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# The statistical dispersion of results of examination of selected vehicle subsystems tested in different technical inspection stations

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**Abstract.** The paper presents results of an experiment taken to find out if the results of examination of selected subsystems performed in many technical inspection station (TIS) for the same car will be different and what will be a statistical dispersion of obtained results. Obtained results show that sometimes the results of examinations in different TIS stations are very different. For example, obtained coefficient of variation (CV) for results of braking force measurements has a value of around 20%, for EUSAMA coefficient obtained CV has value about 8% and for air-fuel ratio ( $\lambda$ ) CV has a value over 60%. Some observations concerning also the correctness of examination procedures performed in tested TIS stations are presented in this paper. General conclusion for obtained results is that it is reasonable to require periodical technical inspections for test stands used in technical inspections stations.

## 1. Introduction

In compliance with the Polish legal requirements, periodical checks of vehicle's technical condition are performed in technical inspection stations. Inspections are conducted by authorized diagnostic technicians who completed a specialized training and passed a relevant state exam [1]. In the course of a vehicle inspection the diagnostic technician must follow established procedures that, in particular, specify the method of making measurements by means of particular control devices.

At the moment there are more than 4000 stations [2] operating on the territory of Poland. Each technical inspection station must be built in compliance with requirements contained in the relevant regulation [3]. Those requirements refer to both, structural conditions as well as available control and measurement equipment. Control and measurement equipment used in TIS stations, prior to its installation, must be inspected in the Motor Transport Institute. Yet, following the installation it is not subject to regular inspections with the exception of exhaust gas analyser and the device for measuring and adjusting pressure in tyres. Owners of technical inspection stations usually fail to perform calibrations of remaining devices that by law do not require it as in this way they strive to reduce the operating costs of their stations.

Devices used in technical inspection stations have various wear and tear levels which result from their production date and the number of performed tests. One may encounter both, devices that are merely several years old as well as those that have been in use for over 20 years. The number of performed inspections, thus the frequency of use of such devices, ranges from several hundred to several thousand in a year [4].



Huge variability in the degree of wear of measurement equipment may result in significant deviations in the accuracy of indicated results. In 2016 the authors of the article performed pilot comparative studies in which within one day they measured the Eusama index values obtained for the same vehicle in eight selected stations. The results of those measurements have not been published yet. Obtained results (table 1) are hugely diversified and therefore, they affect the final outcome of the inspection (positive/negative), determined on the basis of applicable provisions [5].

**Table 1.** The results of the Eusama index measurement

Eusama index left wheel (%)	Eusama index right wheel (%)	Difference between left and right wheel (%)	Final score P–positive, N–negative
57	42	15	P
57	41	16	N
57	45	12	P
71	54	17	N
74	61	13	P
72	57	15	P
74	67	7	P
71	48	23	N

The results obtained from the pilot study (table 1) are characterized by significant variability. The dispersion of test results may stem from both, the technical condition of control devices as well as the accuracy of measurement performed by diagnostic technicians. Huge variability of results in pilot studies was the reason for posing a question whether the results of inspections of the same vehicle (its subsystems) in various technical inspection stations may vary and to what extent.

## 2. Methodology of research

In order to provide an answer to the research question posed above, inspections in several dozen technical inspection stations were planned. Inspections focused on those vehicle subsystems that yield quantitative results in the form of various parameters. Tests also involved the measurement of braking force, determination of Eusama index for assessing the suspension damping performance, quantitative analysis of exhaust gas composition in a petrol engine and smokiness measurement in a diesel engine.

Several cars were used in the course of the project, yet the same car was used for examining a particular subsystem. Tests on the same subsystem were conducted in the shortest possible time (up to several days) to ensure that the technical condition of the vehicle did not change. Researchers also made sure that the distances between particular stations did not exceed a dozen or so kilometres.

Station staff was not interrupted in the course of inspection performance, even when the way they conducted measurements was incorrect, which could lead to the so called gross errors. It was assumed that the dispersion of test results could be attributed to both, diagnostic equipment as well as staff errors.

