Research Article

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Limitations of the effectiveness of Weigh in Motion systems

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Abstract: Overloaded vehicles pose a real threat to road safety and significantly contribute to the degradation of the road surface. High-Speed Weigh in Motion (HS-WIM) stations are the commonly used method of eliminating them from traffic. In Poland, HS-WIM stations operate in pre-selection mode, sending information to services about the potential exceedance of acceptable standards by a specific vehicle. The article presents the results of the data analysis from selected HS-WIM stations operating on the national road network in Poland indicating significant limitations of the effectiveness of the whole system. The main reason for this may be that carriers use the knowledge about the HS-WIM stations location and working time to avoid inspections. The results presented in the paper indicate, among other things, that in some locations the share of vehicles overloaded with traffic increases significantly outside the working hours of the controlling services. For Light Commercial Vehicle, the share of overloaded vehicles in this group is also significant. Also, the paper indicates that the effectiveness of the procedure for determining vehicle overload has been limited due to errors in classification.

Keywords: Weigh in Motion systems, overloaded vehicles, vehicles classification, road safety, road infrastructure

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1 Introduction

Overloaded vehicles have a negative impact on road safety, the state of the environment, road infrastructure and the transport market. The vehicle is overloaded when gross weight or the load on at least one of the axles is greater than the permissible. Limit values for most vehicles on the European Community's roads are set out in Council Directive 96/53/EC of 25 July 1996 [1]. The overload problem applies to all vehicles travelling on public roads. However, it is particularly important in the case of Heavy Commercial Vehicle (HCV) and Light Commercial Vehicle (LCV). For the latter, relative exceedances can be particularly large and often significantly exceed 100%. In an interview with the news agency NEWSERIA, a representative of the toll system operator on national roads in Poland in the years 2011/2018, Kapsch Telematic Services, stated that up to 80% of LCVs are overloaded, and there are vehicles with up to twice the permissible weight [2].

In the context of road safety, vehicle overloading is important for all vehicle categories. It is always associated with an increase in inertia forces, and thus an extension of the braking distance, a decrease in the maximum accelerations and a change in the vehicle's behaviour in curvilinear motion, especially during sudden manoeuvres. In addition to instability and reduced manoeuvrability of the overloaded vehicle, the possibility of overheating the brakes and tires [3] should be taken into account. As a result, these threats contribute to an increase in the risk of an accident, and in the event of its occurrence, they intensify the effects. Overloaded vehicles can also affect the flow of traffic, resulting in the formation of vehicle columns and slowing down the speed of traffic. This can negatively affect other road users and thus reduce the level of traffic safety. Vehicles with excessive gross weight are also a larger source of environmental pollution. This regards both the increased emissions of harmful products of fuel combustion in engines and particulates resulting from the wear of breaks tires and increased noise.

For overloaded HCVs, the excessive degradation of road infrastructure is a very important problem. The roadway itself, as well as engineering structures such as

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bridges, viaducts and flyovers, is subject to degradation. A single pass of an unloaded heavy vehicle is the equivalent of many passes of lighter vehicles. Road construction specialists use the so-called fourth power law. In the calculation of road durability, the exponent $\alpha = 4$ is assumed, according to which the passage of one truck with a load of 100 kN/axle is equivalent to the passage of 20^{α} of passenger cars with loads of 5 kN/axle. Research carried out by OECD/ITF and included in two reports [4, 5] showed that the adopted factor α may be, in the case of some types of roads and pavements, underestimated. In the case of asphalt surfaces it can be $\alpha = 5$, and for concrete surfaces – even $\alpha = 12$ [6]. Moreover, according to conservative estimates, exceeding the allowable pressure by 10% may cause a 45% increase in the degree of pavement degradation [7].

Exceeding the permissible weight of the vehicle, when used in the course of business, also violates the principles of fair competition. It not only allows to reduce the number of vehicles needed to transport a given batch of goods, but also to reduce any possible tolls on public roads. Clearly, such conduct reduces the competitiveness of the transport services offered by other carriers [8].

For these reasons, road operators in most countries strive to eliminate overloaded vehicles from the traffic. The publication [9] indicated that in Switzerland single axle loads are exceeded in 10% of cases and a conclusion was drawn about a similar scale of single axle loads exceedances in the UK. Publication [10] presents data on the overloads of vehicles of particular categories in Portugal for several years, indicating over 20% shares of overloaded vehicles in some classes (*e.g.* tractors with semi-trailers with 5 and 6 axles). The results of stationary weighing presented in [11] indicate, however, a much higher share of overloaded vehicles on national roads in Portugal. According to [12], in Malaysia, the share of vehicles whose weight exceeds the allowable limit is 21.5%. On the other hand, the report [13] states that in Slovenia the share of overloaded vehicles is 10.3% on motorways and 15.3% on national roads. In turn, the results of research conducted on the roads of Bosnia and Herzegovina indicate a 24.2% share of overloaded vehicles [14]. In the paper [15], it was indicated that the share of overloaded vehicles in Poland ranges from 6 to 16.5% depending on the location of the checkpoint.

One of the commonly used ways of limiting the traffic of overloaded vehicles is the installation on the road network of Weigh in Motion stations (WIM stations) operating in continuous mode. These stations categorize all passing vehicles, record axle loads, determine the gross weight of the vehicle and pre-select potentially overloaded vehicles. In Poland, based on this preselection, the Inspectorate of Road Transport undertakes control activities and imposes appropriate fines in the event of an actual overload. However, this procedure requires additional static measurements.

The data obtained automatically at WIM stations allows the user to perform a variety of analyses. The paper [16] presents how to use axle loads and vehicle weights data to build models used in issues related to reliability of bridges. In the work [15] data from WIM stations were used to assess the impact of overloaded vehicles on fatigue life of flexible pavements. Vehicle classification carried out by WIM stations makes it possible to verify the generic structure of traffic and to determine the actual share of heavy vehicle. This information is necessary for balancing emissions of harmful exhaust compounds [17]. Data from WIM stations are also used for direct assessment of the level of environmental impact of road transport. Publications [9, 18] use for this purpose WIM stations equipped in addition with devices recording the level of ground vibration and the level of noise generated by passing vehicles. In [19], data from WIM station with simultaneously measured noise levels were used to develop a noise forecasting model taking into account the speed and gross weight of vehicles. Data from WIM stations were also used to analyze speeds of different categories of vehicles, *e.g.* in article [20] for HDV vehicles in free flow traffic. Sometimes WIM stations are located outside the motorways and allow other unusual applications, such as in the work [21], in which the occupancy rates for urban buses were determined. In addition WIM stations can be an integral part of other systems *e.g.* in China [22] there is a motorway toll system based on the weight of the vehicle. Weight measurement is carried out using the WIM system directly on the toll gate.

