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# Assessment of the Possibility of Using Selected Statistic Tools for Testing Long-Term Stability of Weigh in Motion Systems

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**ABSTRACT**
The article presents selected statistical analyses of data registered by weigh in motion systems (WIM). Particular analyses are intended to determine the distribution of selected parameters and assess the possibility of using statistical measures to test the long-term stability of WIM stations. Dataset from the WIM system was the subject of the research. Dataset is using different measurement solutions and technology.

**KEYWORDS: weigh in motion, vehicle classification, long-term stability**

## 1. Introduction

A disturbing phenomenon observed on Polish roads are overloaded heavy goods vehicles which leads to rapid degradation of the road, in particular its pavement. It is estimated that with an average vehicle overload of only 20% the roads condition is reduced from 50 to 150% (assuming that such vehicles constitute 1/3 of all trucks). This means that this road should be renovated every 3 years instead of every 10 years. Moreover, the detection and exclusion from traffic overloaded vehicles improves road safety and limits excessive destruction of the pavement. In order to stop this unfavourable phenomenon, it is necessary to take preventive actions by permanently controlling, among others, gross weight and axel load of vehicles.

Preventive actions can be implemented through the use of WIM system (Weigh-in-motion). The main task of the WIM system is to detect and register violations of the vehicle gross weight and axle loads, as well as:

- protection of roads against their destruction by overloaded vehicles,
- elimination overloaded vehicles from traffic,
- improvement of road safety,
- preventive impact on drivers related to permissible vehicles parameters.

Such system supports the work of the Inspection Service authorized to control and supervise traffic. The role of the WIM system is to disclose overloaded HGV and notify authorized control services. The WIM system should be localized mainly on roads with intensive HGV traffic. The detection of an overloaded vehicle occurs while it is moving along the road without stopping it (High Speed WIM). However, it should be taken into account that the higher the speed of the vehicle, the lower the accuracy of the measurement. WIM systems enable pre-selective weighing of vehicles up to 160 km/h. The WIM system sends a signal to the control services within a few seconds after the measurement is made. WIM data include following information:

- vehicle data that allow its identification (photo),
- date, time of the event,
- acceptable weight values,

- plate number type and class of vehicle,
- vehicle gross weight,
- axle and wheel load,
- vehicle speed.

Based on the above information, the Inspection Services stop the vehicle for accurate measurements done with the use of certified devices. The results of precise measurements allow to take relevant decisions related to vehicle ban until it is unloaded. Moreover, against the Carrier is initiated administrative proceedings which, in accordance with the applicable regulations, result in an administrative penalty.

What's more data form WIM system can be used to conduct multi-criteria analyses and statistics. Examples of basic statistics can be:

- average vehicle speed as a function of time in relation to the vehicle class,
- number of vehicles with a certain range of gross weight as a function of time,
- intensity of vehicle traffic as a function of time in relation to the type of vehicle,
- axle load as a function of time.

An important element of the WIM is the accuracy and long-term stability of measurement systems. The type and technical class of the sensors and devices determine the efficiency and reliability of the measurements. Apart from weight calibration procedure, significant factor is also the long-term stability and the use of measures and indicators that enable verification of the correct operation of the system. The WIM system should be developed and constantly modified using the latest technologies and technical solutions to improve the work of authorized inspection services.

# 2. Weigh-in-motion (WIM) systems

Typical WIM system consists of several basic modules:

- module for measuring the weight, speed and class of the vehicle
- a set of axle load sensors,
- a set of loop sensors - for vehicle classification,
- a set of cameras, e.g. ANPR, CCTV - for the visual identification of vehicles, including recognition of the vehicle plate number.

The following paragraphs of the paper describe selected technologies of axle load sensors which are the elementary part of the weighing system.