Braking force measurements were performed for the front axis wheel of Audi A3 from 2001. Before the vehicle was sent to each of the selected stations it was ensured that it had comparable temperature of braking discs and tyres, equal tyre pressure and identical axial load. It was also made sure that the tyres were not wet. In each station the measurements were performed five times. Braking force was measured by means of rolling devices and the values were recorded at the border of wheel grip.

Eusama index values were measured for the front suspension of an Opel Corsa from 2004. Prior to each test, it was ensured that wheels had the same air pressure and the vehicle had the same actual mass as well as approximately the same tyre surface and damper surface temperature. The measurement of Eusama index was repeated three times.

The assessment of exhaust gas composition was performed on Opel Astra H with a 1.3 engine from 2007. Prior to test commencement at an inspection station, in line with the procedure contained in [5],

the temperature of the motor oil was ensured to be at least 70°C, and the temperature of the cooling liquid at least 80°C. The measurement in each station consisted in the determination of the content of carbon monoxide (CO), hydrocarbons (HC) as well air-fuel ratio ( $\lambda$ ) in the first place at an increased speed (2000÷3000 rpm/min.), and then at idle speed after 30-60 seconds from the completion of the measurement at an increased rotational speed. Measurements should have been performed while electrical loads such as fans and air conditioning were switched off. Measurements were repeated three times at two speeds.

The exhaust gas smokiness degree was measured in Volkswagen Golf from 2005. Just like in case of the assessment of exhaust gas composition in the petrol engine, also here prior to the test in an inspection station it was ensured that the temperature of the motor oil was at least 70°C, and the temperature of the cooling liquid at least 80°C. The measurement of the smokiness degree, as specified in the procedure in [5], consists in repeatedly pressing the accelerator pedal, then maintaining the increased rotational speed for around a minute, after which the actual measurement takes place when one quickly, yet not violently, presses the accelerator pedal in order to achieve the maximum rotational speed and maintains it for 1.5 seconds. That measurement should be repeated at least three times at 15 second intervals. In order to establish the final result, one takes into consideration the average from three consecutive measurements that do not constitute a decreasing sequence and that do not differ by more than 0.5 m<sup>-1</sup>.

In the course of the tests, as already indicated, researchers did not interfere with the way the staff of technical stations performed measurements. However, the measurements performance method was closely monitored, especially in terms of its compliance with applicable measurement procedures.

### 3. Results of research

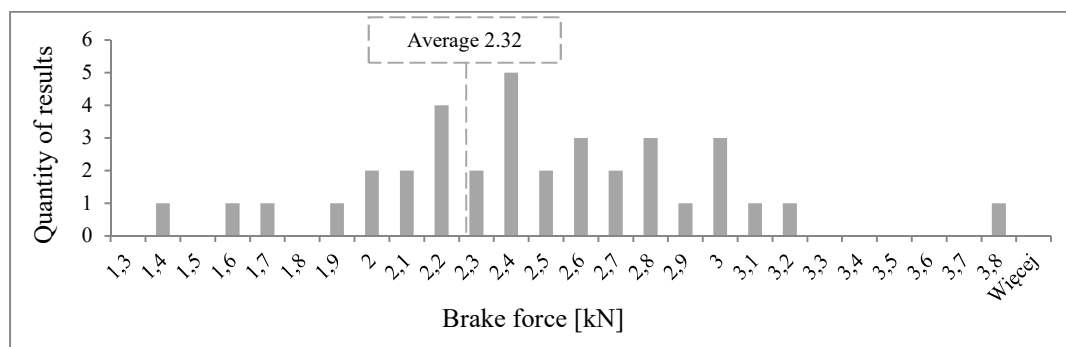
#### 3.1. Results of braking force measurements

Braking force measurements were conducted in 36 technical inspection stations. Those stations were equipped with rolling devices of such producers as Fudim Polmo, Maha, Beissbarth, Cartec, Hoffmann, Trda, Snap-on and Nussbaum. The age of the devices ranged from 5 to 24 years and the average frequency of use ranged from around 500 to around 13 000 times a year.

