects of WIM implementation through SWOT/TOWS and PEST analyses, as well as quantitative estimates of accident and maintenance costs. The results indicate that adopting a "Maxi-Maxi" strategy, which leverages technological strengths and EU funding opportunities, maximizes the system's effectiveness. Simulation results indicate potential savings of PLN 1.82 billion over 10 years from deferred road maintenance expenditures and PLN 20.6 million in accident cost reductions. The implementation of WIM also contributes to reducing emissions, improving infrastructure durability, and improving road safety. The study highlights WIM as a strategic tool to support sustainable, data-driven transport management. However, the environmental and noise impacts have not been quantified, underscoring the need for further research integrating life-cycle assessment and intelligent transport systems.

Keywords

Weigh-in-Motion (WIM); sustainable transport; infrastructure management; road safety; accident costs; maintenance optimization; ITS; transport policy



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Introduction

The modern economy is increasingly dependent on road transport, which is essential to global supply chains and socio-economic mobility. However, the rapid growth in heavy vehicle traffic places a significant burden on road infrastructure, accelerating its degradation. The phenomenon of heavy goods vehicle overloading is one of the main factors accelerating pavement wear, increasing the frequency of repairs, and increasing road maintenance costs. It is estimated that excessive vehicle loads can reduce pavement structure durability by 30-55%, and infrastructure maintenance costs under such conditions can be up to twice as high as when vehicles meet the requirements for permissible axle loads (Sujon & Dai, 2021).

In Poland, as in many European countries, protecting infrastructure from overload is a priority for the Road Transport Inspection (ITD). The solutions currently in use are mainly based on preselection weighing of vehicles, followed by accurate static weighing at designated checkpoints. Although effective at detecting violations, this system does not enable a full assessment of the impact of vehicles on road structures and often causes traffic delays and low acceptance among carriers (Ślusarczyk et al., 2025).

In this context, automatic weigh-in-motion (WIM) systems are becoming increasingly important as one of the key tools for implementing the concept of sustainable transport. WIM systems enable continuous, dynamic measurement of a vehicle's total weight and axle loads without stopping, thereby enabling effective enforcement of regulations on permissible loads while maintaining traffic flow and reducing exhaust emissions from downtime (Rocheti & Bacurau, 2024).

The implementation of WIM technology contributes to the achievement of sustainable mobility goals in three dimensions:

- economic – by reducing infrastructure maintenance costs and increasing the efficiency of heavy transport supervision;
- social – by improving road safety and reducing accidents caused by overloading;
- environmental – by reducing the consumption of construction materials, limiting emissions associated with road repairs, and eliminating excessive fuel consumption by overloaded vehicles (Sujon, 2021; Rocheti & Bacurau, 2024).

In addition, data generated by WIM systems can form the basis for planning and strategic analyses, supporting infrastructure management and transport policy design. Information on traffic structure, axle load distribution, and vehicle types enables rational planning of repairs and investments, as well as more efficient use of public funds allocated for road maintenance (Wang & Wu, 2004).

Technical literature and implementation practice increasingly emphasize that WIM systems are an integral part of intelligent transport systems (ITS), combining traffic control with real-time data analysis. Their development supports the transformation of transport towards a sustainable, safe, and low-emission model, which is a priority for both European Union policy and national transport strategies (Ślusarczyk et al., 2025).

For these reasons, WIM systems not only serve as a control tool, but also constitute a strategic element of the infrastructure supporting the sustainable development of road transport. The aim of this article is to present the role of the WIM system as an instrument supporting infrastructure protection, safety improvements, and the reduction of social and environmental costs, and to assess its importance in building a long-term, sustainable transport system.

Literature review

The automatic in-motion vehicle weighing system (WIM) is an integral part of intelligent transport systems (ITS), enabling the measurement of vehicle weight without stopping them. The system's principle of operation is to record axle loads and total vehicle weight as it passes through the measuring point. This solution ensures smooth traffic flow, reducing downtime and increasing the efficiency of heavy transport management (Traffic Data Systems GmbH, 2024).