## Bending plates

The bending plates are made of two elements: a metal frame mounted in the road pavement and a metal plate placed flush with the road surface. The plate deforms under the load of a passing vehicle. The length of the plate is about 1.75 m, so two sensors can cover a full 3.5-meter roadway. Depending on the type of surface (asphalt or concrete), the system can be installed within 1 day (concrete surface) or within 3 days (bituminous surface or thin concrete surface) [1]. An example of a bending plate is shown in Fig. 1.

**Fig. 1. Bending plate [own study]**

## Quartz sensors

In quartz systems a simple piezoelectric effect is used, which is based on the induction of electric charge on the surface of the dielectric as a result of mechanical forces. Quartz sensors are mounted flush with the road pavement, thanks to which the wheel has direct contact with the sensor [1]. An example of a solution based on quartz sensors is shown in Fig. 2.

**Fig. 2. Quartz sensors [own study]**

## Strain Gauge Load Cell Sensors

Linear strain gauges use resistance strain gauges that change their resistance due to deformation. Such a construction enables measurement of static loads and not only dynamic ones, as is in the case of sensors using a piezoelectric effect. Thus, the calibration process can be carried out using a static load. Linear strain gauges work effectively in a wide range of environmental conditions. Temperature compensation ensures the accuracy of strain gages in a very wide temperature range [2]. The sensors are manufactured in the following lengths: 1, 1.5, 1.75 and 2 m. Two sensors cover the full width of one lane. Examples of a set of strain gauge sensors are shown in Fig. 3.

**Fig. 3. Strain Gauge Load Cell Sensors [own study]**

# 3. Analysis of long-term stability

The presented in paper long-term stability tests were carried out based on data from six WIM stations. The location of the stations is shown in Fig. 4.

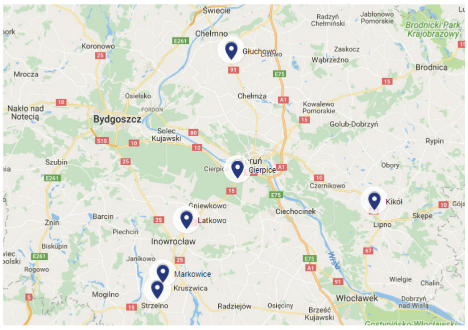


Fig. 4. Localization of selected WIM stations [own study]

Selected stations use axle load sensors made in the technology of bending plates, quartz sensors and strain gauges. A detailed description of the station together with basic traffic characteristics are presented in Table 1.

Table 1. Parameters of selected WIM station [own study]

| WIM station | Weight sensors | Class | Road type | Average daily traffic [veh. Per day] |
|---|---|---|---|---|
| Cierpice | Bending plate | B+(7) | Single carriageway with 2 lanes | 11743 |
| Latkowo | Bending plate | B+(7) | Single carriageway with 2 lanes | 11788 |
| Marowice | Strain Gauge Load Cell Sensors | B+(7) | Single carriageway with 2 lanes | 10528 |
| Strzelno | Strain Gauge Load Cell Sensors | B+(7) | Single carriageway with 2 lanes | 10528 |
| Głuchowo | Quartz sensors | B+(7) | Single carriageway with 2 lanes | 8224 |
| Kikół | Quartz sensors | B+(7) | Single carriageway with 2 lanes | 8757 |

As part of the analyses, the dataset was limited to four basic periods of the year represented by the following intervals:

- winter period: 01/01/2018 - 31/01/2018,
- summer period: 01/08/2017 – 31/08/2017,
- autumn period: 01/10/2017 - 31/05/2017,
- autumn period: 01/11/2017 - 30/11/2017.

In order to illustrate the weather conditions in Fig. 5 and 6 presented the average air temperature and the rain/snow intensity for particular days of the measurement periods. Meteorological data has been registered by a road weather station located in near the town Toruń.