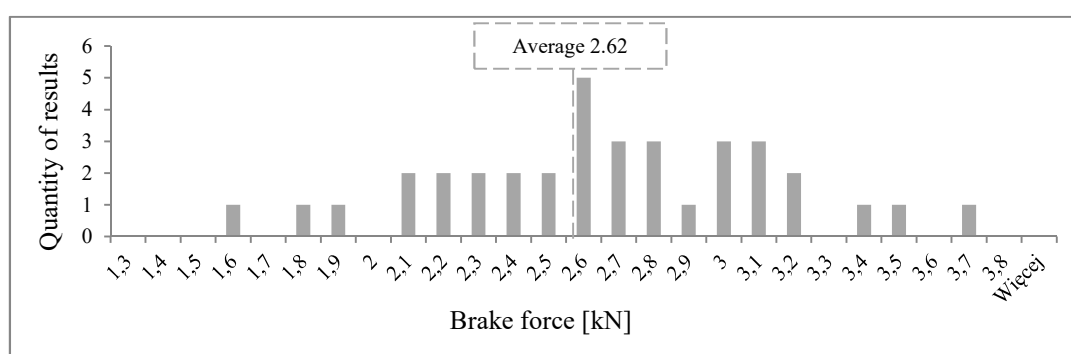
Measurements were repeated five times in each station; hence ultimately 180 individual results were obtained. Based on them it was possible to determine mean values, standard deviation as well as coefficients of variation. Additionally, results histograms were prepared. They are presented in figure 1 and 2 and relate to braking force of the left and right wheel, respectively.

Among individual results of the braking force on the left side of the vehicle, the lowest recorded value amounted to 0.95 kN and the highest 4.47 kN. The mean value was 2.32 kN, with the standard deviation of 0.54 kN and coefficient of variation at 22.5%. After assuming that the final outcome for a given station is a product of five consecutive measurements it was possible to determine mean values in the range from 1.30 to 3.74 kN, while standard deviation decreased to 0.49 kN and resulted in the lower coefficient of variation at the level of 20.2%.

Individual results of the braking force measurement on the right side of the vehicle ranged from 1.29 kN to 4.02 kN and the mean value was 2.62 kN, with the standard deviation of 0.53 kN and coefficient of variation at 20.3%. After assuming that the final result for a given station was the product of five, consecutive measurements it was possible to determine mean values that ranged from 1.56 kN to 3.63 kN, which affected the value of standard deviation – 0.48 kN and the coefficient of variation – 18.3%.



**Figure 1.** The results of brake force measurement in the left wheel



**Figure 2.** The results of brake force measurement in the right wheel

It is noteworthy that in 33 technical inspection stations the average value of the braking force in the right wheel exceeded the average value recorded for the left wheel. With respect to results of 180 individual measurements, in 26 instances the measured braking force in the left wheel was higher than the force in the right wheel. Absolute value of the difference between the average braking force in left and right wheel ranged from 0.0 kN to 0.99 kN and the average value of that absolute difference amounted to 0.24 with the standard deviation at the level of 0.19 kN, which translated into the coefficient of variation that amounted to 79.1%.

The assessment of the observance of the braking force measurement procedure indicated that in 5 instances diagnostic technicians performed the required tyre air pressure check prior to the measurement and in 9 stations brake pedal pressure gauge was used. Yet, only in 3 stations both, the air pressure was verified prior to measurement commencement and the gauge for determining the pressure on the brake pedal was used.

### 3.2. Results of Eusama index measurements

Tests related to the determination of the Eusama index were performed in 27 technical inspection stations. Those stations were equipped with measuring devices of such manufacturers as: Hoffman, Cartec, Unimetal, Maha, Trda, Beissbarth, Fudim-Polmo, Cemb, Ryme, Saxon, Nussbaum and Snap-On. In each station the measurements were repeated 3 times for the left and right side, which gave rise in the end to 162 individual results. Based on obtained results, which are presented in table 2, it was possible to determine average values, standard deviations as well as coefficients of variation.

