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COMBATING OVERLOADED VEHICLES ON THE ROADS – POTENTIAL ECONOMIC BENEFITS

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Abstract: Overloaded trucks have a significant impact on road surface degradation, leading to premature damage to infrastructure. Reducing the number of overloaded trucks can help decrease the extent of this damage, which, in turn, will result in less frequent need for repairs and lower road maintenance costs. These conclusions suggest that effective control of vehicle weight is a key element in strategies aimed at maintaining the durability of road infrastructure and optimizing spending on its upkeep. To this end, calculations of potential savings on periodic maintenance as a result of implementing the WIM system were carried out, based on literature assumptions. The results obtained showed that the implementation of a more efficient heavy vehicle weighing inspection system can significantly contribute to reducing road repair costs as a result of a reduction in the share of these vehicles in traffic.
Keywords: overloaded trucks, weighing of vehicles in motion, WIM, road maintenance, cost maintenance

1. INTRODUCTION

According to a report by The European Automobile Manufacturers' Association (ACEA) (2024), Poland is the European leader in the number of registered trucks. At the end of 2022, 1,276,594 trucks were registered in Poland. Moreover, according to data from a report by the Polish Automotive Industry Association (Drążkiewicz, 2024), in 2022 the share of heavy vehicles, i.e.: trucks, special-purpose vehicles and truck tractors with the GVW of between 3.5 tons and 16 tons, increased by almost 7% compared to the previous year, and for vehicles with the GVW of more than 16 tons - by 5%. At the same time, the number of trailers and semi-trailers with the GVW of more than 3.5 tons amounted to more than 3.4 million units. In turn, the data published by the Central Statistical Office of Poland (2024) shows that domestic freight increased by 8.8% in 2022, while international freight - by 6% year by year, and more than 85% of all cargo (by weight) was transported by road. The registered number of international carriers (up by 17%) and the resulting number of trucks (up by 4%) also increased during the period under review, due to the re-registration of a large number of transport companies from Ukraine to Poland (Automotive Industry Report, 2024).

All of these vehicles heavily use the Polish national road network on a daily basis and have a significant impact on its durability, which is being tested by the weight of the load. At the same time, the share of overloaded trucks in traffic can be about 18.5%, with the largest share of overloaded vehicles (more than 25%) occurring in the absence of any type of inspection, while with intensive inspections - the share is relatively small and can be just over 1% (Kula and Rafalski, 2021; Grondys et al.,2024). Numerous studies prove that such a high share of heavy trucks in traffic plays a significant role in the rate and extent of road degradation (Suzuki et al., 2023, Ślusarczyk et al., 2023). This, in turn, translates into road maintenance costs, which, per truck, can be as much as 100 % higher than the same calculated for a vehicle loaded properly (Pais et al., 2013). This means that a decrease in the proportion of overloaded trucks can significantly reduce the cost of maintaining the national road infrastructure, which is possible by providing a more accurate vehicle weighing inspection system as a result of implementation of the Weight in Motion (WIM) automatic weighing system.

Based on preliminary analyses, the objective of the study was to estimate the potential economic benefits resulting from a reduction in the share of overloaded trucks on the national road network as a result of implementing the WIM system. It is assumed that a reduction in the number of overloaded trucks will result in real opportunities to generate savings from unpaid or reduced road maintenance expenses in the long-term.

2. IMPACT OF OVERLOADED VEHICLES ON SURFACE DAMAGE

The consequence of loading the road surface with heavy traffic is the gradual accumulation of damage, which leads to exhaustion of the fatigue life of the pavement structure (Sałek, 2024; Chłąd, 2024). Pavement structure is an assembly of appropriately selected layers that rests on top of the subsoil or on top of a layer of improved subsoil (Kędzierska, 2021). The primary damage to asphalt road pavements is permanent deformation and cracking of these layers. Degradation can occur through the formation of cracks, cavities, deformation of the pavement (ruts), which affects the deterioration of its functional properties, i.e. an increase in noise generated by vehicle tires, an increase in vehicle and load vibration, deterioration of comfort and road safety caused by changes in the adhesion of vehicle wheels to the road surface and problems with vehicle stability due to overcoming irregularities in the form of ruts. Ryś et al. (2014) observed that the contribution of overloaded vehicles to the total fatigue damage of pavements is significant, ranging from 35% to 70%, which means that overloaded vehicles cause an average of ca. 53% of total fatigue damage to road pavements. Similarly, Kula and Rafalski (2021) investigated that increasing the proportion of overloaded vehicles from 0% to 20% reduces the fatigue life of susceptible and semi-rigid pavements by an average of 55%. In turn, Jacob and Labry (2002) noted that exceeding the gross vehicle weight by 15% can cause as much as twice the fatigue damage to a bridge. Consequently, degradation by overloaded heavy vehicles significantly shortens the life of the pavement, as shown in Figure 1.

