# Securing Cargo during Transport on Roads of Different Quality

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Abstract: The article compares the magnitude of shocks generated by the Tatra T-810 on two types of roads (high-quality – highway and lower-quality – roads paved with granite blocks). As the primary data, sets of acceleration coefficients in the three axes (x, y and z) were used as part of a transport experiment using a three-axis accelerometer with a datalogger and a calibration certificate – OM-CP-ULTRASHOCK-5-CERT. Data analysis is performed using descriptive statistics. The mean values and variations of measured acceleration coefficients on the roads we examined are compared. The graphical comparison of the roads studied is covered in a separate section. The results of the transport experiment show that the magnitude of generated shocks is even higher at a lower average transport speeds on a low-quality roads. The distribution of acceleration coefficient values also differs for both roads.

## 1 INTRODUCTION

Within the European Union (EU), over 76% of cargo is transported using road transport (Fenollar-Solvay et al., 2016). Over the last ten years (2008-2017), a total of 147,047,868,000 tons of freight was transported across the EU, an annual average of 14,704,787,000 tons of transported cargo (EUROSTAT, 2018).

Due to these large volumes of cargo transported by road, a high number of roads are overloaded. According to the Road Transport Services Center, established by the Ministry of Transport of the Czech Republic, over a half of all vehicles are overloaded during weight checks, which amount to over 2,000 per year in the Czech Republic (CSPSD, 2014).

According to the Regional Road Administration and Road Maintenance statistics, a single truck will damage a road more than 10,000 passenger cars (AKTUALNE, 2018). Cargo transport makes high demands on road infrastructure that is more quickly worn out (damaged). Annual maintenance is not always able to ensure its required quality.

Quality of roadways directly affects the magnitude of the inertial forces that affect cargo during transport. Generally, on a damaged road, characterized by a large amount of unevennesses (holes, seals, etc.), higher values of acceleration coefficients (shocks) that directly affect the magnitude of inertial forces are assumed. On the basis of the assumed size of inertial forces acting on transport, it is necessary to choose appropriate methods of securing (fastening) cargo and evaluating the lashing capacity of the respective fastening means.

Determining the magnitude of the inertia in the actual transport is possible by using a suitable measuring device (accelerometer) and the appropriate calculation, mainly by using the formulas from the norms, eg. EN 12195-1:2011 (UNMZ-EN 12195-1, 2011). Selected cargo shippers and carriers use accelerometers to detect undesirable shocks (acceleration) during shipment of particularly fragile or otherwise sensitive goods (dangerous goods etc.). These are, for example, multinational companies DHL (DHL, 2018), GEIS (GEIS, 2018) or TNT (TNT, 2018).

Exceptions do not even apply in an advanced army, such as the United States Army, which complements its transport and transport means (mainly containers) with a set of measuring devices that monitor (among others) the cargo space (SAVI TECHNOLOGY, 2014). The temperature, relative humidity, acceleration in individual axes, etc. are determined in the respective transport means.

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From the point of view of inertial forces influencing cargo, the key values of acceleration coefficients in individual axes are primarily influenced by the following three basic factors:

- vehicle,
- driver,
- road (Lerher, 2015 and Vlkovský et al., 2018).

In the case of a vehicle, it is also important whether it is moving with or without cargo. The key technical factors of the vehicle are its tires, chassis, structure of the vehicle hull and its connection with the chassis, including the age of the vehicle and its individual components, etc. The driver's driving style is a significant factor, especially the speed of the vehicle as well as driver skills, experience and mental condition (Vlkovský et al., 2016 and Vlkovský and Šmerek, 2018).

The purpose of this article is to prevent problems associated with incorrect or insufficient cargo securing through knowledge of the transport parameters – the roads before it starts – and thus increase transport safety. The risks associated with inertia forces on cargo are generally higher for specific shipments that are carried by the military or components of the Integrated Rescue System (Vlkovský et al., 2018).

## 2 TRANSPORT EXPERIMENT

The transport experiment was carried out on two types of roads using a Tatra T-810 6x6 (T-810) with less than 45,000 km. The first type of highway was the D1 highway, measured from Brno to Vyškov and back. The second type was a lower quality transport road (third class road); a paved road measured from the Vyškov to Vyškov-Dědice training polygon and back.