**Table 2.** The results of the Eusama index measurement [%]

Measurement on the left				Measurement on the right			
1	2	3	Average	1	2	3	Average
78	76	77	77.0	66	67	65	66.0
79	77	76	77.3	71	70	69	70.0
68	69	68	68.3	66	66	67	66.3
72	72	72	72.0	64	65	66	65.0
69	68	68	68.3	68	67	66	67.0
73	73	73	73.0	73	72	71	72.0
85	85	85	85.0	74	74	72	73.3
78	78	77	77.7	74	73	73	73.3
68	68	68	68.0	64	63	64	63.7
77	77	78	77.3	71	71	71	71.0
79	78	78	78.3	71	71	70	70.7
73	72	73	72.7	72	72	71	71.7
73	72	73	72.7	71	70	71	70.7
68	68	66	67.3	67	66	66	66.3
86	88	87	87.0	78	77	78	77.7
78	78	78	78.0	74	73	74	73.7
72	72	72	72.0	64	64	64	64.0
78	77	78	77.7	86	88	87	87.0
68	68	68	68.0	64	58	64	62.0
73	71	72	72.0	73	72	73	72.2
78	79	78	78.3	70	72	71	71.0
74	72	73	73.0	72	69	70	70.3
78	78	78	78.0	74	73	73	73.3
78	79	78	78.3	71	72	70	71.0
78	77	78	77.7	86	88	87	87.0
62	62	62	62.0	62	62	62	62.0
73	72	72	72.3	72	72	71	71.7

The lowest value from individual Eusama index measurements on the left side of the vehicle amounted to 62% and the highest to 88%. Determined average value was 74.4% and standard deviation 5.47%, which gave rise to the coefficient of variation on the level of 7.35%. After assuming that final results are derived from the average of three individual measurements, the value of standard deviation and coefficient of variation amounted to 5.51% and 7.40%, respectively.

The values of individual results of Eusama index on the right side of the vehicle ranged from 58% to 88%. The average value determined on the basis of all individual results was 70.8% and the standard deviation 6.09%, which gave rise to the value of the coefficient of variation at 8.60%. After assuming that an average from three measurements constitutes the final result for a given station, the value of the standard deviation changed to 6.10%.

A significant parameter in the evaluation of obtained results is the value of difference between average values of Eusama index for wheels on the left and right side. The average difference value was 3.7%, yet extreme values ranged from 9.3% to 11.7%. It should be observed that in 24 stations the average value from results for the left side was always higher than the average for the right side. Only three remaining stations recorded the opposite results.

The assessment of measurement performance method in 27 technical inspection stations revealed that in 14 instances the required tyre air pressure check was conducted prior to measurements whereas such an activity was skipped in the remaining stations. Relatively correct positioning of vehicles on measuring boards was performed in all stations.