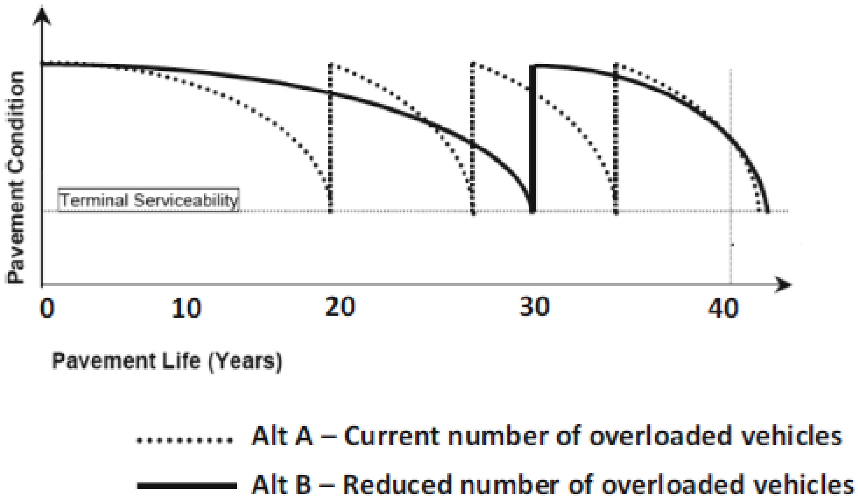

Fig. 1. Road Life due to Reduction of Overloaded Trucks (Ryś and Jaskuła, 2019)

Assuming an increase in the volume of overloaded truck traffic over time, a faster decline in the condition of the road surface is observed. It reaches its final serviceability limit after 20 to 30 years (depending on class of the road). After that period, it is essential to carry out repairs that include replacing the deep layers of the road surface. However, assuming a reduction in the proportion of overloaded vehicles, the durability of the pavement can be extended by at least 10 years (Ryś and Jaskuła, 2019). This means that from the original estimated length of 20 years for national roads, the useful life could be as long as 30 years, with motorways going from 30 years to as long as 40 years. This perspective shows that the construction and development of a WIM system can significantly postpone the need for structural/periodic repairs and generate tangible savings.

3. ROLE OF THE WIM SYSTEM IN REDUCING OVERLOADED VEHICLES

Currently, Poland has a selective vehicle weighing system, with large gaps in its effectiveness. This is mainly due to the complex weighing process and the need for a lot of direct involvement of the relevant officers. Moreover, the measurements made are prone to significant errors (Gajda et al, 2016). This means that a significant proportion of trucks in traffic are not subjected to weight control, and continue to damage the road infrastructure. According to Ryś et al. (2017) the average percentage of overloaded vehicles on the roads ranges from 6% to 23%, but the phenomenon of overloaded vehicles intensifies when traffic control is irregular. In turn, the higher the proportion of overloaded vehicles, the greater the degree of infrastructure degradation. Therefore, the condition of the infrastructure depends heavily on the effectiveness of detecting overloaded vehicles and can be improved through regular weighing inspections (Dey et al., 2015). More frequent and effective inspection of both vehicle weight and axle load can be provided by a system of automatic weighing of vehicles in motion (WIM) (Burnos et al., 2021), which can bring many economic, social and environmental benefits. The most important benefits of WIM are (Kim and Jung, 2021; Dontu et al., 2020):

- greater traffic flow, as the entire weighing process is much more efficient, vehicles do not have to stop for weighing, and can continue driving while their weight is checked in nanoseconds;
- immediate identification of overloaded vehicles;

- improved efficiency - weighing on the move enables a completely unattended weighing operation, which is an obvious increase in the efficiency of the system and eliminates errors that can be made by the personnel during selective weighing of vehicles;
- comprehensive reporting and full integration with other systems and
- peripheral devices, in order to improve safety and meet public transportation requirements;
- profitability of the investment as a result of balancing the costs of installing and operating the system with the expenses incurred on repairing and renovating the road infrastructure, damaged by overloaded trucks.

4. IMPACT OF OVERLOADED VEHICLES ON PAVEMENT REPAIR COSTS

Further research indicates that if the percentage of overloaded vehicles drops from 23% to 5%, the maintenance costs of the road section borne by the road manager can drop by up to 11% (Ryś and Jaskuła, 2019). The results may be slightly different for different scenarios, but making the service life longer will always result in economic benefits. Previous observations and studies show that the installation of WIM stations reduces the rate of pavement damage caused by overloaded vehicle traffic, thereby reducing the maintenance costs and reducing the frequency of road repairs (Ryś et al., 2014). This is supported by the results of the TRL study, according to which, when axle load increases by 30%, from 10 to 13 tons, the annual maintenance costs can increase by 30%-40% (Musbah, 2017). What is more, the presence of overloaded vehicles can increase pavement maintenance costs by more than 100% compared to maintenance costs at an acceptable load (Pais et al, 2013).