The system based on WIM stations is not free from disadvantages and restrictions. In most cases, HS-WIM are used, in which the load sensors are placed directly in the road lane and vehicles pass over them without significant speed reduction. This solution means that the measurement does not cause major disruption in motion. However, it is subject to considerable uncertainty, as dynamic phenomena occurring during the movement of the vehicle suspension mean that the axle loads change over time. At a speed of 80 km/h, the pressure changes on particular axles reach even 40% compared to static pressure [23]. Therefore, as mentioned, HS-WIM stations perform a preselection role - to be able to take administrative action concerning the driver of a vehicle identified by the station as being overloaded, the vehicle must be placed on a fixed scale by authorised services. However, these services do not work 24 hours per day and do not simultaneously operate in all locations (there are more than 100 WIM station on national road networks in Poland). The system's performance is additionally limited by the applicable procedures, which realistically allow checking only a few vehicles during an 8-hour shift. Moreover, due to the costs of installing HS-WIM systems, they are built primarily on the national road network. Thus, drivers of overloaded vehicles have the option of avoiding road sections where inspection patrols are currently working. As a consequence, this may lead to significant degradation of the surface of the alternative road networks. A sure solution would be to use a portable WIM system [24], but this solution requires calibration each time the system is set in a new location, which makes such operation not very effective. For lighter LCVs, one must take into account additional difficulties when attempting to detect an overload, including exceeding the permissible axle loads. In this category of vehicles, the maximum allowable axle loads are not related to the allowable road limits set by the road operator but are the result of the vehicle design and are usually specified by the manufacturer. Although the LCV overloading contributes slightly to the degradation of road infrastructure, it has a significant impact on reducing the overall level of traffic safety. Therefore, one could agree with the statement that HS-WIM technology alone, without ensuring appropriate legal regulations, is not an effective way to reduce the number of overloaded vehicles [22]. At the same time, in many countries, including Poland, work is underway, both in the construction of the HS-WIM stations and the amendment of legal provisions, aimed at creating HS-WIM systems enabling automatic enforcement.

This paper presents the results of the study indicating the limited in practice effectiveness of HS-WIM station in eliminating overloaded vehicles from traffic on national roads in Poland.

2 Methods

2.1 Study locations

The analyses presented in this work were carried out for data obtained from four HS-WIM stations located on national roads in Poland. Their location on the map of the national road network is shown in Figure 1. The stations are located on North-South roads. Stations 13 and 22 are located in the southern part of the country, in the foothill area with a relatively rare national road network, on-road sections directly connecting to the A4 motorway. Stations 58 and 59 are located in the northern part of central Poland, in an area with a denser network of national roads, on the section connecting to the A1 motorway. Table 1 contains basic data about the location of particular stations.

Table 1: Information on the location of the HS-WIM station

Number	Place	GDDKiA branch	Road No.	Geographical coordinates
13	Miechów	Kraków	DK7	50.371714N, 20.045422E
22	Kurów	Kraków	DK75	49.675509N, 20.663465E
58	Latkowo	Bydgoszcz	DK15	52.830481N, 18.312170E
59	Cierpice	Bydgoszcz	DK15	52.964796N, 18.537019E

2.1.1 Data collection

The analyses presented in the paper were made based on the automatically recorded measurements results, during the operation of the HS-WIM station in August 2018. Therefore, unless explicitly stated otherwise, vehicles indicated by particular HS-WIM stations will be considered as overloaded vehicles. The measurement period was selected taking into account the number of vehicles registered on road sections covering the selected locations of the HS-WIM station for one year. Data indicate that the largest traffic on the national road network occurs in August. At the same time, August is the month in which the highest number of road accidents is recorded [25]. The considerations were limited to vehicles of categories 9 and 11 according to the 8+1 classification developed by the German Federal Road Research Institute [26]. Category 9 includes HDVs, such as tractors with trailers, which is the most popular type of HDVs used in Poland in regional and international transport. Due to the significant permissible axle loads, these are vehicles whose overloading has a particularly negative impact on road infrastructure. LCV (up to 3.5 tonnes of permissible weight) belong to category 11. Therefore, they are vehicles commonly used in local transport of goods and people, which overload does not cause major damage to the infrastructure of national roads, but significantly affects the level of safety and distorts competitive integrity.

Figure 2 shows the typical configuration of the HS-WIM stations used for collecting measurement data in Poland. The basic components of the WIM system are:

– weight sensors built into the road surface for measuring single axle load, multi-axle load and gross vehicle weight,

Figure 1: Location of HS-WIM station on the map of national roads (map source: Google Maps)

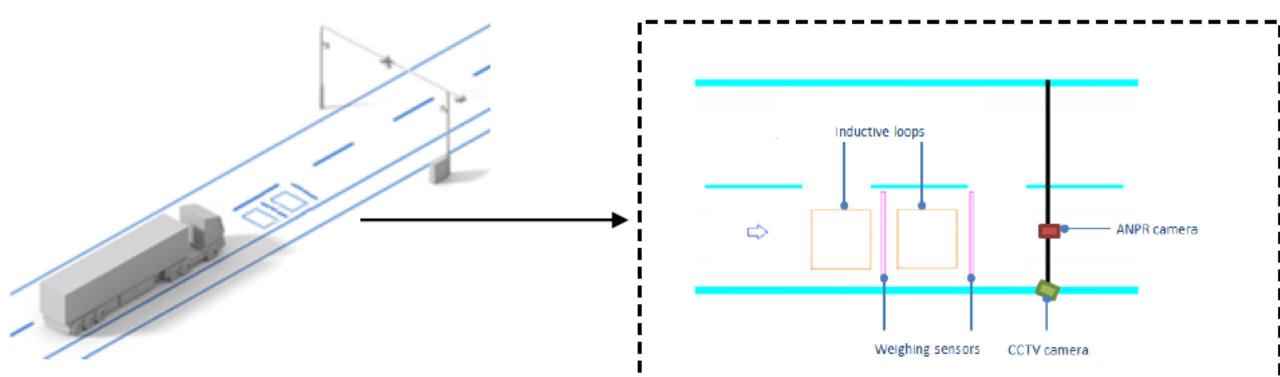

Figure 2: Diagram of an HS-WIM station (source: based on https://apm.pl/systemy/wim/)