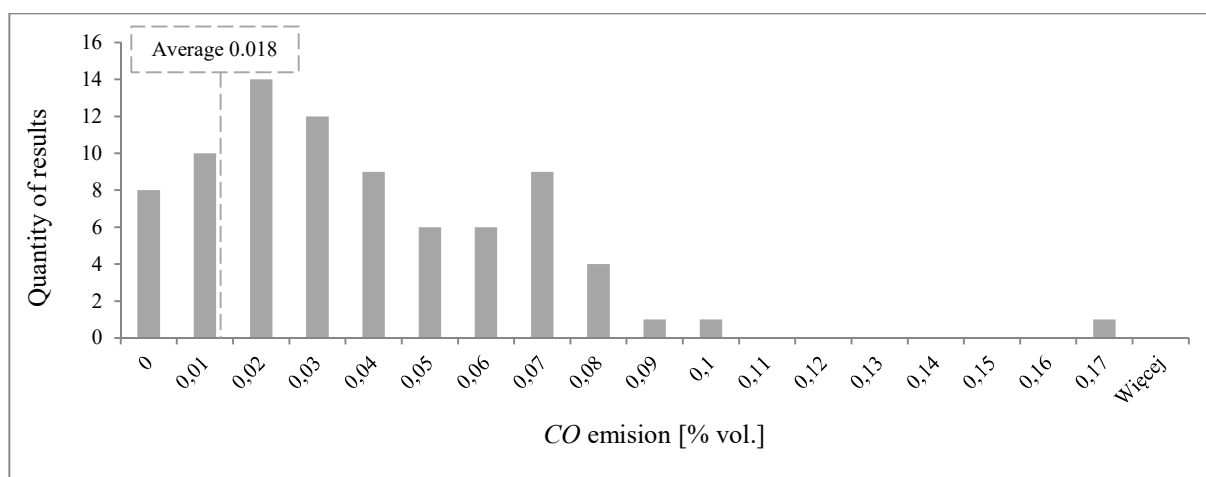
### 3.3. Results of the exhaust gas analysis

Exhaust gas composition analysis in a petrol engine was performed in 27 stations. Those stations were equipped with exhaust gas analysers of such producers as Capelec, Arcon, Radiotechnika, Maha, Atal, AVL Hermann, Motorscan, Cartec, Bosch, Brain and Grundig.

The measurements were taken both, at an increased engine rotational speed as well as at an idle speed. For each of those speeds the  $CO$ ,  $HC$  and  $\lambda$  ratio were measured. In each of 27 stations measurements were repeated three times for both rotational speeds.

Taking into account the results of individual measurements of the carbon monoxide content ( $CO$ ) at an increased rotational speed the average value amounted to 0.018% vol. Extreme values ranged from 0.000 to 0.100% vol. Therefore, the value of standard deviation amounted to 0.023% vol. and the coefficient of variation to 127.3%. The histogram of frequency of results for individual measurements is presented in figure 3. The final result was assumed to be the average from three consecutive measurements. Therefore, the extreme values ranged from 0.000 to 0.057% vol. and the standard deviation value decreased to 0.018% vol. while the value of the coefficient of variation went down to 101.7%.

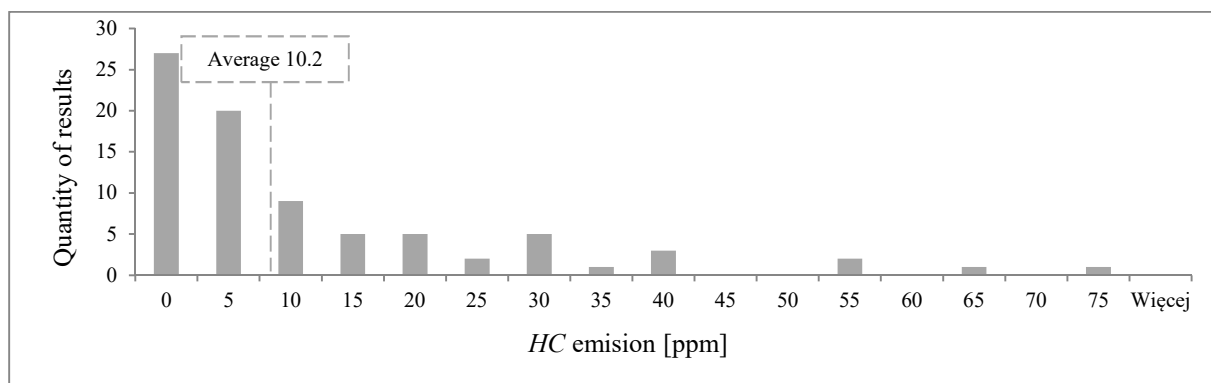
At idle speed the obtained average  $CO$  from individual measurements was 0.037% vol., with extreme values ranging from 0.000 to 0.166% vol. and deviation at 0.029% vol. and coefficient of variation at 78.2%. Since the final result in each station was agreed to be the average from three measurements, extreme values ranged from 0.007 to 0.108% vol. while the values of standard deviation decreased to 0.023% vol. and the coefficient of variation went down to 63.8%.