Repair and renovation costs are generated over the useful life of the pavement. This includes both the initial cost of road construction and future cost associated with maintenance to ensure the road condition is proper. These costs represent the average unit cost of operation and periodic maintenance of a road, with the assumption that the overall replacement/modernization of a new or repaired road should be carried out 10 years after it is put into service (JASPERS, 2023). The unit costs of road infrastructure maintenance (relating to asphalt and concrete pavements) depend on the class of the road. In 2023, new values for the unit cost of periodic road maintenance for EU transport infrastructure projects were determined (Table 1).

Table 1
Unit periodic maintenance costs [PLN/km], 2022 prices (JASPERS, 2023)

Road type	Road class	Net unit cost of periodic maintenance [PLN/km]
2-lane expressway, e.g. a motorway	A,S – 2/2	+1 600 000
1-lane expressway with an additional lane	S 1/2+1	+1 100 000
1-lane expressway	S 1/2	+900 000
main roads with fast traffic, 2-lane	GP 2/2	+1 200 000
main roads with fast traffic, 1-lane	GP 1/2	+780 000
Main road	G	+670 000

Source: (JASPERS, 2023).

These costs represent the most current value of structural road repairs, assigned to one kilometer depending on the type of road.

5. PURPOSE AND OBJECTIVES OF THE STUDY

The considerations made regarding research in the area of the impact of overloaded heavy vehicles on the condition of roads motivated an attempt to make an overall calculation of the savings that can be achieved as a result of reducing the share of these vehicles. The purpose of this study was to estimate the potential economic benefits resulting from a reduction in the share of overloaded trucks on the national road network as a result of implementing the WIM system. In line with the results of previous studies, the following assumptions were made:

- The regular interval for carrying out structural repairs to the road surface is every 20 years for national roads and every 30 years for motorways and expressways,
- Implementation of the WIM system will result in a decrease in the proportion of overloaded vehicles from the current 23% to 5% within 8 years;
- The cost of repairs depends on the class of road, the number of lanes and the number of kilometers of the road section where a WIM station is installed.

The study assumes that the implementation of the WIM system at 300 strategic locations throughout the country will allow for an assessment of its impact on road infrastructure maintenance costs. This means that the system is tasked with protecting much of the infrastructure of the national road network. All the WIM station locations were selected based on the national traffic model (CUPT) and the 2002 General Traffic Measurement (GPR).

6. STUDY RESULTS

The calculation procedure included identification of 300 reference sections where the installation of WIM stations is recommended. The sections were then classified according to the type of road and number of lanes, as well as the unit cost of periodic repairs (as shown in Table 1). The total cost of periodic road maintenance for the selected 300 WIM locations was calculated as the product of the unit cost of periodic maintenance and the length of the reference sections. It was assumed that the value obtained corresponds to the cost of the periodic repairs needed after 20 or 30 years of road pavement life, with the current high volume of overloaded heavy vehicle traffic. The results are presented in Table 2.

Table 2
Summary of the cost of periodic road surface repairs for 300 WIM site locations with the current share of overloaded vehicles in traffic

Road type	Net unit cost of periodic maintenance [PLN/km]	Number of reference sections	Number of kilometers of reference sections [km]	Total net cost of periodic maintenance of sections [PLN]
2-lane expressway, e.g. a motorway	+1 600 000	204	3 951,34	+6 322 144 000
1-lane expressway	+900 000	3	58,62	+52 758 000
Main road with fast traffic, 2-lane	+1 200 000	21	322,52	+387 024 000
Main road with fast traffic, 1-lane	+780 000	64	1 520,76	+1 186 192 800
Main road	+670 000	8	164,08	+109 933 600
TOTAL	**-**	**300**	**6,017.32**	**8,058,052,400**

Source: own research.

The pavement life (in years) - before and after implementation of the WIM system - was then determined according to the assumptions made. The difference in pavement life cycle before and after implementation of the WIM system represents the potential period over which savings can be generated from deferred periodic repairs. Thus, the life of the pavement was extended by 10 years for each type of road, thus automatically postponing the need for periodic repairs. This difference is the basis for assessing potential savings, so for this purpose the value of periodic maintenance costs was estimated both before and after implementation of the automatic vehicle weighing system. The difference between the costs of periodic repairs of the reference section, specific to the WIM station location before and after implementation of the WIM system, thus represents the values of potential savings (Table 3).