Table 2: Number of category 9 and 11 vehicles registered by selected HS-WIM stations during the measurement period

Station	13 Miechów	22 Kurów	58 Latkowo	59 Cierpice
The number of cat. 9 vehicles	21069	14310	28766	29612
Including the number of cat. 9 vehicles with at least 5 axles	13268	8735	22460	18764
The number of cat. 11 vehicles	24829	34467	73958	33305

Table 3: Descriptive statistics for the gross weight of overloaded category 9 vehicles

Station	Max [kg]	Percentile 25 [kg]	Median [kg]	Percentile 75 [kg]	Average value [kg]	Standard deviation [kg]
13 Miechów	56539	40539	41194	42013	41366	2106
22 Kurów	54733	40513	41075	41725	41087	2440
58 Latkowo	57750	40160	40410	40980	41069	2591
59 Cierpice	57530	40450	40980	41730	41246	1438

– automatic number plate recognition cameras (ANPR), day/night view cameras to record a colour image of each detected vehicle (CCTV), sensors to measure the height and length of vehicles, and structures to support additional equipment (gantries/booms),
– inductive loops to measure speed and generate a trigger signal,
– telecommunications facilities with electronic controls.

HS-WIM stations are often equipped with additional elements, including road weather stations.

The stations listed in Table 1 work in B+(7) accuracy class, which means that they measure the gross weight with an accuracy of 7%, single axle load up to 11%, axle load in the group up to 14% and axle group up to 10% [27].

3 Results

Table 2 shows the total number of vehicles of both categories registered by selected HS-WIM stations during the measurement period.

In Table 2, category 9 includes isolated articulated vehicles with at least 5 axles because, according to Polish regulations in force since January 1, 2017 [28], among other things, the permissible vehicle weight depends on the number of axles. The weight of 4-axle articulated vehicles can be 36000 kg (38000 kg after additional construction conditions are met, or 35000 kg for a 3-axle tractor), while articulated vehicles with 5 or 6 axles can reach 40000 kg (42000 or 44000 kg in intermodal transport, with the first value being for 2-axle tractors and the second for 3-axle tractors).

In the following part of the article, for the sake of greater clarity, the data obtained for category 9 will be presented before category 11.

Table 3 presents the basic descriptive statistics concerning the overloaded gross weight of category 9 vehicles for particular HS-WIM stations. Therefore, the table only includes vehicles indicated by the system as overloaded. Descriptive statistics concerning the daily shares in traffic of overloaded category 9 vehicles due to the gross weight at particular stations determined for the entire measuring period are given in Table 4. Table 5 contains similar statistics regarding daily traffic shares in overloaded category 9 vehicles due to the axle loads.

The data in Table 3 indicate that in most cases the exceedances of gross weight in category 9 vehicles are relatively small. The highest 75th percentile value of 42010 kg was recorded for station 13. This value is 5% higher than the permissible weight of most category 9 vehicles. In turn, the maximum weight of category 9 vehicles recorded at all stations significantly exceed 54000 kg, reaching up to 57750 kg. So these exceedances are over 40%. The analysis of the results presented in Tables 4 and 5 also shows that gross weight exceedance was more often indicated than

Table 4: Descriptive statistics concerning the daily shares in traffic of overloaded category 9 vehicles due to their gross weight

Station	Max	Percentile 25	Median	Percentile 75	Average value	Standard deviation	Coefficient of variation
13	18.4%	11.3%	12.3%	13.6%	12.5%	2.4%	19.1%
22	24.8%	11.4%	15.7%	19.0%	15.0%	5.5%	36.6%
58	8.0%	5.1%	5.9%	6.9%	5.6%	1.7%	30.5%
59	13.9%	8.7%	9.2%	10.2%	9.3%	1.8%	19.0%

Table 5: Descriptive statistics concerning the daily shares in traffic of overloaded category 9 vehicles due to their axle loads

Station	Max	Percentile 25	Median	Percentile 75	Average value	Standard deviation	Coefficient of variation
13	11.6%	3.9%	4.5%	5.5%	5.1%	2.0%	39.2%
22	3.1%	0.4%	1.0%	1.9%	1.1%	0.8%	77.0%
58	2.9%	1.4%	1.7%	2.1%	1.8%	0.5%	30.7%
59	4.7%	2.9%	3.4%	4.0%	3.4%	0.7%	20.0%

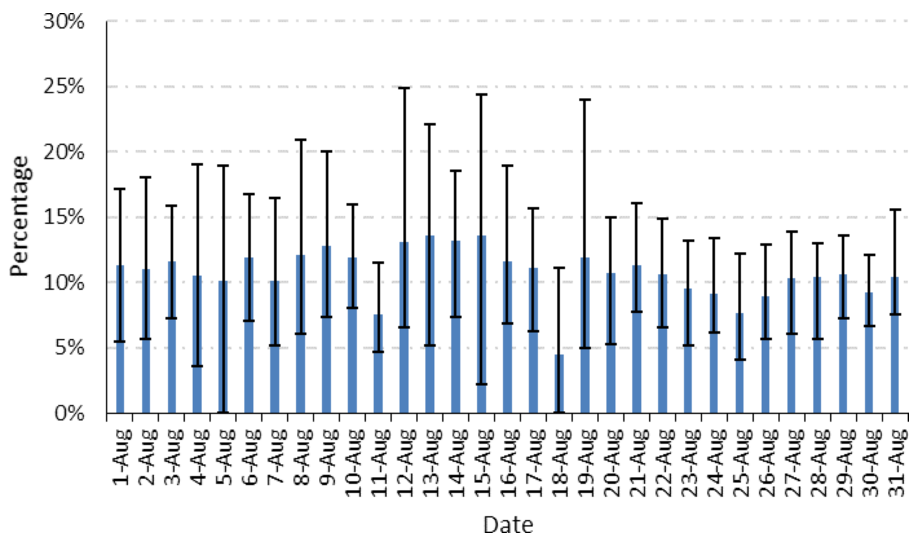

Figure 3: Shares of overloaded category 9 vehicles due to the gross weight, averaged for all stations, on particular measurement days (whiskers represent the minimum and maximum values)

axle loads. The maximum values of daily shares in the traffic of vehicles overloaded due to weight were 8÷24.8% depending on the station, whereas for the axle loads it was 2.9÷11.6%.