These systems consist of linear sensors embedded in the road surface and a set of cameras that record images of vehicles and their license plates. Data from sensors and cameras is transmitted in real time to the system's control center, where it is analyzed and archived. Modern systems use multi-sensor measurement systems that not only determine the vehicle's weight but also its type, number of axles, and wheelbase. This enables automatic vehicle classification based on technical parameters (Kistler Group, 2018; SHERWOOD Digital a.s., 2024). In addition, modern WIM stations are equipped with self-calibration modules that allow the accuracy of measurements to be adjusted in real time to changing environmental conditions, such as temperature, humidity, and road surface conditions. This allows for stable measurement precision over a long period of use.

Impact of truck overloading on road infrastructure

The problem of overloaded heavy goods vehicles is one of the most serious threats to the durability of road infrastructure. Excessive axle loads cause accelerated pavement wear, leading to fatigue cracks, ruts, and plastic

deformation. As a result, the service life of roads is shortened and the costs of their maintenance and modernization increase.

Studies conducted in Southeast Asian countries indicate that in regions with weaker transport supervision, the share of overloaded vehicles may exceed 60% of total heavy traffic, resulting in a reduction in road structure durability by up to several years relative to design assumptions (Jihanny & Subagio, 2018). Similar trends have been observed in Pakistan and Afghanistan, where up to 90% of commercial vehicles are overloaded, leading to a reduction in pavement life from 10 to 3 - 4 years (Kamran et al., 2020; Mokhlis Khan, 2023). In African countries, it has also been confirmed that as little as 13% of vehicles exceeding the permissible gross weight can reduce road durability by more than 9 years, generating significant costs for infrastructure managers (Agoro & Johannes, 2024). In addition, research by Richardson and Jones (2014) confirms that excessive vehicle axle loads significantly accelerate material fatigue in bridges and viaducts, reducing their service life and increasing structural risk.

The results of national studies confirm these observations. Ryś et al. (2014) showed that overloaded vehicles are responsible for an average of about 53% of the total fatigue damage to the pavement, and their share in the total destruction of the road structure ranges from 35% to 70%. Kula and Rafalski (2021) showed that increasing the share of overloaded vehicles from 0% to 20% reduces the fatigue life of flexible and semi-rigid pavements by an average of 55%, indicating the high sensitivity of road structures to loads exceeding standards. Jacob and Labry (2002), on the other hand, emphasize that exceeding the permissible total weight of a vehicle by as little as 15% can double fatigue damage to bridge structures, significantly shortening their service life.

The above results clearly indicate that overloaded vehicles are a significant factor in the degradation of road infrastructure, both globally and locally. As a result, many countries are seeing increased interest in technologies that enable effective, continuous monitoring of vehicle weight. The Weigh-in-Motion (WIM) system, which enables real-time monitoring of vehicle weight and axle loads without stopping vehicles, is becoming increasingly widespread. The literature emphasizes that WIM systems not only increase the effectiveness of overload control but also provide reliable data on actual pavement loads, enabling rational maintenance planning and strategic road infrastructure management (Hronský, 2015).

Social and environmental costs of overloaded vehicles

The phenomenon of overloaded trucks poses a serious challenge to modern transport systems. Its effects include not only accelerated degradation of road surfaces and structures but also an increase in accidents, environmental pollution, and the disruption of fair competition in the transport industry.

According to research by Liu and Mu (2017), the lack of effective mechanisms to control overloading in intercity transport leads to increases in the number of accidents, material losses, and exhaust emissions, while reducing transport energy efficiency. In Southeast Asia, overloaded vehicles account for 25-30% of all road collisions involving trucks (Jihanny & Subagio, 2018). In turn, data from China show that on mountain roads, as many as 80% of truck accidents are caused by overload (Wen et al., 2022). Research by Wen, Du, Chen, and Zhao (2022) has shown that overloaded trucks are more likely to be involved in accidents resulting in serious injuries, especially on roads with steep gradients and limited visibility. In turn, the GDDKiA Report (2024) confirms that areas with a high proportion of heavy traffic are characterized by higher accident rates and a greater frequency of collisions involving overweight vehicles.

Road protection and improved road safety are therefore among the most significant social effects of implementing the WIM system. Overloaded vehicles not only accelerate pavement degradation, necessitating more frequent and costly repairs, but also pose a significant threat to road traffic. Increased weight leads to accelerated wear and tear on braking and suspension systems, increasing the risk of technical failures. Overloaded vehicles are less stable on the road, especially when maneuvering, and their longer braking distance significantly increases the likelihood of collisions in emergency situations. Reducing the number of vehicles exceeding the permissible axle loads, achieved through the use of WIM systems, thus contributes to a reduction in the number of accidents, material losses, and fatalities and injuries. As a result, implementing WIM not only enhances road user safety but also improves traffic flow and driving comfort, constituting an important element of the concept of sustainable transport.