Table 3
Potential savings from periodic road repair for 300 WIM site locations after implementation of the WIM system

Type of reference section	Net annual cost of periodic section maintenance [PLN] before WIM implementation	Annual net cost of periodic maintenance of sections [PLN] after WIM implementation	Total savings from WIM implementation over 10 years [PLN]
2-lane expressway like a motorway	+210 738 133	+158 053 600	+526 845 333
1-lane expressway	+2 637 900	+1 758 600	+8 793 000
Main road with fast traffic, 2-lane	+19 351 200	+12 900 800	+64 504 000
Main road with fast traffic, 1-lane	+59 309 640	+39 539 760	+197 698 800
Main road	+5 383 673	+3 607 950	+17 757 233
TOTAL	**297,420,546**	**215,860,710**	**815,598,366**

Source: own research.

The cost of performing regular periodic repairs on 300 sections of national roads, on average every 20 years, is more than PLN 297 million per year. Meanwhile, with implementation of the WIM system and assumption that the share of overloaded heavy vehicles will drop to 5%, the need for periodic maintenance will be postponed by at least 10 years. In such a case, the cost of periodic maintenance could fall to as much as PLN 215 million a year. Savings generated over the 10-year period of non-implementation of the renovations are at a total level of PLN 815 million and demonstrate the profitability of studied investments.

The average unit cost of a periodic renovation of a road section can amount to as much as PLN 50,000/km while the selective vehicle weighing system is in effect, while the implementation of the WIM system can reduce these costs to as much as PLN 36,000/km, i.e. by almost a third. Moreover, if it is assumed that the indicated sections represent only the minimum road network that will be directly protected from excessive degradation due to overloaded trucks, the estimated savings represent the minimum level of savings that can be generated thanks to operation of the WIM system all over Poland. This means that the identical postponement of periodic repairs for the entire national road network could yield billions of zlotys in benefits. According to current statistics, Poland currently has 17,800 kilometers of roads, including 5102.3 kilometers of freeways, including 1849.2

kilometers of motorways and 3253.1 kilometers of expressways (General Directorate for National Roads and Motorways (GDDKiA), 2024).

Table 4
Potential savings from periodic road repair for 300 WIM site locations after implementation of the WIM system

Road class	Number of kilometers	Net unit cost of periodic maintenance [PLN/km]	Total costs of periodic repairs [PLN]
2-lane expressway like a motorway	1 712	+1 600 000	+2 739 200 000
1-lane expressway	2 557	+900 000	+2 301 300 000
Main road with fast traffic, 2-lane	3 804	+780 000	+2 967 120 000
Main road with fast traffic, 1-lane	9 727	+670 000	+6 517 090 000
Total	17 800	-	+14 524 710 000

Source: own research.

It is assumed that an effective WIM system, covering numerous strategic locations of significant truck traffic, can protect a significant portion of the entire national road network. The potential savings could thus be as much as PLN 4 billion (based on the values in Table 4) spread over at least 40 years. In contrast, other studies state the savings could be around 11%. (Ryś and Jaskuła, 2019) with a reduction in the share of overloaded vehicles from 23% to 5%, which could result in more than PLN 1.5 billion of total savings. Of course, the values obtained for potential savings are very general. They can evolve as a result of changes over time, as a result of changes in the unit cost of repairs, the type of materials and technology used in repairing the road surface, or the varying demand for repairs depending on the age of the road and the level of damage.

7. CONCLUSIONS

Overloaded trucks contribute to road degradation much faster than normative vehicles. Implementation of the WIM system can help significantly reduce the number of overloaded vehicles. The study estimates the potential savings from deferred periodic maintenance as a result of implementation of the WIM system in Poland and the associated reduction in the proportion of overloaded heavy vehicles. Based on the share of overloaded heavy vehicles in traffic in Poland to date, the costs of performing regular periodic repairs on 300 sections of national roads, which were the recommended locations for the weighing stations, were calculated. These costs were also calculated identically for the scenario in which the share of overloaded heavy vehicles falls to a minimum after implementation of the WIM system. This contributes to stretching out the need for structural repairs of road surfaces by at least 10 years. The estimated possible savings are a sign of profitability of the investment under the assumptions made. The results show that the implementation of a WIM system consisting of 300 weighing stations on Poland's road network can result in up to 30% savings generated from unpaid repair costs over the first ten years of the system's operation. The study conducted has some limitations due to the forecast nature of the traffic model, and relying only on data on unit cost of periodic repairs. Further studies should consider both the age of the national road network and the cost of partial repairs in estimating potential savings.

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