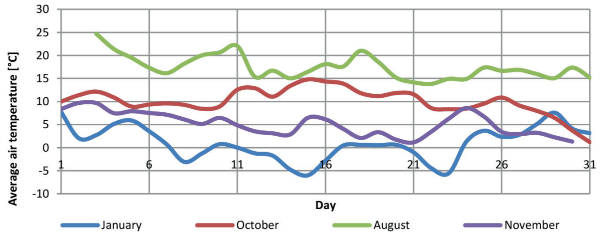


Fig. 5. Air temperature registered by weather station [own study]

The air temperature diagram (Fig. 5) indicates a large variety of conditions for data logging periods. In the winter period there were several times negative temperatures with an amplitude of -5 Celsius degrees. In the summer, the average daily temperature was around 18 degrees.

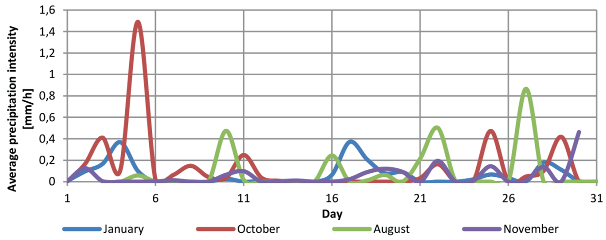


Fig. 6. Precipitations intensity registered by weather station [own study]

During the observations, a particularly intense rainfall was noted in the first few days of October and an increased amount of rainfall was registered in the last few days of August (Fig. 6).

## 3.1. Analysis of the first axel load distribution of tractors with semi-trailers

In the first step of the analysis was used the measure of first axle load of vehicles category 5 (according to the COST 323 classification [3]). This factor was defined as the measure with lowest variability and its characteristics are presented in work [4]. The set of vehicles, according to the guidelines, was selected in terms of gross weight, speed and the first axle load.

## Bending plate

As part of the first test, the mean load of the first axle of category 5 vehicles was determined for stations equipped with the bending plates. The results of the analyses are presented in Fig. 7 and 8.

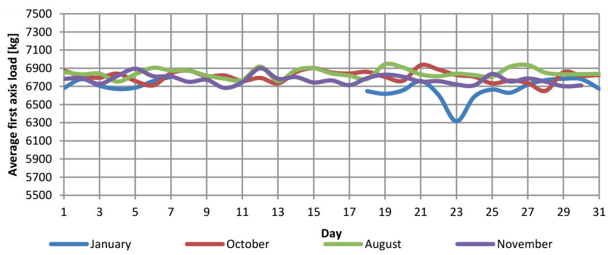


Fig.7. First axis load of tractors with semi-trailers in Cierpice [own study]

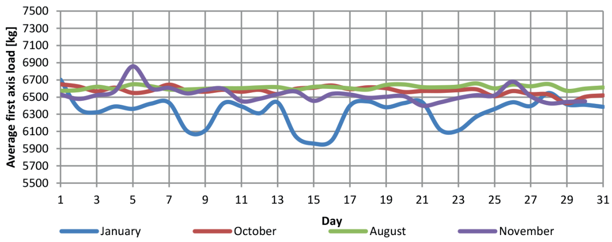


**Fig.8. First axis load of tractors with semi-trailers in Latkowo [own study]**

For the station located in Cierpice (Fig.7) and Latkowo (Fig. 8), during the observation a high variability of the recorded values for the winter period was noted. The overlapping of the local minimum with the average temperature drops below -5 Celsius degrees is particularly noticeable.

## Strain Gauge Load Cell Sensors

The test results for stations equipped with strain gauges are shown in Fig. 9 and 10.