Figure 3 presents in the form of bars the percentage shares of overloaded category 9 vehicles due to the gross weight, averaged for all stations, on particular measurement days, together with the recorded minimum and maximum values. Similarly, Figure 4 presents the percentage shares of overloaded category 9 vehicles due to axle loads.

Then the percentage share in the traffic of overloaded category 9 vehicles in particular hours of the day was determined. To this end, the results of the measurements were aggregated on an hourly basis for the entire measurement period, separately for each HS-WIM station. Figure 5 presents graphs including all overloaded category 9 vehicles. In order to better illustrate the hourly dependencies, data from hours where heavy vehicle traffic restrictions occur (selected hours on Saturdays, Sundays and public holidays) were removed from the dataset. The graphs show: mean value (horizontal line), 25th, 75th percentile (box boundaries) and 10th and 90th percentile (whiskers).

In the case of vehicles of category 11, it was limited to the analysis of exceeding the permissible gross weight. Exceeding axle loads in this category of vehicles do not have a significant impact on the destruction of road infrastruc-

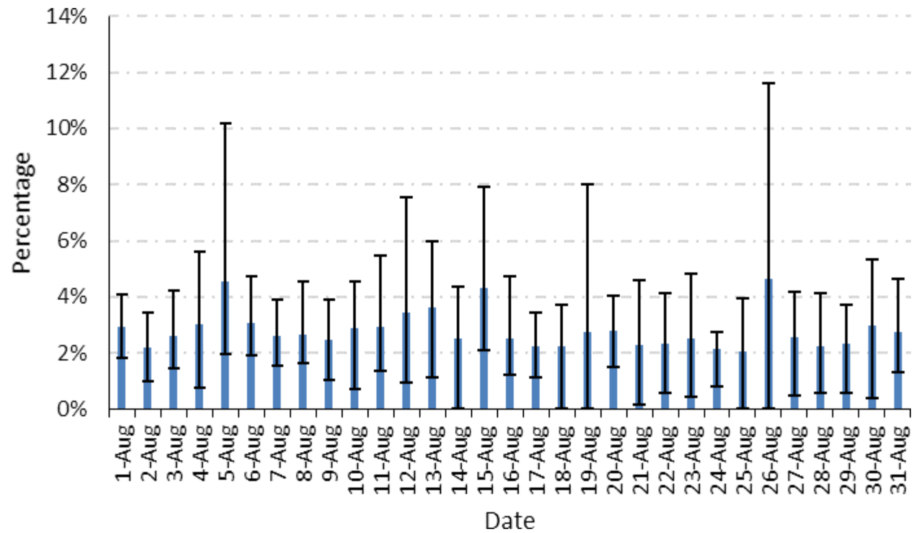

Figure 4: Shares of overloaded category 9 vehicles due to the axle loads, averaged for all stations, on particular measurement days (whiskers represent the minimum and maximum values)

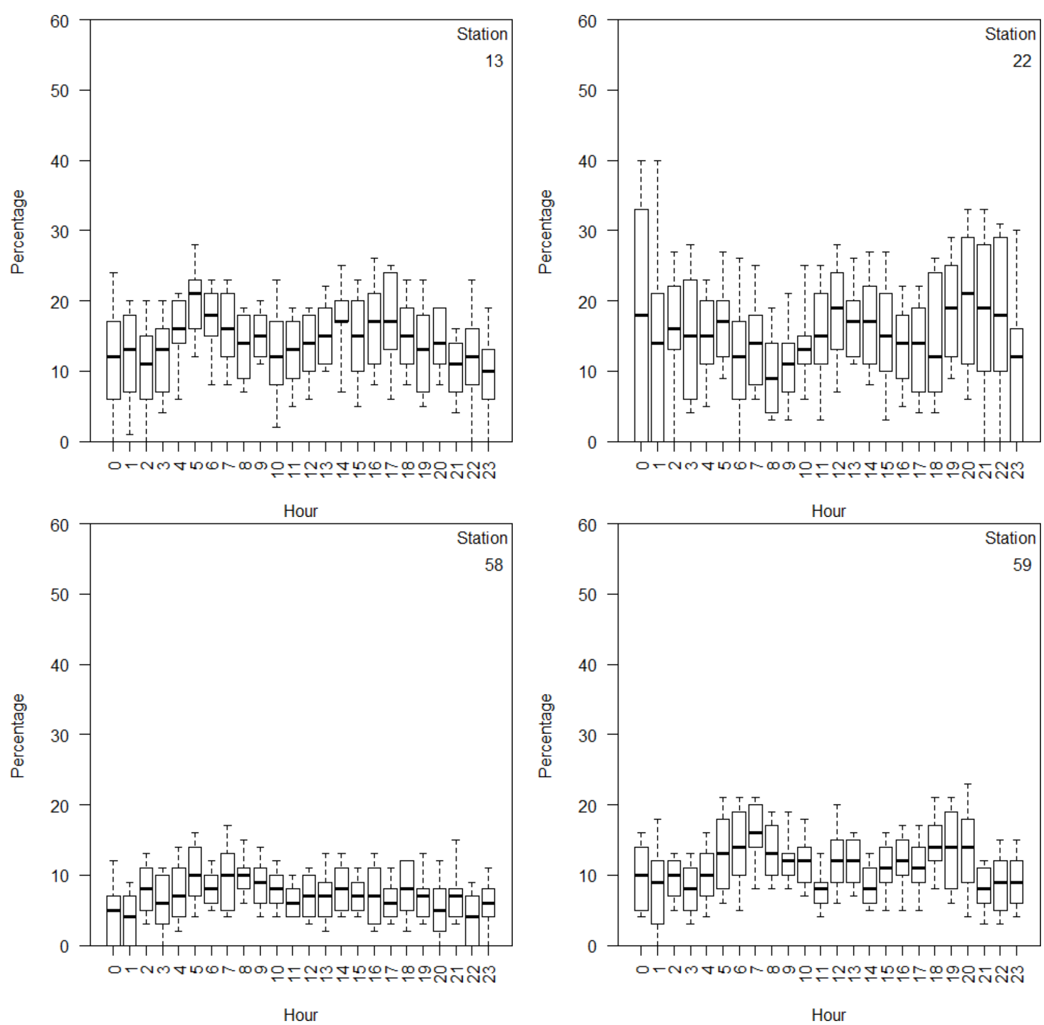

Figure 5: Percentage of overloaded category 9 vehicles in the following hours of the day for particular HS-WIM stations