The social costs of overloading include not only the direct effects of accidents (treatment, rehabilitation, loss of productivity), but also the so-called external costs borne by society as a whole, including deterioration of air quality, noise, excessive wear and tear on infrastructure, and a reduction in the quality of life for residents of urban areas (JASPERS, 2023). Heavy loads also increase fuel consumption and pollutant emissions. According to data from the State of California Department of Transportation (Caltrans, 2024), overloaded trucks emit on average 25-35% more CO₂ per kilometer than vehicles that meet load standards, and exceeding the permissible weight by 20% results in an increase in fuel consumption of 0.5-0.8 liters per 100 km. The cumulative effect of these phenomena is higher emissions of nitrogen oxides, PM10 particles, and traffic noise, which negatively affect the health of residents and the natural environment. As demonstrated by Osarbski and Kaszubowski (2016) using the example of the implementation of the WIM system in Gdynia, precise control of heavy vehicle traffic in urban areas can reduce exhaust and particulate matter emissions by up to 15% and reduce travel time by about 10%, which translates into improved traffic flow and energy efficiency in transport. Reducing particulate matter (PM10 and

PM2.5) emissions has a direct impact on public health, especially in urban areas where air pollution poses a significant threat to residents' quality of life. Overloaded vehicles generate more dust not only from the exhaust system but also from increased friction with the road surface. In addition, excessive vehicle loads contribute to increased traffic noise, which negatively affects the quality of life of people living in roadside areas. As a result, the implementation of WIM systems contributes not only to protecting road infrastructure but also to reducing pollutant emissions, improving air quality, and enhancing public health and living conditions for residents.

The problem of overloading is also linked to the violation of fair competition rules in road transport. Carriers who overload their vehicles to transport more cargo gain an undue economic advantage over companies that comply with regulations. Such practices reduce the profitability of legally operating companies and encourage the undercutting of transport rates. As the European Commission (DG MOVE, 2023) notes in its report on enforcement in the transport sector, the lack of effective oversight of vehicle weights contributes to "unfair competition, social dumping, and cost pressure" among carriers operating in the European Union. In the long term, this results in reduced investment in modern, low-emission fleets and hinders the implementation of sustainable transport policies.

The WIM system also has a preventive and educational function. The mere awareness of its presence influences driver and carrier behavior, reducing the number of vehicle overloading incidents. In this way, the system not only reduces the number of violations but also shapes a culture of compliance and contributes to raising safety standards in transport (Jung & Lee, 2024).

The implementation of automatic vehicle weighing systems (Weigh-in-Motion, WIM) is an important element of the sustainable transport development strategy. The results of research by Jung and Mizutani (2025) show that appropriate placement of WIM stations can lead to an 18% reduction in road infrastructure load and a 12% reduction in social costs—including accident-related costs and pollutant emissions—per year. The implementation of this system on a national scale, therefore, translates into real infrastructural, social, and economic benefits, improving traffic management efficiency and environmental protection and thus strengthening the foundations of sustainable mobility.

Methodology

The successful implementation of a vehicle weighing system in motion is an essential step towards building a sustainable and efficient transport network in Poland. As part of the GOSPOSTRATEG project "Automatic Weigh-in-Motion System," comprehensive analytical and estimation work was carried out between October 1, 2023, and December 31, 2024, to assess the effectiveness of implementing this solution, including:

- SWOT/TOWS analysis,
- PEST analysis,
- estimation of the costs of accidents involving overloaded heavy goods vehicles,
- identification and quantification of expenditures related to the maintenance and upkeep of road infrastructure,
- estimation of the value of administrative penalties for vehicle overloading during the investment period,
- identification and quantification of cost factors related to the implementation and management of WIM stations,
- assessment of the effectiveness of the implementation of the automatic vehicle weighing system.

Given the adopted research objective and the publication's thematic scope, the study focused on four areas: SWOT/TOWS, PEST, accident cost estimation, and road repair costs. These are the areas that most directly relate to sustainable transport, allowing for an assessment of both the strategic and socio-economic effects of implementing the WIM system.