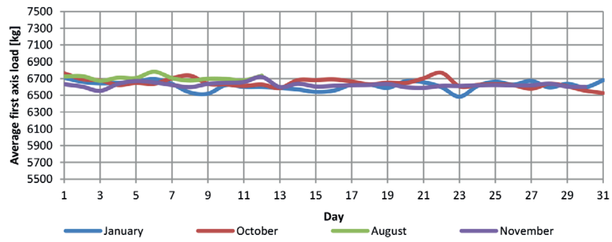


**Fig.9. First axis load of tractors with semi-trailers in Strzelno [own study]**

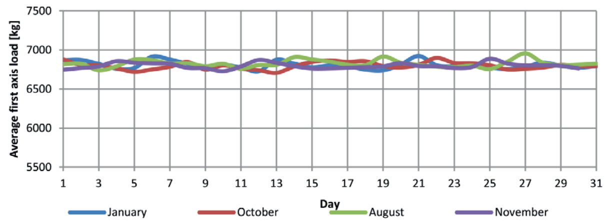


**Fig.10. First axis load of tractors with semi-trailers in Markowice [own study]**

For the Strzelno station (Fig. 9) and Markowice (Fig.10), no visible correlation between the temperature and the average value of the first axle load was observed. The influence of the rain/snow intensity on the analysed value was also unaffected. The local maximum for the Markowice station (Fig.10) for 27/08/2017 is most likely related to the reduced size of the data set, which results from the day with limited HGV traffic (Sunday).

## Quartz sensors

In the next step, the data was analysed for stations equipped with quartz sensors. Data register in Głuchowo station are shown in Fig. 11, while for Kikół station in Fig. 12.

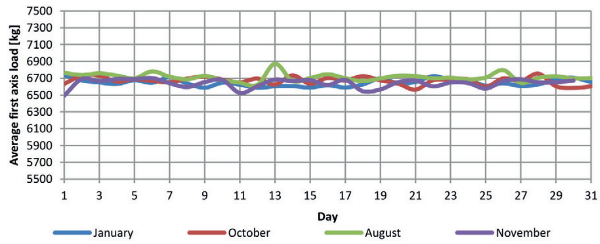


**Fig.11. First axis load of tractors with semi-trailers in Głuchowo [own study]**

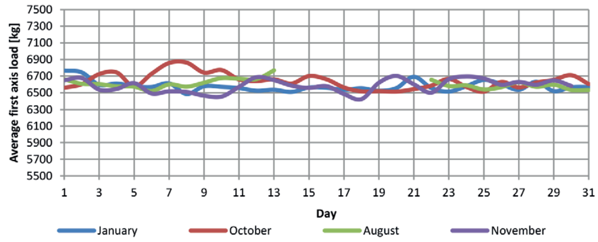


**Fig.12. First axis load of tractors with semi-trailers in Kikół [own study]**

For the Głuchowo station (Fig. 11) for August 13, 2017, observed the local maximum which could also be related to the day off (Sunday). For other periods, the average value was not significantly correlated with the temperature and intensity of precipitation. However, for Kikół station, increased values were recorded in the period from October 7 to October 11, i.e. subsequent weekend days, albeit occurring after a period of intense rainfall.

In order to summarize the test results, table 2 presents the mean values ($\mu_{nl}$) and standard deviation ($\sigma_{nl}$) for particular WIM stations.