Table 6: Descriptive statistics for the weight of overloaded category 11 vehicles

Station	Max [kg]	Percentile 25 [kg]	Median [kg]	Percentile 75 [kg]	Average value [kg]	Standard deviation [kg]
13	7465	3682	3941	4376	4126	616
22	7492	3705	4039	4768	4376	886
58	7420	3680	3930	4320	4103	587
59	7330	3646	3859	4275	4053	564

Table 7: Descriptive statistics concerning daily shares in the traffic of overloaded category 11 vehicles

Station	Max	Percentile 25	Median	Percentile 75	Average value	Standard deviation	Coefficient of variation
13	19.8%	14.8%	15.9%	17.0%	15.6%	2.0%	13.1%
22	13.8%	8.7%	12.0%	12.8%	10.8%	3.0%	28.0%
58	11.3%	4.8%	9.0%	9.8%	7.9%	2.8%	34.9%
59	13.9%	7.1%	10.3%	12.3%	9.5%	3.4%	35.9%

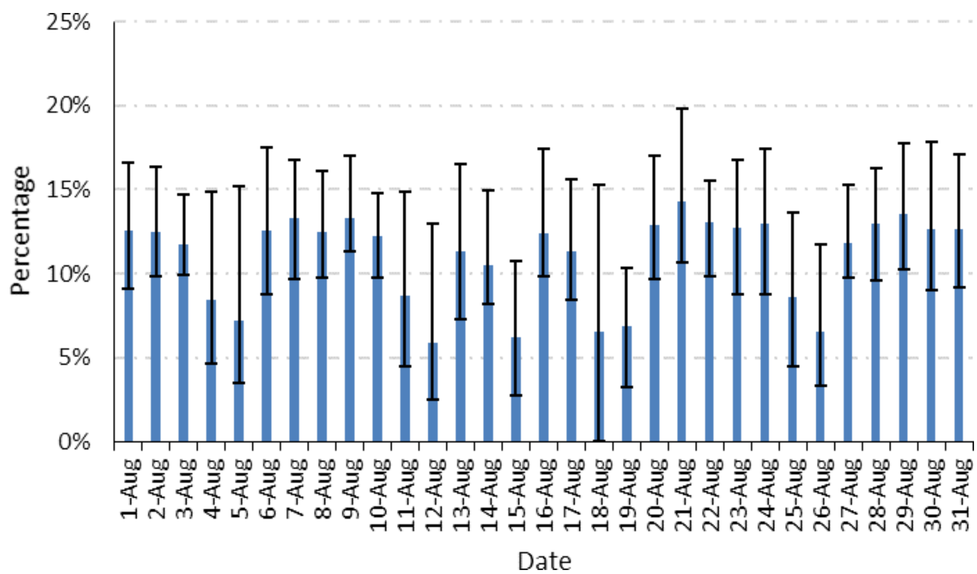

Figure 6: Shares of overloaded category 11 vehicles averaged for all stations, on particular measurement days (whiskers represent the minimum and maximum values)

ture. In addition, the exceedances in this area usually relate to the maximum construction loads (specified by the vehicle manufacturer), which vary considerably depending on the model. At the current stage of development, HS-WIM systems do not have access to this type of data. Table 6 presents the basic descriptive statistics regarding weight of the overloaded category 11 vehicles for particular HS-WIM stations; in Table 7 – descriptive statistics in relation to daily traffic shares of overloaded category 11 vehicles; Figure 6 – percentage shares of overloaded category 11 vehicles averaged for all stations on particular measurement days with the minimum and maximum values recorded; Figure 7 – percentage shares of category 11 vehicles with the exceeded gross weight in subsequent hours of the day of the measurement period.

Because there is an objective difficulty in the correct categorization of LCVs (the topic will be developed in the "Discussion" chapter), an additional analysis of the gross weight exceedances in the hourly system was conducted. This time, however, 3750 kg was used arbitrarily as the threshold for exceeding the gross weight. The appropriate graphs are shown in Figure 8.

The presented results indicate that the scale of overloads of category 11 vehicles is larger than for category 9