The transport experiment was undertaken by one professional driver and a 3-axis accelerometer with a datalogger and a calibration certificate – OMEGA-OM-CP-ULTRASHOCK-5 (see the Figure 1).

A measuring range of ±5g was used to obtain the values of the acceleration coefficients. A sampling rate of 512 Hz was used with a record for every second of the highest (or possibly) lowest value of the respective acceleration coefficient in the given axis (x, y and z) (Grzesica, 2018). The axes are designated according the Figure 2: x – longitudinal, y – transverse and z – vertical.

Figure 1: Mounting of the measuring device.

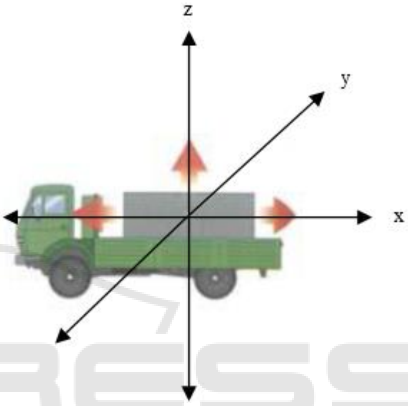


Figure 2: Axes designation (PRORIDICE, 2019).

The accelerometer was mounted on the steel center frame of the vehicle body in the front of the T-810 load compartment and the transport experiment was carried out without any load. Optimal climatic conditions included dry roads, excellent visibility, absence of congestion and rainfall. Outdoor temperature was in the range of 7-11° C.

### 2.1 Methods

To accomplish a comparison of the above described roads, as specified in section 2.2, descriptive statistics were used and basic descriptive characteristics were found (mean values – arithmetic mean, modus and median, scattering, slope coefficients and kurtosis). Comparison also includes the detection of extreme values in individual axes (both positive and negative). The selected values are compared with the use of one and two-choice tests of statistical hypotheses on the equivalence of mean values (arithmetic mean) and variance (part 2.3).

In a separate section (2.4) a graphical comparison of the distribution of measured values of acceleration coefficients on the examined roads is shown.

## 2.2 Basic Descriptive Characteristics of Measured Data Files

The first data file (formally marked as dataset 1) was obtained on the Brno-Vyškov (highway) route (see the Figure 3 with raw data). In a stretch of 27.0 km long, a total of 3,804 values of acceleration coefficients were recorded and the average vehicle speed was 76.66 km·h$^{-1}$. The basic descriptive characteristics of dataset 1 as well as the extremes in the individual axes, in both positive and negative directions are illustrated in Tables 1 and 2.

Table 1: Dataset 1 – Basic descriptive characteristics.

| **Characteristics** | **x** | **y** | **z** |
|---|---|---|---|
| **Arithmetic Mean** | –0.2953 | 0.2284 | 1.6381 |
| **Modus** | –0.6100 | 0.5100 | 1.6000 |
| **Median** | –0.5400 | 0.5000 | 1.6200 |
| **Variance** | 0.2923 | 0.4059 | 0.0304 |
| **Skewness Coeff.** | 1.0464 | –0.5862 | 1.0127 |
| **Kurtosis Coeff.** | –0.5327 | –0.7773 | 2.2971 |

Table 2: Dataset 1 – Extremes of measured acceleration coefficient values.