However, CO₂ emissions, environmental costs, and noise costs were not taken into account because no measurements were conducted during the project to enable their reliable estimation. Despite this limitation, the selected analyses reflect critical aspects of sustainable development: improving road safety, rationalizing operating costs, and protecting infrastructure resources, providing a basis for further research on a comprehensive assessment of the WIM system's impact on the Polish transport system.

The analyses focused on identifying the conditions, barriers, and opportunities for implementing the WIM system in Poland. All studies were included in a broader evaluation process to support the development of a national concept for the automated weighing of moving vehicles in the context of sustainable transport. The methodological approach used comprised four main stages:

1. Data collection: obtaining empirical data and documentation from pilot WIM installations and related subsystems (such as preselection weighing stations, ITS networks, and GITD and GDDKiA databases).
2. Desk research: analysis of national and international literature on the functionality of WIM systems, integration with intelligent transport systems, and sustainable transport management strategies.
3. Expert consultations: conducting structured workshops and interviews with project partners, representatives of road administration, supervisory authorities, and the TSL sector.

4. Analytical synthesis: development of SWOT and PEST matrices and conducting economic analyses of road accident costs and infrastructure maintenance expenditures, the results of which were subjected to strategic interpretation and validation through consensus among industry experts.

The use of SWOT/TOWS and PEST analyses enabled the simultaneous capture of internal factors (technological potential, resources, organizational barriers) and external factors (legal, economic, and environmental conditions) that determine the feasibility of implementing the WIM system. In turn, estimates of accident and road repair costs enabled a quantitative assessment of the impact of investments on the efficiency and safety of the transport network.

The sequence of methods adopted ensured the triangulation of quantitative and qualitative data, increasing the reliability of strategic conclusions. However, it should be noted that the dynamic nature of the transport sector—including the rapid development of digital technologies and changes in EU policy—may affect the relevance of some factors in the longer-term analysis.

Results and Discussion

SWOT/TOWS analysis

In accordance with the assumptions of the SWOT analysis, which aimed to assess the effectiveness of the WIM system in terms of its internal and external factors, each factor was assigned a weight (the results of the analysis are presented in more detail in Chład, 2024). They were assigned based on the results of a literature review of the analyzed problem and expert consultations. The identification of interactions between factors was carried out using eight systems: four for SWOT analysis and four for TOWS analysis.



Figure 1. Strategic SWOT Matrix for the implementation of the Weight-in-Motion (WIM) System in Poland

Source: own study based on the results of research carried out as part of the project "Automatic Weighing System for Vehicles in Motion (WIM)"

The identification of key factors indicates that the strategy for implementing the Weigh-in-Motion (WIM) system in Poland should be based on a "Maxi-Maxi" approach, utilizing strong technological potential and institutional support to maximize the opportunities offered by European Union policies and financing mechanisms. Basing the development of the WIM system on innovation, digitization, and sustainable development principles enables it to be transformed from a technical solution into a strategic transport policy tool that supports the implementation of priorities in road safety, infrastructure protection, and fair competition in the transport sector. In this sense, the WIM system symbolizes a shift from a reactive enforcement model to a proactive, integrated road transport management approach.

The results of the SWOT/TOWS analysis confirm that the most appropriate direction for the development of the WIM system in Poland is an aggressive strategy (Maxi-Maxi), focused on intensifying control and integration activities. Its main objective is to increase enforcement effectiveness, improve road safety, and protect infrastructure from degradation caused by overloaded vehicles. In practice, this strategy should include:

- the installation of numerous WIM points on critical sections of the road network and in locations with heavy truck traffic,
- integration of the WIM system with national and regional traffic management systems and transport databases, enabling rapid identification of and response to overloaded vehicles,
- the development of systems for the automatic transmission of information on weight violations to the relevant control services,
- introduction of effective procedures for the immediate imposition of administrative sanctions on owners of vehicles exceeding the permissible weight limits,
- conducting information and education campaigns aimed at carriers and drivers on the consequences of overloading vehicles,
- implementation of training programs for WIM system operators and enforcement agencies,
- raising awareness among carriers of their responsibility to comply with vehicle weight and technical condition standards.