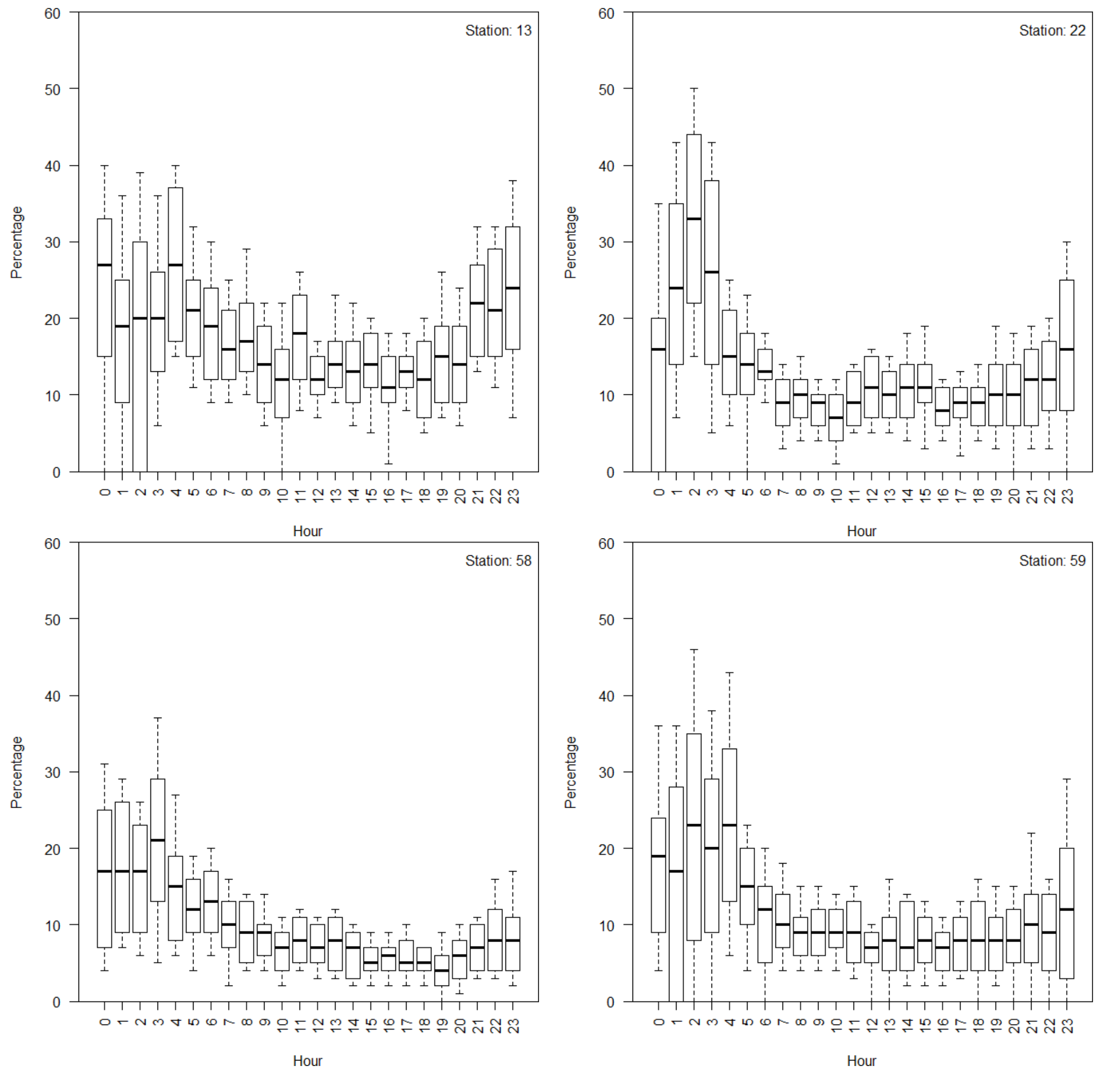

Figure 7: Percentage of category 11 vehicles with the exceeded gross weight in subsequent hours of the day of the measurement period for particular HS-WIM stations

vehicles. During some hours of the day, the average share of overloaded vehicles in this category fluctuates around 30%. These are also greater overloads in the context of the exceeding of the permissible weight. Even after adopting a higher threshold for exceeding the permissible gross weight, the maximum shares of overloaded vehicles for night hours were on average a dozen or so percent, and the maximum for three stations significantly exceeded 30%.

4 Discussion

The measurement results presented in this article come directly from selected HS-WIM stations located on national roads in Poland. This is important because the purpose of the article was to show the real limitations of the effectiveness of the elimination system of overloaded vehicles based on HS-WIM stations. Therefore, there will be some inconveniences, *e.g.* lack of data in short periods. For example, this case occurred for station 22 on August 18, which was reflected in the graphs in Figure 3, 4 and 6 in the form of zero minimum value of the share of overloaded vehicles. However, because the authors operate primarily with aggregated values of the share of overloaded vehicles concerning all vehicles in a given category, the general trends should not be significantly disturbed due to this.

Analysing the results obtained, it is possible to formulate theses regarding the effectiveness of the HS-WIM station system. They are discussed below as the following sections.

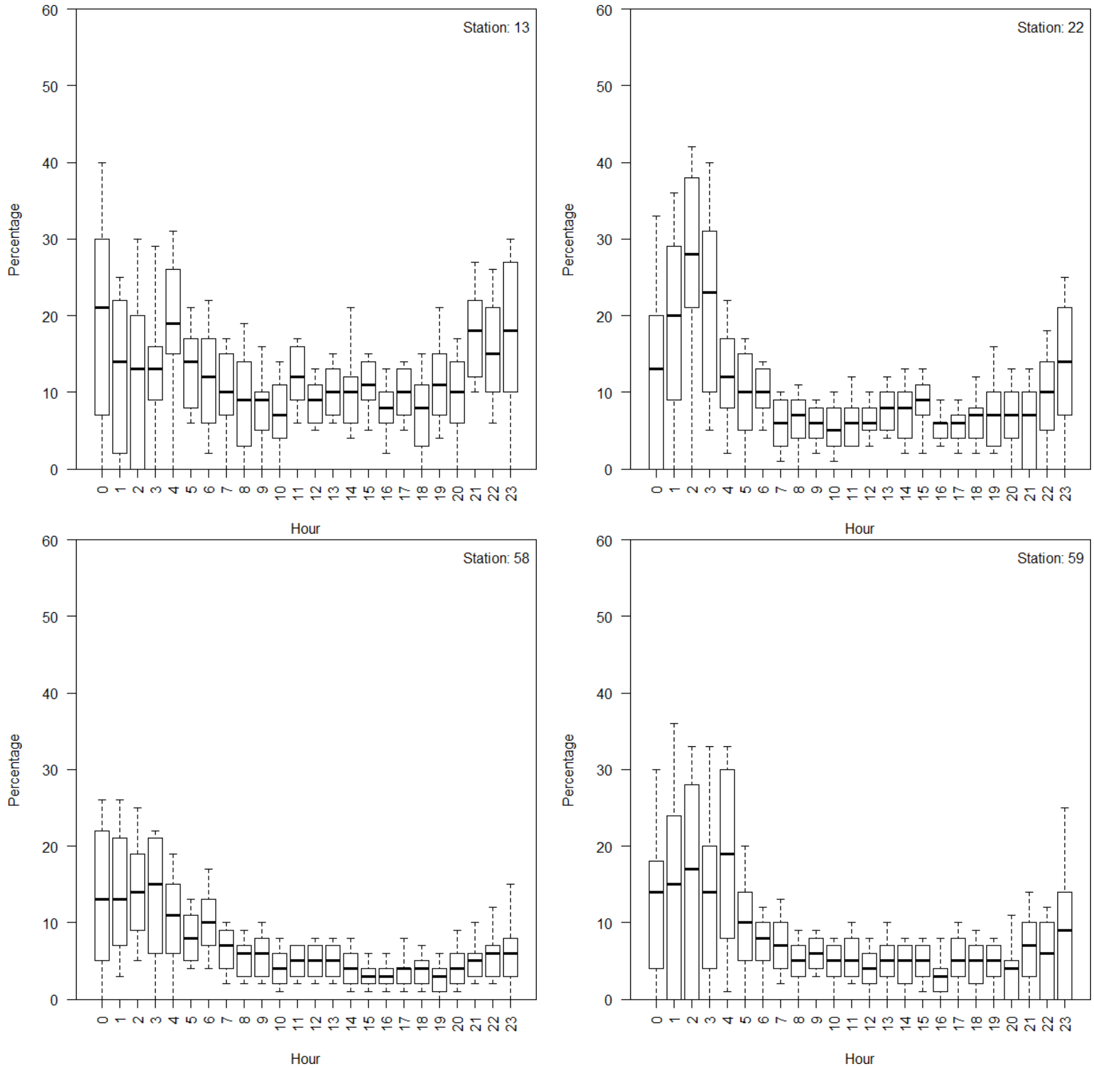

Figure 8: Percentage of category 11 vehicles with gross weight greater than 3750 kg in subsequent hours of the day of the measurement period for particular HS-WIM stations