**Figure 3.** The results of  $CO$  emission at high speed

The average hydrocarbon emission value at high speed was 7.2 ppm, while extreme values for individual measurements ranged from 0 to 87 ppm, which gave rise to standard deviation of 16.0 ppm and the coefficient of variation of 222%. After assuming that the final outcome is derived from three measurements from a given station, the results ranged from 0 to 53 ppm, standard deviation decreased to 12.9 ppm and the coefficient of variation to 179%.

At idle speed, on the other hand, the average value was 10.2 ppm. In case of individual measurements the values ranged from 0 to 74 ppm, which gave rise to the level of standard deviation – 15.2 ppm and the coefficient of variation – 152%. Histogram for the results of individual measurements is presented in figure 4. The deviation and variability coefficient values amounted, given that the final result is derived for each station from three measurements, to 14.9 ppm and 146% respectively and extreme values ranged from 0 to 63.6 ppm.



**Figure 4.** The results of *HC* emission at idle speed

Air-fuel ratio  $\lambda$  at a high speed on average amounted to 1.096, with extreme values ranging from 0.991 to as much as 7.009, which resulted in standard deviation of 0.669 and the coefficient of variation at the level of 61.1%. Given that the final result is derived from three measurements taken at each station, the extreme values ranged from 0.996 to 3.003 and the values of standard deviation and coefficient of variation decreased to 0.388 and 35.4% respectively.

The average value of the air-fuel ratio, in turn, at idle speed was 1.019. Yet, when considering the results of individual measurements the values ranged from 0.990 to 1.379 and the value of standard deviation and coefficient of variation were at the level of 0.071 and 6.95%. Given that the final result from each station is derived from three measurements, the value of standard deviation and coefficient of variation changed slightly, which was the result of extreme values ranging from 0.993 to 1.372.

The observation of the measurement procedure conducted by technical inspection station personnel showed that full compliance was ensured only in 7 facilities. The most common mistakes included the failure to check the temperature of the cooling liquid and oil as well as leaving electric loads on. In almost 40% of facilities the measurements were performed in a reverse order, i.e. first at idle speed and then at high speed. In some cases, the measurement for high speed was taken when the reading of the revolutions per minute exceeded the scope specified in the procedure – 2000÷3000 rpm/min. In the course of all individual measurements the applied scope of rotational speed ranged from 1631 to 3966 rpm/min.

### 3.4. Results of smokiness measurement

The smokiness degree in a diesel engine was subject to measurement in merely 12 technical inspection stations, since often the performance of relevant measurements was refused. Those stations that agreed to perform measurements were equipped with devices of such producers as Cartec, ISC, Atal, Radiotechnika, Maha, Bosch and Arcon.

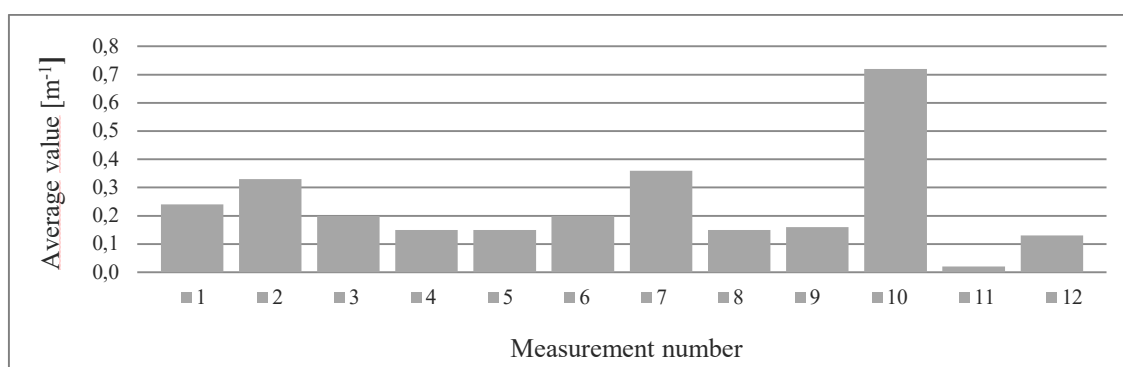
Obtained results from individual measurements that were repeated three times are presented in table 3. Based on those results average values were calculated. In line with the previously quoted procedure they constitute the final outcomes. Average values are presented in figure 5.