**Table 2. The average load of the first axle of the cat.5 vehicle and the standard deviation [own study]**

| WIM station | Load sensors | January | October | August | November |
|---|---|---|---|---|---|
| Cierpice | Bending plate | $\overline{\mu}_{nl} = 6680$ $\sigma_{nl} = 106,1$ | $\overline{\mu}_{nl} = 6811$ $\sigma_{nl} = 61,14$ | $\overline{\mu}_{nl} = 6845$ $\sigma_{nl} = 50,37$ | $\overline{\mu}_{nl} = 6773$ $\sigma_{nl} = 52,03$ |
| Latkowo | Bending plate | $\overline{\mu}_{nl} = 6333$ $\sigma_{nl} = 167,14$ | $\overline{\mu}_{nl} = 6571$ $\sigma_{nl} = 45,65$ | $\overline{\mu}_{nl} = 6611$ $\sigma_{nl} = 23,45$ | $\overline{\mu}_{nl} = 6527$ $\sigma_{nl} = 87,43$ |
| Marowice | Strain Gauge Load Cell Sensors | $\overline{\mu}_{nl} = 6807$ $\sigma_{nl} = 49,1$ | $\overline{\mu}_{nl} = 6798$ $\sigma_{nl} = 46,38$ | $\overline{\mu}_{nl} = 6826$ $\sigma_{nl} = 47,18$ | $\overline{\mu}_{nl} = 6798$ $\sigma_{nl} = 36,96$ |
| Strzelno | Strain Gauge Load Cell Sensors | $\overline{\mu}_{nl} = 6616$ $\sigma_{nl} = 52,74$ | $\overline{\mu}_{nl} = 6647$ $\sigma_{nl} = 53,95$ | $\overline{\mu}_{nl} = 6708$ $\sigma_{nl} = 30,04$ | $\overline{\mu}_{nl} = 6623$ $\sigma_{nl} = 29,05$ |
| Głuchowo | Quartz sensors | $\overline{\mu}_{nl} = 6646$ $\sigma_{nl} = 41,83$ | $\overline{\mu}_{nl} = 6668$ $\sigma_{nl} = 47,26$ | $\overline{\mu}_{nl} = 6713$ $\sigma_{nl} = 48,37$ | $\overline{\mu}_{nl} = 6639$ $\sigma_{nl} = 53,7$ |
| Kikół | Quartz sensors | $\overline{\mu}_{nl} = 6580$ $\sigma_{nl} = 64,04$ | $\overline{\mu}_{nl} = 6642$ $\sigma_{nl} = 94,25$ | $\overline{\mu}_{nl} = 6605$ $\sigma_{nl} = 57,91$ | $\overline{\mu}_{nl} = 6584$ $\sigma_{nl} = 77,58$ |

## 3.2. Analysis of the first axel load distribution of cars

The next part of the research was the assessment of the possibility of using the average load of the first axle of passenger cars (category 1 according to COST 323 [3]). The rationale for the use of the above measure is the size of data sets, which in the case of the analysed values reached levels nearly 10 times higher than in the case of the tests presented in Chapter 3.1. The basic assumption was to limit the dataset to vehicles with a total weight below 1.8 tonnes.

## Bending plate

The results of the axle load analysis for stations using bending plates are presented in Fig. 13 and 14.

As in the case of the analysis of the first axle load of category 5 vehicles, during the winter, observations showed a visible dependence of the value of the load and the temperature. This visibility is particularly evident for the Latkowo station.

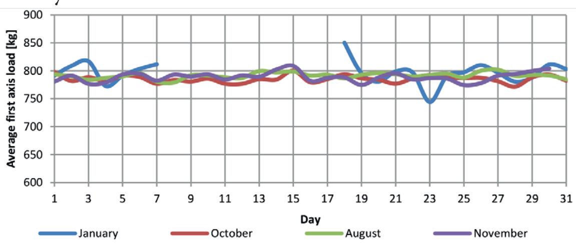


**Fig.13. First axis load of cars in Cierpice [own study]**

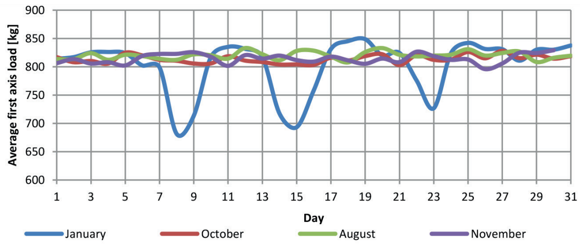


**Fig.14. First axis load of cars in Latkowo [own study]**

## Strain Gauge Load Cell Sensors

The test results of stations equipped with strain gauges are shown in Fig. 15 and 16. For the station located in Strzelno, local minimum values for the winter period were observed for 17 and 20 January. In the above days there were no significant disturbances in the size of the analysed sample of data and any local minima of temperature were recorded. On the other hand, in the 17th of January the intensity of precipitation decreased. This change is not visible at the indicator of average load of the first axle of category 5 vehicles.