4.1 Location of the station

A characteristic feature of the HS-WIM station is their permanent location known to road users. The question is therefore whether drivers do use this knowledge to bypass stations. To attempt to answer this question, the location of particular HS-WIM stations should be analysed (Figure 2) and related to *e.g.* the results presented in Tables 4 and 6. The stations in Miechów (No. 13) and Kurów (No. 22) are located in an area with a relatively scarce national road network. Bypassing them along main (national) roads in regional or national transport is difficult. A completely different situation is with the location of the stations in Latkowo (No. 58) and Cierpice (No. 59), in the vicinity of which there are numerous connections of national roads. Drivers in this area have much more freedom in choosing the route. Analysing the data from Table 4 regarding the exceeded weight of category 9 vehicles, it can be seen that indeed a significantly higher number of offences were recorded at stations 13 and 22. This phenomenon can also be observed by analyzing the gross weight distribution of category 9 vehicles for particular WIM stations (Figure 9). For stations 58 and 59, vehicles with a total gross weight ranging from 39000 to 40000 kg, whereas for stations 13 and 22, the most numerous groups are vehicles weighing from 40000 to 41000 kg. These differences in the total gross weight distribution confirm the hypothesis that some drivers of overloaded vehicles choose available alternative routes.

A similar trend, but with less variation, can be seen for category 11 vehicles. This is understandable because category 11 vehicles are usually used for local transport and it

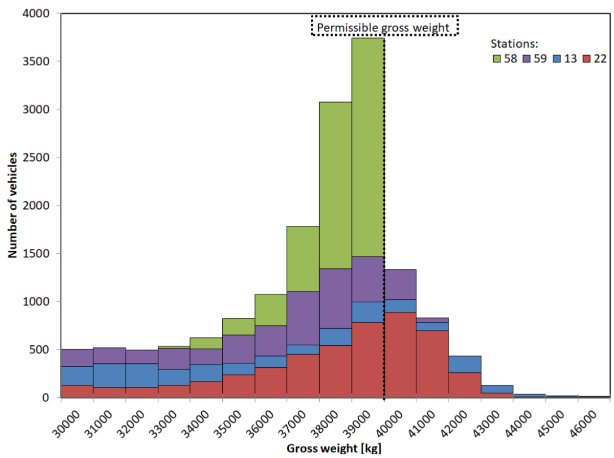

Figure 9: Gross weight distribution of category 9 vehicles for particular WIM stations

is not always cost-effective to choose an alternative route. The problem of avoiding WIM stations can be minimized by planning their deployment on the road network. The optimization of WIM stations location in the road network is the subject of consideration, *e.g.* in the works [14, 29].

4.2 Working hours of the Inspectorate of Road Transport

As mentioned in the introduction, in Poland the HS-WIM stations have only a pre-selective role for now. Administrative actions can be taken by the Road Transport Inspectorate only after taking static measurements. The problem, however, are the working hours of Inspectors – they usually work one shift per day. Therefore, in the evening and at night, the system for eliminating overloaded vehicles on national roads practically does not work. Drivers know that outside the working hours of the Inspectors they can drive overloaded vehicles on national roads with a marginal risk of detecting an offence. In this context, the results obtained for category 9 vehicles may be a surprise. It is difficult, while analysing the graphs in Figure 5, to indicate a clear relationship between the percentage of overloaded category 9 vehicles and the time of day. At most, one can indicate a moderate decrease in the number of overloaded vehicles between 8 am and 11 am occurring in the case of three stations. The situation is completely different in the case of category 11. Figure 7 and 8 clearly show a significant increase in the share of vehicles overloaded outside the working hours of the Inspectorate of Road Transport, approximately from 7 p.m. to 6 a.m. The observed distribution differences for categories 9 and 11 can be explained in this way that category 9 vehicles are mainly used in regional and international transport, while category 11 vehicles are used in local transport. In the case of transport over considerable distances, it is difficult to plan the journey time to avoid crossing a specific point on the route at certain times. The route depends here on many other, more important factors, *e.g.* the date of receipt and delivery of goods, driving possibilities resulting from the provisions on the working time of drivers, etc. In local transport, where the travel time is much shorter, there is a greater chance to avoid passing through the HS-WIM station during the working hours of the Inspectorate of Road Transport.

4.3 Non-working days

Analysing the results presented in Figure 6, it can be seen that the percentage of overloaded LCVs (category 11) in traffic decreases on non-working days. Apart from weekends, this decline is also noticeable on August 15, which is a public holiday in Poland. This phenomenon can be connected to the fact that on non-working days local transport related to such sectors of the economy as construction or trade virtually disappears. And it is mainly vehicles that carry out orders for these fields that can be overloaded, in contrast to vehicles that carry passengers. However, in the case of category 9 vehicles, the percentage of overloaded vehicles does not depend on the type of day (holiday, working day).