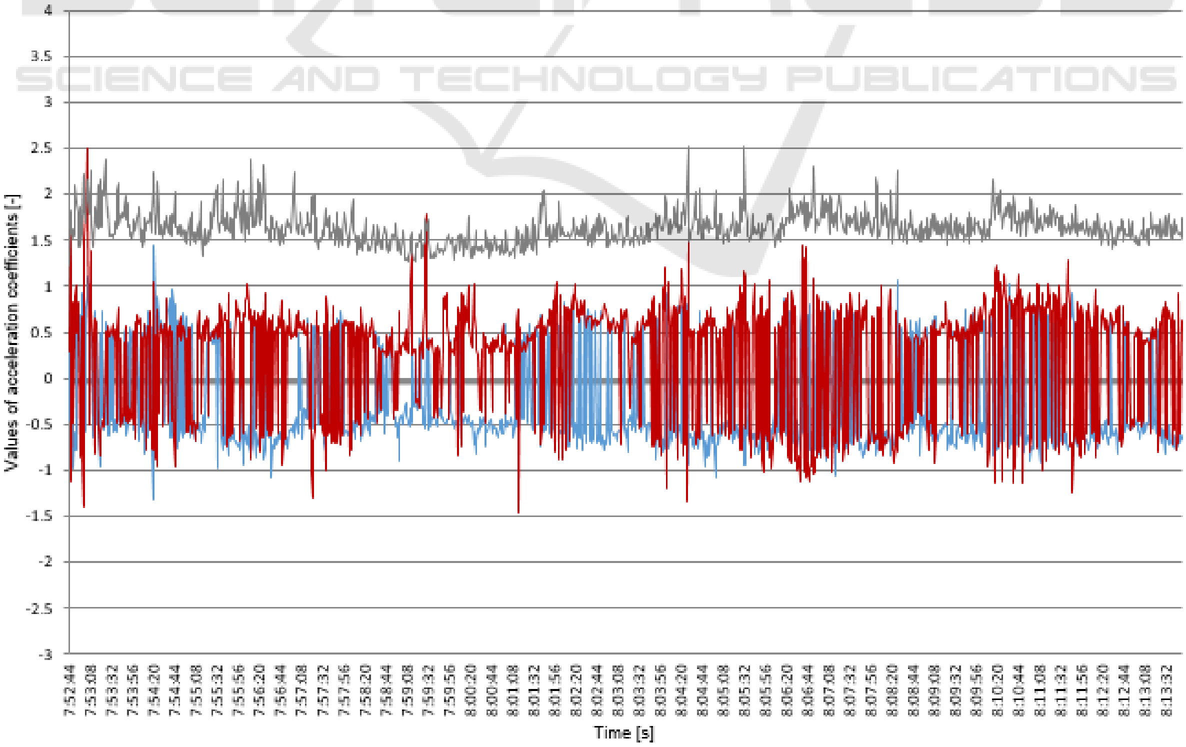
| **Extremes** | **x** | **y** | **z** |
|---|---|---|---|
| Positive | 1.4400 | 2.5100 | 1.5300 |
| Negative | –1.3200 | –1.4700 | – |

According to Table 1, a higher value of z-axis acuity can be identified which is slightly elevated (positive), while in the other two axes, the values are less than 0. This is due, among other things, to the displacement of the coordinate axis due to gravity acceleration.

Z-axis scatter is also more than 13 times smaller than the y-axis, respectively almost 10× in the x-axis. Extremes – the highest and lowest values of the acceleration coefficients in the individual axes are given in Table 2.

The highest value of the acceleration coefficient was in the y-axis where the measured value $c_y$ = 2.51, corresponding to 2.5 times the gravity acceleration g.

The second data file (formally identified with Dataset 2) was obtained on the route Vyškov – Brno (highway). In a 27.0 km long section, a total of 4,059 values of acceleration coefficients were recorded and the average speed of the vehicle was



Legend: blue – x axis, red – y axis, grey – z axis.

Figure 3: Dataset 1 – Raw data.

71.84 km·h$^{-1}$. The basic descriptive characteristics of Dataset 2 and the extremes in the individual axes, in the positive and negative directions, are presented in Tables 3 and 4.

Table 3: Dataset 2 – Basic descriptive characteristics.

| Characteristics | x | y | z |
|---|---|---|---|
| **Arithmetic Mean** | –0.2530 | 0.2226 | 1.7075 |
| **Modus** | –0.6500 | 0.6900 | 1.6700 |
| **Median** | –0.5900 | 0.5700 | 1.6900 |
| **Variance** | 0.4330 | 0.5169 | 0.0291 |
| **Skewness Coeff.** | 0.7439 | –0.5277 | 1.1093 |
| **Kurtosis Coeff.** | –1.1524 | –1.2530 | 5.5130 |

Table 4: Dataset 2 – Extremes of measured acceleration coefficient values.

| Extremes | x | y | z |
|---|---|---|---|
| Positive | 1.6700 | 2.3100 | 1.9600 |
| Negative | –1.3600 | –1.2900 | – |

Table 3 shows a higher coefficient of kurtosis in the z-axis. The highest measured value within Dataset 2 (Table 4) was in the y-axis ($c_y$ = 2.31), roughly equivalent to 2.3 times the gravity acceleration g.