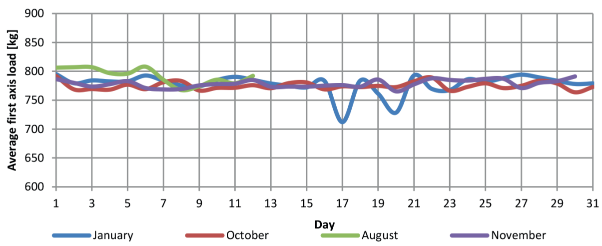


**Fig.15. First axis load of cars in Strzelno [own study]**

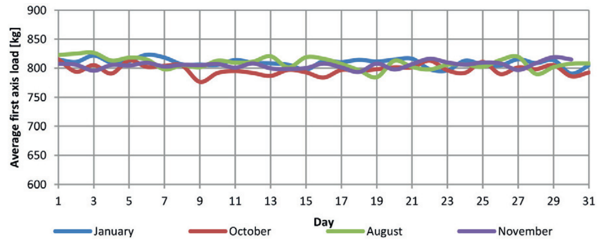


**Fig.16. First axis load of cars in Markowice [own study]**

The mean load indicator of the first axis for the Markowice station (Fig. 16) shows no correlation between the temperature and the rainfall intensity.

## Quartz sensors

The test results for the station which are using quartz sensors are shown in Fig. 17 and 18.

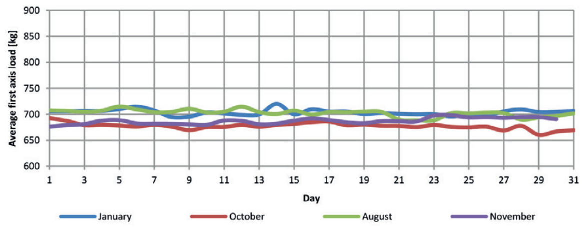


**Fig.17. First axis load of cars in Głuchowo [own study]**

For the Głuchowo station (Fig. 17) there was also no disturbance of the average load indicator of the first axle of passenger vehicles for winter periods. In the final period of the October, the value of the indicator was gradually falling. This phenomenon also occurred for the average day air temperature (Fig.5).

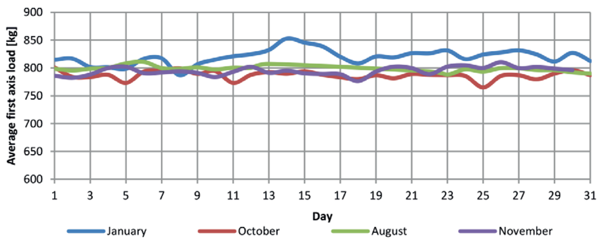


**Fig.18. First axis load of cars in Kikół [own study]**

For the Kikół station, the value of the indicator showed clear disturbances for the period January 12-17, i.e. the period with air temperature below zero, although this exchange is also not visible at the indicator of mean load of the first axle of vehicles category 5.

## 3.3. Analysis of the gross weight mass distribution of semi-trailers

The last element of the study was the analysis of the gross weight distribution of category 5 vehicles. This approach was presented in [5].

## Bending plate

For Cierpice (Fig. 19) and Latkowo (Fig. 20) stations equipped with bending plates, significant differences were found in the distribution for vehicles with a total weight of 40t. This is especially visible when comparing the winter and summer periods.