When analysing the final results of smokiness measurements in all 12 technical inspection stations it should be indicated that the global average from those measurements was  $0.23 \text{ m}^{-1}$ , extreme values ranged from  $0.02 \text{ m}^{-1}$  to  $0.72 \text{ m}^{-1}$  and the value of standard deviation for those 12 final results was  $0.17 \text{ m}^{-1}$  while the coefficient of variation amounted to 79.3%.



**Table 3.** The results of smokiness measurement [ $\text{m}^{-1}$ ]

Number on measurement			Average
1	2	3	
0.30	0.20	0.23	0.24
0.10	0.15	0.75	0.33
0.18	0.21	-	0.20
0.24	0.14	0.07	0.15
0.14	0.16	0.15	0.15
0.07	0.41	0.12	0.20
0.37	0.31	0.41	0.36
0.12	0.17	0.17	0.15
0.24	0.14	0.11	0.16
0.66	0.90	0.60	0.72
0.02	-	-	0.02
0.09	0.15	0.14	0.13

**Figure 5.** The results of smokiness measurement

The observation of the method for performing the measurements revealed that, in principle, the majority of stations repeated the measurements three times. Only in case of two facilities, the staff decided that performing one or two measurements was sufficient to obtain a final result, which was reflected in the outcomes presented in table 3. It was also observed that in 7 out of 12 stations the exhaust system was cleaned prior to basic measurements. The inspection of motor oil temperature was performed in 2 stations while the cooling liquid temperature was checked in only one station.

#### 4. Discussion of results

The number of technical inspection stations in which the braking force was measured, the Eusama index was determined and the emission in petrol engines and smokiness level in diesel engines was checked varies significantly. Inability to perform measurements in some stations resulted from the refusal of staff who justified it with the lack of time, temporary defects of the measurement devices or lack of legal grounds for making a measurement that is not directly related to acknowledging the vehicle as roadworthy.

When analyzing the obtained results one should bear in mind that the authors decided not to interfere directly in the way the measurements were conducted in particular stations. Yet, what the authors made sure of was that the vehicle referred for measurements to inspection stations was in unchanged technical condition. Authors also attempted to ensure that the method of performing measurements was being observed by the station staff, even though it was not possible in all cases. Given those circumstances, it

cannot be clearly determined whether the dispersion of results stemmed from the failure to observe measurement procedures or the functioning of devices or maybe both of those reasons combined.

It should also be noticed that in measurement procedures followed by technical inspection stations it is not required to repeat the same measurements for the purpose of eliminating the so called gross errors. It is sufficient, therefore, to take a single measurement and based on it the diagnostic technician may decide about the vehicle's technical condition. It is only good practice, backed by many years of experience, that requires station staff to repeat measurement several times in doubtful cases.

Moving on to the analysis of obtained results, it should be observed that in case of braking force measurement for wheels on the left and right side of the vehicle, similar standard deviation values amounting to around 0.50 kN were recorded, just like the values of the coefficient of variation that amounted to around 18-22%. Such values should not be viewed as hugely questionable as the authors of the paper [6] highlighted that what affected the results of measurements in up to even 35% is the type of used sensors and the measurement system. What gives rise to concerns, however, are the extreme values that may differ between each other even five times. Equally disturbing may be the fact that in around 14.4% of all results there was a reverse correlation in values for the braking force in wheels on the left and right side of the vehicle. Those circumstances demonstrate that the problem of dispersion of results for braking force may be serious. The authors of that paper decided to examine this problem more closely [7].