A third data set (formally marked with Dataset 3) was obtained on the Vyškov – training polygon Vyškov-Dědice (the road paved with granite blocks). Over a 4.3 km long section, a total of 1,182 acceleration coefficient values were recorded and the average vehicle speed was 39.29 km·h$^{-1}$. The basic descriptive characteristics of Dataset 3 and the extremes in the individual axes, in the positive and negative directions, are presented in Tables 5 and 6.

Table 5: Dataset 3 – Basic descriptive characteristics.

| Characteristics | x | y | z |
|---|---|---|---|
| **Arithmetic Mean** | –0.1904 | 0.0730 | 1.9924 |
| **Modus** | 0.4500 | 0.4100 | 1.6000 |
| **Median** | –0.5150 | 0.4500 | 1.9500 |
| **Variance** | 0.7927 | 1.0016 | 0.1784 |
| **Skewness Coeff.** | 0.1441 | –0.2296 | 0.9992 |
| **Kurtosis Coeff.** | –1.1163 | –1.0862 | 1.9430 |

Table 6: Dataset 3 – Extremes of measured acceleration coefficient values.

| Extremes | x | y | z |
|---|---|---|---|
| Positive | 1.8300 | 2.2800 | 3.1100 |
| Negative | –3.0800 | –2.4400 | – |

Table 5 identified higher kurtosis in the z-axis. The highest measured value within Dataset 2 (Table 6) was in the z axis ($c_z$ = 3.11), roughly equivalent to more than 3.1 times the gravity acceleration g.

A fourth data set (formally marked with Dataset 4) was obtained on the training polygon Vyškov-Dědice – Vyškov (road paved with granite blocks). Along a 4.3 km long section, a total of 1,203 acceleration coefficient values were recorded and the average speed of the vehicle was 38.60 km·h$^{-1}$. The basic descriptive characteristics of Dataset 4 and extremes in individual axes, positive and negative, are given in Tables 7 and 8.

Table 7 shows the difference in variance of the z axis, which is significantly lower than that of the other two axes. The highest measured is in the y-axis ($c_z$ = 2.70), which corresponds to 2.7 times the gravitational acceleration g.

Table 7: Dataset 4 – Basic descriptive characteristics.

| Characteristics | x | y | z |
|---|---|---|---|
| **Arithmetic Mean** | –0.4425 | 0.0562 | 2.0047 |
| **Modus** | –0.8000 | 0.8300 | 2.0000 |
| **Median** | –0.7300 | 0.4500 | 1.9500 |
| **Variance** | 0.7532 | 1.1867 | 0.1742 |
| **Skewness Coeff.** | 0.9505 | 0.0755 | 0.8825 |
| **Kurtosis Coeff.** | –0.1423 | –1.1141 | 0.7597 |

Table 8: Dataset 4 – Extremes of measured acceleration coefficient values.

| Extremes | x | y | z |
|---|---|---|---|
| Positive | 1.9700 | 2.7000 | 2.6300 |
| Negative | –2.3000 | –2.4200 | – |

## 2.3 Statistical Hypotheses Tests

For the purpose of comparing a high-quality road (highway) with a poor quality road (paved with granite blocks), partial zero and alternative hypotheses were formulated to compare the individual datasets ($d_1$ – $d_4$) in pairs. Two singlechoice tests of partial statistical hypotheses were used for testing:

- mean values compliance test,
- variances compliance test.

The zero hypothesis is assumed to be valid (resp. partial zero hypotheses for the respective dataset pairs) concerning the parity of the relevant dataset parameters, for the mean values $\mu = \mu_0$, resp. variances $\sigma^2 = \sigma^2_0$. For an alternative hypothesis in the double – side test applies $\mu \neq \mu_0$, resp. $\sigma^2 \neq \sigma^2_0$. Subsequently, one-sided tests are performed to determine whether $\mu > \mu_0$ or $\mu < \mu_0$, resp. $\sigma^2 > \sigma^2_0$ or $\sigma^2 < \sigma^2_0$.