However, the effective implementation of an aggressive strategy requires significant investment in measurement infrastructure, ICT systems, and cooperation between road administration, control services, and local government authorities. Despite the high initial costs, consistent implementation of the adopted measures can yield measurable, long-term benefits, including improved road safety, reduced infrastructure operating costs, and a stronger systemic foundation for sustainable transport development.

PEST analysis

The purpose of the PEST strategic analysis was to identify scenarios of the environment's impact on the investment resulting from external factors (the results of the analysis are presented in more detail in Sałek, 2024). At this stage, a total of 50 macro-environmental factors (divided into five categories) were identified that may affect the effectiveness of the WIM system. Among them, the following were distinguished:

- political and legal: PP – 10 factors,
- economic: EK – 10 factors,
- socio-demographic: SD – 10 factors,
- technological: TE – 10 factors,
- environmental: SR – 10 factors.

In the next step, the factors were analyzed, taking their weights into account, and the percentage shares were calculated based on the average weight for each factor. The purpose of this procedure was to identify the set of factors with the greatest impact on the investment project under study. This made it possible, using the Pareto-Lorenz method, to determine cumulative percentages and identify the most important macroenvironmental factors, which account for 80% of the total impact of all factors on the investment under study (Figure 2).

The characteristics and parameterization of the selected factors formed the basis for developing three variants of scenarios for the impact of macroenvironmental factors on investment: optimistic, pessimistic, and most likely.

The optimistic scenario indicates a dominant, positive impact of technological and economic factors. The quality of road infrastructure and modern measurement technologies, which determine the effectiveness of WIM station construction and operation, is of fundamental importance here. Economic factors are equally important, in particular the availability and stability of investment financing and the condition of the transport sector, which determine the project's long-term effectiveness.

In the pessimistic scenario, environmental and socio-demographic factors pose the greatest threat. There may be an increase in transport costs due to restrictions on combustion-engine vehicles, a greater share of electric trucks, and more overloaded vehicles. In conditions of increasing weather anomalies, such as floods, heavy rainfall, or strong winds, disruptions to the WIM system may occur in some regions.

The realistic scenario assumes a moderately positive impact from socio-demographic and technological factors, while also recognizing the risk of reduced public funding due to geopolitical and fiscal changes. An increase in freight transport volume is expected, supported by the country's economic development, while no significant changes in road transport regulations are expected in the legislative sphere.

To achieve maximum efficiency of the WIM system, future actions should focus on the development directions highlighted in the optimistic scenario. Weigh-in-motion systems should be considered in the context of technological progress, including increased digitization and information management, as well as the development of manufacturing technologies for road infrastructure construction. These actions should be complemented by ensuring appropriate legal regulations and financing sources for the development of an automatic weigh-in-motion system.



Figure 2. Macroenvironmental factors with the greatest impact on the effectiveness of the WIM system (PEST analysis)
Source: own study based on the results of research carried out as part of the project "Automatic Weighing System for Vehicles in Motion (WIM)"

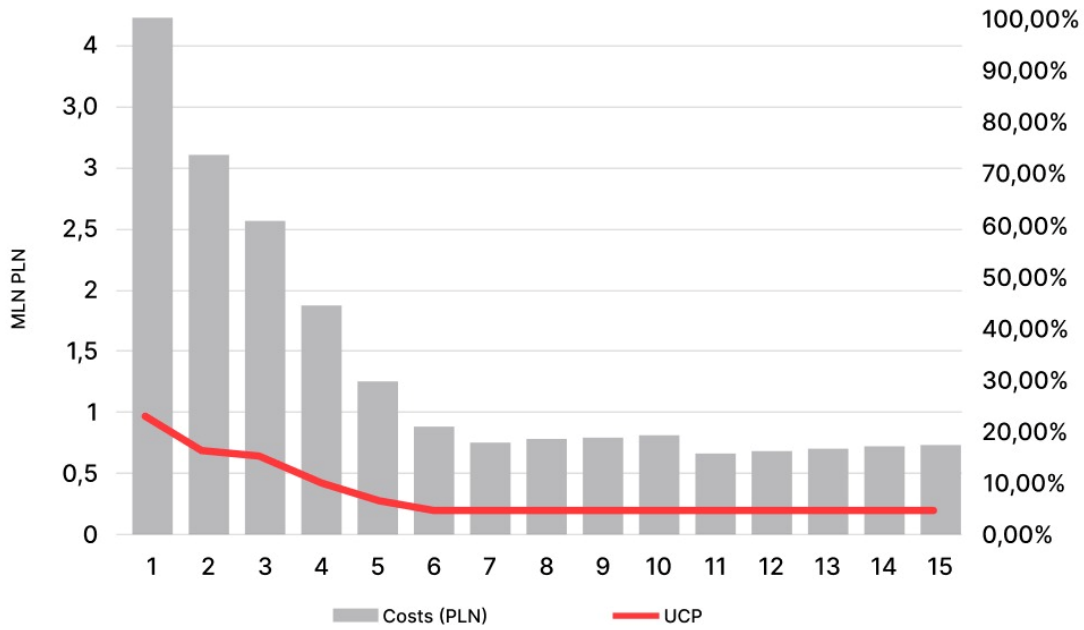
Estimating the costs of accidents involving overloaded heavy goods vehicles