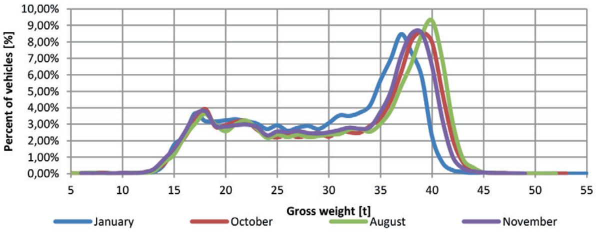


**Fig. 19. Gross weight of tractors with semi-trailers in Cierpice [own study]**

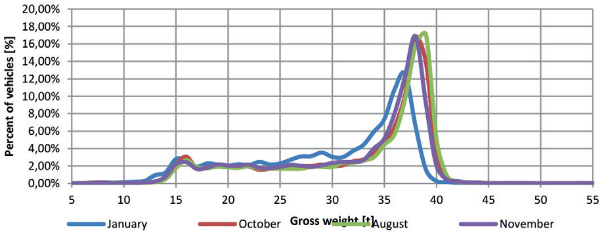


**Fig. 20. Gross weight of tractors with semi-trailers in Latkowo [own study]**

## Strain Gauge Load Cell Sensors

In the case of Strzelno station (Fig.21) and Markowice (Fig.22) equipped with strain gauge sensors, the observer a high degree of similarity of the distribution regardless of the measurement period.

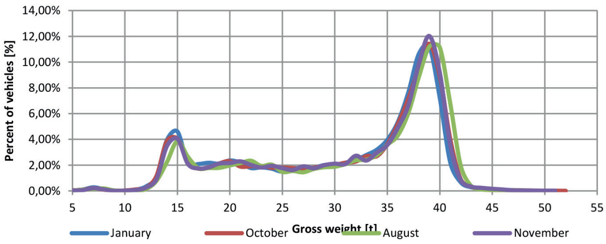


**Fig. 21. Gross weight of tractors with semi-trailers in Strzelno [own study]**

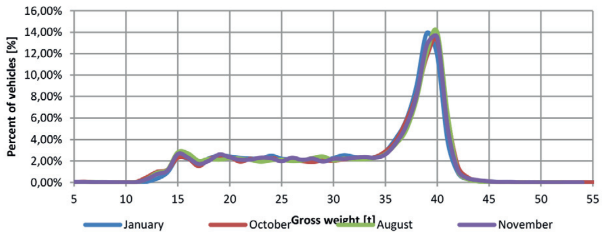


**Fig. 22. Gross weight of tractors with semi-trailers in Markowice [own study]**

## Quartz sensors

For stations equipped with quartz sensors, i.e. Głuchowo (Fig.23) and Kikół (Fig.24), there are slight differences between the distribution but without the possibility of indicating correlation of data and the winter and summer period.

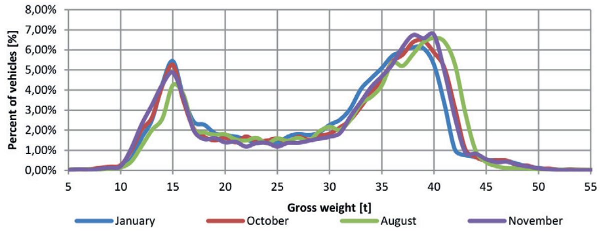


**Fig. 23. Gross weight of tractors with semi-trailers in Głuchowo [own study]**

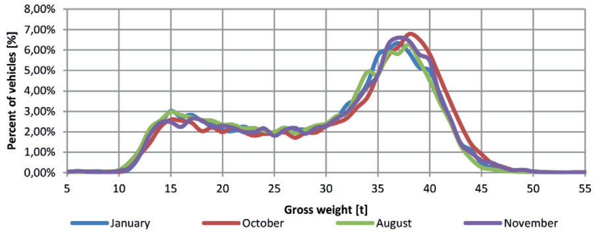


**Fig. 24. Gross weight of tractors with semi-trailers in Kikół [own study]**

# 4. Conclusion

The paper presents selected indicators of long-term stability of the weigh-in-motion stations. The widely recognized mean load indicator of the first axle of tractors with semitrailers was compared with the first axle load of passenger vehicles and gross weight distribution of category 5 vehicles. The above indicators were referred to three leading pressure sensor technologies. The presented approach is aimed at determining the applicability of selected measures to assess the stability of measurement systems. The obtained results indicate the potential usefulness of the described measures, although they require further work to determine the boundary conditions and the reasons for the deviations in the determined values.

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