For test purposes, a critical value range was constructed and a test criterion value calculated.

To test the hypothesis an appropriate statistic $T = T(x_1, x_2, \ldots, x_n)$ is used, the so-called test criterion that has, when the zero hypothesis is valid, known probability distribution (Student's or t distribution).

The area of these values of statistics is divided into two disjoint fields:

- $W_{1-\alpha}$ is the domain of accepting a zero hypothesis – a set of values that testify in favor of a zero hypothesis,
- $W_\alpha$ is a critical domain (domain of zero hypothesis rejection) – that testify in favor of an alternative hypothesis.

For example, for the hypothesis test of the mean value μ of the normal distribution zero hypothesis: $\mu = \mu_0 \rightarrow$ alternative hypothesis: $\mu > \mu_0$ will be critical domain $W_\alpha = \{t, t \geq t_{1-\alpha}(\nu)\}$, where $\mu_0$ is the expected value of the parameter μ, t is the value of the test criterion and $t_{1-\alpha}(\nu)$ is quantile of Student's distribution – so-called critical value (Neubauer, et al., 2016). Tests for variances are performed analogously. For all tests, the level of significance chosen was $\alpha = 0.05$.

On the basis of these tests, the individual partial zero hypotheses were verified, from which the relevant conclusions are subsequently formulated.

A normality test was performed prior to statistical analysis. Normality was verified graphically using Q-Q plots (Johnson and Wichern, 2007), including the determination of skewness and kurtosis coefficients. Minor deviations from normality were found, especially when testing the kurtosis of distribution. However, the graphical analysis did not show significant deviations from normality, theoretical quantil and the corresponding empirical quantils were approximately on a straight line (Vlkovský et al., 2017).

The Stat1 software tool was used to perform statistical hypothesis tests. (Neubauer et al., 2016).

In individual partial tests (Table 9), the hypotheses on equivalence of the mean values are always tested (arithmetic means in absolute value) $\mu_{i(abs)}$ for given values of acceleration coefficients in individual axes ($c_x$, $c_y$ and $c_z$). Analogously, variances in acceleration coefficients in individual axes are tested. The aim of the tests is to find out whether the individual data sets ($d_1$ – $d_4$) significantly statistically differ at the $\alpha = 0.05$ level of significance.

Table 9 shows that, using a mean value (arithmetic averages in absolute values), there is a statistically significant difference between individual datasets with the exception of $d_3$ – $d_4$. Where it shows the similarities of both files found on the same road in the opposite direction. A statistically significant difference between $d_3$ and $d_4$ was shown only in the axes x and y.

Table 9: Comparison of mean values (in absolute values) of acceleration coefficients in all three axes.

| **Characteristics** | $\mu_{i(abs)}$ | | |
|---|---|---|---|
| **Coef.** **Dataset** | $c_x$ | $c_y$ | $c_z$ |
| **$d_1$–$d_2$** | $\mu_1<\mu_2$ | $\mu_1<\mu_2$ | $\mu_1<\mu_2$ |
| **$d_1$–$d_3$** | $\mu_1<\mu_3$ | $\mu_1<\mu_3$ | $\mu_1<\mu_3$ |
| **$d_1$–$d_4$** | $\mu_1<\mu_4$ | $\mu_1<\mu_4$ | $\mu_1<\mu_4$ |
| **$d_2$–$d_3$** | $\mu_2<\mu_3$ | $\mu_2<\mu_3$ | $\mu_2<\mu_3$ |
| **$d_2$–$d_4$** | $\mu_2<\mu_4$ | $\mu_2<\mu_4$ | $\mu_2<\mu_4$ |
| **$d_3$–$d_4$** | $\mu_3<\mu_4$ | $\mu_3<\mu_4$ | NO |

Note: *NO indicates the non-demonstration of a statistically significant difference between the monitored data files at the level of significance α = 0.05. Greens are marked with statistically significant differences demonstrated for all three axes.*

From partial hypothesis tests it follows that, from the point of view of the mean values (arithmetic averages in absolute values), there is a statistically significant difference at the level of significance $\alpha = 0.05$ between a high-quality road (highway) and a lower quality road (paved with granite blocks). The conclusion is valid in both directions. Because it is valid, it means that values are statistically significantly lower (in all three axes) for datasets 1 and 2 compared to datasets 3 and 4.