The determination of the Eusama index is, according to the authors of the paper [8], repetitive provided that such factors as, for example, tyre pressure or tyre types, are constant. As has already been mentioned, in the course of all measurements, effort was made to ensure the unchanged nature of measurement conditions. Obtained outcomes indicate that the dispersion of results around the average value defined by means of standard deviation and coefficient of variation was similar for both, the left and right side of the vehicle. In the measurements related to the determination of the Eusama index, the values of the coefficient of variation were over 50% lower than in case of brake force measurements, which indicates a significantly lower dispersion of results around the average value. Moreover, only in 4.9% of individual results a reverse relationship between the values recorded for the left and right side of the vehicle was observed, as compared with the remainder of results.

In case of the results of exhaust gas emissions in a petrol engine, the authors of the paper were expecting to obtain the highest variability as results are heavily affected by the engine warmth and strict observance of the measurement procedure. With respect to the results of *CO* carbon monoxide measurement, the *HC* hydrocarbons measurement and the air-fuel ratio  $\lambda$  what is particularly noteworthy are high values of the coefficients of variation. Both, in case of increased rotational speed as well as at idle speed, the values in question range from a dozen or so to over two hundred percent. Such high values indicate a significant difference in extreme values, in particular in individual results that considerably deviate from the average value and therefore fail to fit in with the statistical normal distribution. When analyzing the values of intervals in which extreme values obtained in the course of measurements are comprised one can see that usually one end of such an interval is significantly more distant from the average value than the other end.

With respect to the smokiness degree in the diesel engine one can observe the same tendency as in case of exhaust gas emission measurement in the petrol engine. Also here high values of the coefficient of variation were obtained. Just like earlier, that outcome stems from the fact that in individual results there are single values that significantly deviate from the average value. In particular, extreme values of  $0.02 \text{ m}^{-1}$  and  $0.72 \text{ m}^{-1}$  deviate considerably from the average value amounting to  $0.23 \text{ m}^{-1}$ . Obtaining a minimum value of  $0.02 \text{ m}^{-1}$  resulted from the fact that the diagnostic technician confused the procedure for measuring the smokiness degree in diesel engines with the procedure for measuring the emission of harmful substances in petrol engines.

In all types of measurement performed in technical inspection stations there were sometimes cases of non-observance of measurement procedures even though those procedures have hardly changed over the last several years. Presumably, departures from the procedures affected the obtained results and in particular their extreme values in particular sets. It should also be remembered that had it not been for

the verification of the vehicle condition prior to subjecting it to inspection in particular stations (e.g. inspection of tyre pressure as well as motor oil and cooling liquid temperature) discrepancies between results would have probably be even bigger.

## 5. Conclusions

Outcomes obtained in the course of performed tests indicate dispersion between particular results of measurements. The level of dispersion in some cases is so significant that it can affect diagnostic technician's decision to either issue the certificate of roadworthiness or not. The reasons for discrepancies may be attributed to both, the personnel operating the devices as well as to the measurement devices as such.

Diagnostic technicians working in the technical inspection stations undergo extensive training preparing them for the profession and they need to pass a state exam comprising both, a written and a practical part. After they receive their professional license there is no requirement to undergo additional or refresher training concerning the method of taking measurements. The observation of the work of diagnostic technicians performing measurements, whose results were presented in this paper, indicates that it would be reasonable to introduce periodic training to refresh and verify one's knowledge, and in particular one's practical skills.

Significant dispersion of measurement outcomes poses a further research question concerning the impact of measuring devices on obtained results. Examining this question in the course of further research would indicate whether it is necessary to introduce the obligation to calibrate all measurement devices.

The obtained results determine the question about the reasons for the dispersion of measurement results. Obtaining a response to this question requires separate, more detailed and technically complicated research.

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