4.4 Uncertainty about vehicle categorization, in particular regarding LCVs

In Poland, depending on the HS-WIM station class, the General Directorate for National Roads and Motorways has different requirements regarding the accuracy of categorization, with the level of accuracy varying for different categories of vehicles [27]. Each company supplying measuring equipment for HS-WIM stations may apply its original vehicle categorization algorithms. The algorithms take into account such parameters as the vehicle's magnetic profile, weight, number of axles and distance between them, sometimes additionally the load on the first axle. The obtained level of accuracy is checked by an expert who verifies the categorization based on the analysis of images from the HS-WIM station. This method is effective for most vehicles and categories. However, some cause serious difficulties. These are LCVs, as well as vehicles from the SUV, SAC-SUV and similar commercial segments. LCVs, how-

Table 8: Basic parameters of Iveco Daily vehicles in van version (Iveco materials [30])

Wheelbase [mm]	Vehicle length [mm]	Load compartment length [mm]	Load compartment width [mm]	Height/load volume H1 (1545 mm)	H2 (1900 mm)	H2 (1900 mm)	Gross vehicle weight (tons) Min.	Max.
3000	5080	2610	1800	7.3 m^3			3.5	3.5
3520	5600	3130	1800	9 m^3	10.8 m^3		3.5	5.2
	6000	3540	1800		12 m^3	13.4 m^3	3.5	5.2
4100	7170	4680	1800		16 m^3	18 m^3	3.5	7
	7540	5125	1800		17.5 m^3	19.6 m^3	3.5	7

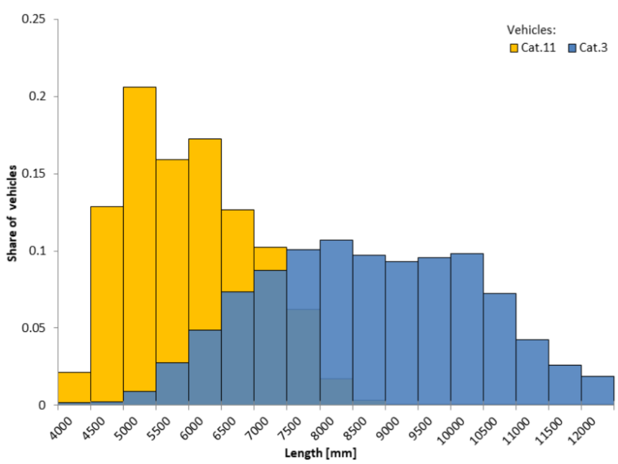

Figure 10: Length distribution of category 3 and 11 vehicles

ever, are particularly troublesome due to their large numbers and construction diversity. Often, even when viewing an image of a vehicle, it cannot be 100% categorized in a specific category. Depending on the maximum gross weight, it should be classified in category 11 (delivery vehicles up to 3.5 tonnes) or category 3 (rigid trucks). How difficult, in principle impossible, is the correct categorization of this type of vehicles by currently operating HS-WIM stations is demonstrated by the design diversity of the Iveco Daily – see Table 8. For example, for vehicles with 4100 mm wheelbase with the same external dimensions, the permissible gross weight can vary widely from 3500 kg to 7000 kg. At the same time, depending on the solution used, the maximum front axle load on this vehicle is between 1900 and 2700 kg.

This is also confirmed by the length distribution of category 3 and 11 vehicles registered in the particular WIM stations (Figure 10). This distribution shows a significant proportion of vehicles with lengths between 6000 and 7500 mm for both LCVs and lorries. The classification of these vehicles is relatively difficult and very often it is fraught with significant errors.

5 Conclusion

The measurement results provided in this article confirmed that in Poland, as in other countries, the share of overloaded vehicles in traffic is significant. According to the average data collected in the analysed period, the daily share of overloaded vehicles was over a dozen percent for both analysed categories.

Considerations presented in the paper are based both on the measurement results from four HS-WIM stations and discussions with the administrators of such systems. They point to significant restrictions on the effectiveness of the HS-WIM system in eliminating overloaded vehicles from traffic in Poland. These restrictions can be divided into three main types, resulting from:

- functional features of the HS-WIM station measuring system – here the most important is the measurement uncertainty resulting mainly from dynamic measurement (this uncertainty is also affected by other factors, *e.g.* atmospheric),
- organization of the process – location of HS-WIM stations known to drivers, control carried out during the working hours of Road Transport Inspectors,
- the difficulty of proper categorization of vehicles caused by extensive legal regulations, and above all the diversity of vehicle designs within the series of types (vehicle's maximum gross weight and axle loads largely depend on the suspension and wheels used – single, double, Super Single).

In many countries, work is underway on the development and implementation of automatic HS-WIM stations which indications would be sufficient for direct enforcement of overloaded HCVs [31]. Such a system would work similarly to a speed camera system. Automated HS-WIM systems would have to have significantly lower measurement uncertainty so that their readings could not be undermined by transport companies. The creation of automatic HS-WIM stations would free the system from some restrictions related to the organization of the elimination of overloaded vehicles from traffic – they could work 24/7. Problems related to the proper categorization of vehicles could be solved by adopting appropriate legal regulations, *e.g.* at the European Union level. All countries undoubtedly want to eliminate the overloaded vehicles from the traffic. There are also technical possibilities to provide information to the HS-WIM station enabling faultless categorization of vehicles. One solution would be to provide HS-WIM station access to the vehicle database based on the license plate read by ANPR cameras. The second solution could use stickers placed on the windscreen with coded data regarding the vehicle category, its maximum weight and axle loads. Both of the above suggestions seem relatively simple to introduce for vehicles of category 11 and other categories of heavy vehicles (3 – rigid trucks, 8 – trucks with trailers, 5 – buses), which burden the road infrastructure the most. For reasons such as safety, the diversity of design solutions and the resulting difficulties in proper categorization, it would be important to introduce such systems also for LCVs. As the last step, the system should cover category 7 vehicles (passenger vehicles), which overloads also significantly reduces the overall level of road safety.

Moreover considering the selected provisions from [28] cited in Chapter 3, it can be seen that within particular vehicle categories (including category 9) there are significant differences in permissible gross weight and axle loads. Since the number of vehicle axles and the distance between the axles (including axles in the group) is determined by HS-WIM stations, it is relatively easy to interpret the provisions related to these parameters. The legally permissible maximum weight and load values also depend on the type of tires (they are sometimes raised for Super Single tires), suspensions (pneumatic or equivalent according to [32]) or the type of transport carried out (intermodal). Determining some of this data by HS-WIM stations would require in most cases their expansion with new measurement systems (*e.g.* Super Single tire detection system). Others, like the type of suspension, are very difficult to automatically determine at the HS-WIM station with existing measuring methods. The problem of exceeding the permissible axle loads is even more complex for lighter vehicles, including those in category 11. LCVs do not exceed the permissible loads (specified by the legislator or road operator) but maximum, resulting from the construction and specified by the vehicle manufacturer. Currently, unfortunately, it is not possible to obtain this information in real-time at the HS-WIM station.

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