Table 10: Comparison of variances acceleration coefficients across all three axes.

| **Characteristics** | **$\sigma_i^2$** | | |
|---|---|---|---|
| **Coef.**<br>**Dataset** | **$c_x$** | **$c_y$** | **$c_z$** |
| **$d_1$–$d_2$** | $\sigma_1^2<\sigma_2^2$ | $\sigma_1^2<\sigma_2^2$ | NO |
| **$d_1$–$d_3$** | $\sigma_1^2<\sigma_3^2$ | $\sigma_1^2<\sigma_3^2$ | $\sigma_1^2<\sigma_3^2$ |
| **$d_1$–$d_4$** | $\sigma_1^2<\sigma_4^2$ | $\sigma_1^2<\sigma_4^2$ | $\sigma_1^2<\sigma_4^2$ |
| **$d_2$–$d_3$** | $\sigma_2^2<\sigma_3^2$ | $\sigma_2^2<\sigma_3^2$ | $\sigma_2^2<\sigma_3^2$ |
| **$d_2$–$d_4$** | $\sigma_2^2<\sigma_4^2$ | $\sigma_2^2<\sigma_4^2$ | $\sigma_2^2<\sigma_4^2$ |
| **$d_3$–$d_4$** | NO | NO | NO |

Note: *NO indicates the non-demonstration of a statistically significant difference between the monitored data files at the level of significance α = 0.05. Greens are marked with statistically significant differences demonstrated for all three axes.*

Table 10 shows that, by using variances, there is a statistically significant difference between individual datasets with the exception of $d_1$ and $d_2$, respectively $d_3$ and $d_4$. Where the similarity can be seen in both pairs of files found on the same traffic path in the opposite direction. Statistically significant difference $d_1$ – $d_2$ is only shown in the axes x and y. Between the $d_3$ – $d_4$ datasets a statistically significant difference was not demonstrated in either of the axes

Partial hypothesis tests show that, from the point of view of the variances, there is a statistically significant difference in the level of significance α = 0.05 between a high-quality transport road (highway) and a lower quality road (paved with granite blocks). The conclusion is valid in both directions, because the results show that variances are statistically significantly lower (in all three axes) for dataset 1 and 2 compared to dataset 3 and 4. For some axes, it can be assumed that a statistically significant difference between the pairs of the dataset with a higher test strength (at the level of significance α = 0.01) would be demonstrated.

## 2.4 Graphical Comparison of Roads

The individual datasets ($d_1$ – $d_4$) can be viewed in terms of the number of values of the acceleration coefficients in the individual axes that fall within the respective intervals. Figures 4 – 7 show the frequencies of acceleration coefficients in individual axes, divided into intervals of multiples of gravitational acceleration (0.5g).

It can be seen from Figures 4 – 7 that the character of the distribution of values at individual intervals differs significantly between the tested roads. Although the frequencies of the acceleration coefficients differ, it is possible to illustrate the different character of the high-quality road (highway) and the lower quality road (road paved with granite blocks).

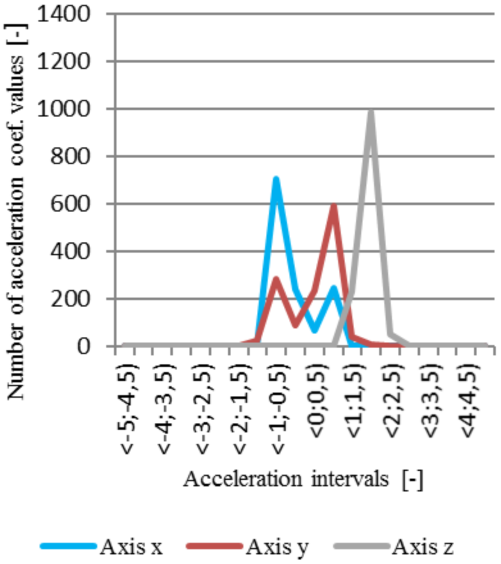


Figure 4: Dataset 1 – Frequency of acceleration coefficients.