The analysis of road accident costs carried out as part of the GOSPOSTRATEG project is an important element in assessing the effectiveness of WIM implementation in the context of sustainable transport (the results are presented in detail in Sałek, 2025). It covers both direct expenses, such as vehicle repairs and medical treatment for victims, and indirect costs, including economic losses from lost productivity, social burdens, and victims' suffering. In the context of implementing the WIM system, it was particularly important to take into account not only current events but also projected changes in accident rates, thereby enabling a more complete assessment of the financial and social impacts of infrastructure projects.

The cost analysis used took into account a wide range of financial factors – from administrative and legal costs, through productivity losses and material losses, to expenses related to hospitalization, funerals, and compensation. The calculations were performed using Method II described in the Blue Book on Road Infrastructure. Updated edition 2023 (JASPERS, 2023), the choice of which was justified both by the availability of data and the possibility of taking into account a wide range of variables in the analytical process.

The value of potential road accident costs, estimated using Method II for 300 planned WIM station locations in Poland, amounted to approximately PLN 20.6 million over 15 years. The calculation model assumed the maximum number of stations launched in the first year of the investment and their continuous operation throughout the entire study period. The projected costs were calculated under fixed boundary conditions regarding the number of stations, their locations, and the implementation strategy.

Based on the results (Fig. 3), a clear downward trend in annual accident costs over time was observed. The largest decrease is expected in the first 6 years of the investment, which corresponds to a reduction in the number of overloaded trucks resulting from the launch and stabilization of the WIM system. The reduction in the share of vehicles exceeding the permissible gross weight leads to fewer road incidents and lower social and infrastructure costs. In subsequent years, costs stabilize, with slight fluctuations due to the adopted time impact coefficients. The model indicates that after the seventh year of the investment, the effects are consolidated, and in the long term, further reductions in costs are possible while maintaining the existing assumptions regarding the reduction of overloading in heavy transport.



UCP – share of overweight trucks

Figure 3. Annual aggregate accident costs projected for the planned network of WIM stations over a 15-year investment horizon
 Source: own study based on the results of research carried out as part of the project "Automatic Weighing System for Vehicles in Motion (WIM)" and Salek, R. (2025).

The variability of cost dynamics is shown in Figure 4, which shows a sharp decline in value in the first seven years of WIM implementation, followed by a gradual decline. Positive values reflect the rapid pace of cost reduction, while negative values indicate stabilization or slight increases observed in the 7–10 and 11–15 year ranges. The single increase in dynamics in the eleventh year is due to a slight year-on-year reduction in costs between the tenth and eleventh years.

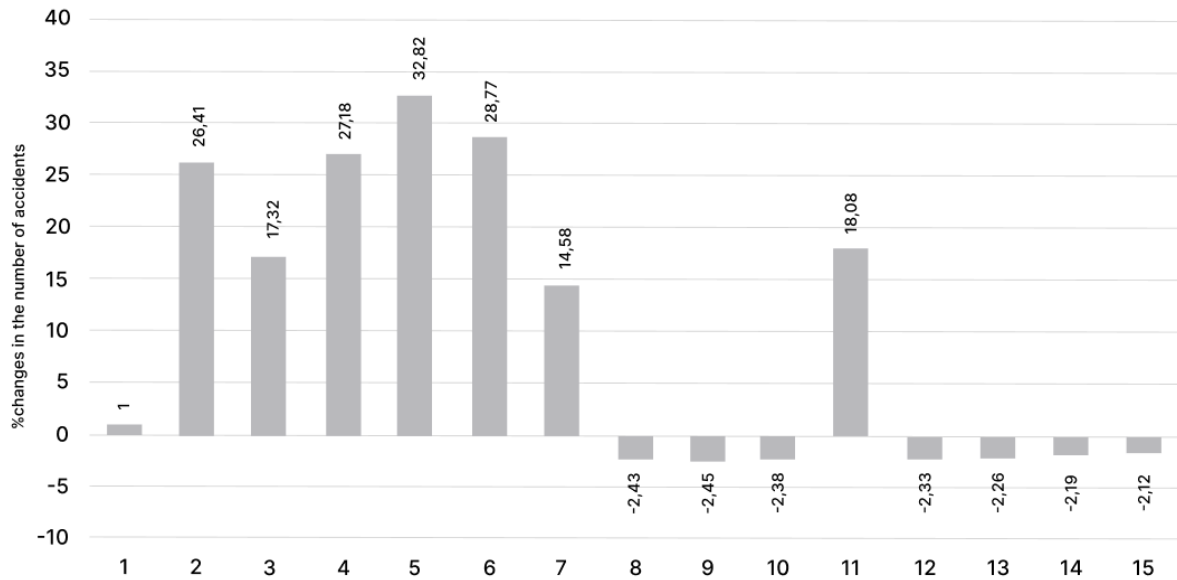


Figure 4. Annual variation in the reduction of road accident costs associated with overloaded vehicles throughout the planned investment period
 Source: own study based on the results of research carried out as part of the project "Automatic Weighing System for Vehicles in Motion (WIM)" and Salek, R. (2025).

The results presented provide a synthetic picture of economic forecasts based on the location data for planned WIM stations and confirm that the system's implementation at a national scale can contribute to a significant reduction in the social and economic costs associated with road accidents.

Estimating the costs of periodic and partial repairs

The methodology for estimating potential savings from reducing periodic and partial repair costs after the implementation of the WIM system was based on several key assumptions (the results of the analysis are presented in detail in the publication by Ślusarczyk & Grondys, 2025).

Firstly, it was assumed that implementing an automatic vehicle weighing system in traffic would allow for a systematic reduction in the proportion of overloaded vehicles – from around 23% (under the current preselection system) to around 5% within 15 years of the system's operation. This decrease will translate into cumulative savings in road maintenance and repair costs, especially in the initial investment period.

The unit costs of periodic and partial repairs were estimated based on values from the "Blue Book – Road Infrastructure" (JASPERS, 2023). In the absence of accurate data on partial repairs, unit costs for ongoing road maintenance were assumed, considering them representative given the similarity of material, labor, and technical resource expenditures.

The analysis covered 300 planned WIM station locations on sections of national and express roads. It was assumed that the indicated routes constitute the minimum road network protected against excessive degradation. The service life of the pavement was set at 20 years for national roads and 30 years for expressways and motorways. Currently, partial repairs are carried out on average every 5 years, and periodic repairs every 10 years. By reducing the number of overloaded vehicles, it was assumed that these cycles would be extended to 6 years (partial repairs) and 30-40 years (periodic repairs), respectively, which provided the basis for estimating long-term savings.

Table 1 shows the total savings resulting from reducing the frequency of partial repairs and postponing periodic repairs.

Table 1. Summary of total savings for 300 locations generated over 10 years as a result of the implementation of the WIM system due to the postponement of periodic and partial repairs

| <i>Reference section type</i> | <i>Total savings from periodic repairs due to the implementation of the WIM system over a period of 10 years [PLN]</i> | <i>Total savings from partial repairs due to the implementation of the WIM system over a period of 10 years [PLN]</i> |
|---|--|---|
| <i>2-lane expressway</i> | <i>526,845,333</i> | <i>790,268,000</i> |
| <i>Single carriageway expressway</i> | <i>8,793,000</i> | <i>8,597,600</i> |
| <i>2-lane main road for fast traffic</i> | <i>64,504,000</i> | <i>57,219,067</i> |
| <i>Main road for fast traffic, 1 lane, and main roads</i> | <i>215,456,033</i> | <i>149,608,320</i> |
| TOTAL | 815,598,366 | 1,005,692,987 |
| | 1,821,291,353 | |

Source: own study based on the results of research carried out as part of the project "Automatic Weighing System for Vehicles in Motion (WIM)"

Based on the assumptions and calculations, the potential savings from implementing the WIM system could reach PLN 1,821,291,353 over a 10-year period. This amount includes the cumulative effects of deferring the costs of periodic and partial repairs, which, in the traditional infrastructure maintenance model, are a main component of road administrators' operating expenses. This means that by reducing the number of overloaded vehicles and extending the intervals between repairs, it will be possible to generate real financial savings that can be allocated to other infrastructure modernization and road safety initiatives.

Given that the calculations are based on installing 300 automatic vehicle weighing stations (WIM) at strategic points in the transport network, it can be assumed that the planned investment is systemic and will potentially cover a significant part of the national road infrastructure. In practice, this means not only reduced maintenance costs but also improved pavement durability, reduced traffic disruption from repairs, and increased transport fluidity and safety.

From a sustainable development perspective, the economic effects achieved should be treated not only as measurable financial savings but also as contributions to the development of a more efficient and resilient transport system, in which infrastructure investments deliver long-term environmental and social benefits.

Conclusion

The analyses confirm that implementing the Weigh-in-Motion (WIM) system is an important step towards building a sustainable, safe, and economically efficient road transport network in Poland. The results of the SWOT/TOWS and PEST analyses clearly indicate that the most advantageous implementation strategy is to leverage technological and institutional strengths to capitalize on the opportunities presented by EU policy and financing mechanisms. This "Maxi-Maxi" approach transforms WIM from a tool focused solely on enforcement into a strategic management instrument that enhances infrastructure protection, road safety, and market fairness—the three fundamental pillars of sustainable transport development.

The results obtained are consistent with previous studies highlighting the multidimensional benefits of WIM systems. Vasilyeva (2019) showed that integrating WIM with intelligent transport infrastructure reduces the number of overloaded vehicles, maintenance costs, and accidents, results closely related to those of the GOSPOSTRATEG project. Similarly, Jung, Mizutani, and Lee (2025) found that optimal WIM station placement can reduce overall traffic congestion and associated social costs by up to 12%, confirming this study's estimate of savings from delayed maintenance work of nearly PLN 1.82 billion over ten years. Long-term assessments by Gajda et al. (2023, 2025) further confirmed that implementing WIM improves infrastructure durability and reliability by increasing detection accuracy and reducing pavement fatigue.

From an economic perspective, the estimated reduction in accident-related costs (approximately PLN 20.6 million) and savings in maintenance work confirm that implementing the WIM system has both direct financial and broader socio-economic effects. These effects are consistent with international studies by Pionar et al. (2022) and Singh (2024), which emphasize that the systematic use of WIM data can extend road service life and optimize transport energy efficiency. The system thus serves as both a regulatory mechanism and a proactive management tool, supporting the transition to a low-carbon, data-driven transport infrastructure.

In the broader context of sustainable development, the WIM system contributes not only to rationalizing infrastructure spending but also to reducing external environmental effects. Reducing the incidence of overloaded vehicles reduces the need for energy-intensive road repairs and helps mitigate associated emissions, in line with the objectives of the European Green Deal and the UN 2030 Agenda for Sustainable Development.

Nevertheless, the study has some limitations. Due to data availability, the analysis did not account for costs associated with CO₂ emissions, environmental degradation, or traffic noise, which could further enhance the comprehensiveness of the sustainability assessment. Furthermore, the dynamic evolution of EU transport policy and digital technologies means that the relative importance of some factors identified in the SWOT and PEST analyses may change over time, thereby affecting long-term projections of system performance.

Future research should therefore focus on extending the analytical framework to include life cycle environmental cost assessment (LCA), particularly in the context of CO₂ reduction and energy efficiency. Further integration of WIM data with intelligent transportation systems (ITS) and AI-based predictive maintenance platforms could underpin adaptive real-time policy management. Long-term studies analyzing the impact of behavior and compliance among carriers would also deepen understanding of WIM's role in shaping a culture of sustainable transport.

In summary, the results confirm that the Weigh-in-Motion system, thanks to its technological maturity, economic efficiency, and preventive potential, plays a strategic role in supporting sustainable transport by integrating infrastructure resilience, safety improvements, and market integrity within a unified development framework.

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