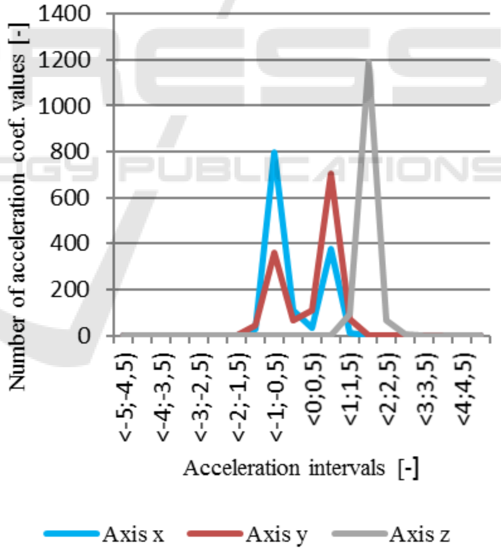


Figure 5: Dataset 2 – Frequency of acceleration coefficients.

This conclusion can be demonstrated by the number of intervals in which the values of the coefficients of acceleration in the individual axes fall. While for dataset 1 it is 6 in the x-axis, 8 in the y-axis and 4 in the z-axis, respectively 7, 8 and 4 for dataset 2, on lower quality road it is for the dataset 3 in the x-axis 10, in the y-axis 10 and in the z-axis 7, respectively 9, 11 and 6 for dataset 4.

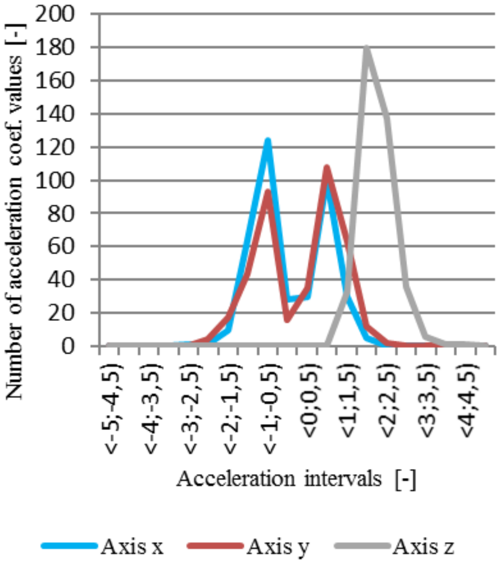


Figure 6: Dataset 3 – Frequency of acceleration coefficients.

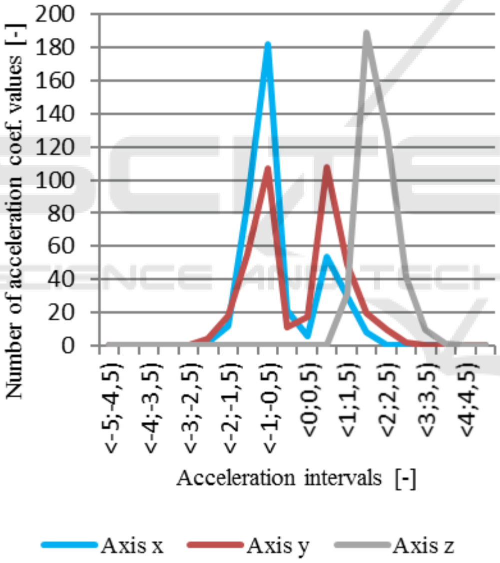


Figure 7: Dataset 4 – Frequency of acceleration coefficients.

## 3 RESULTS AND DISCUSSION

On the basis of these comparisons, it is obvious that even at a lower average speed (about half) there is a statistically significant difference between the tested roads at the significance level $\alpha = 0.05$. This conclusion applies to both tested basic descriptive characteristics (mean values in absolute values as well as variance of values of acceleration coefficients in all three axes).

It can be concluded that the T-810 vehicle generates on lower quality road (third class road) in average greater shocks (higher values of acceleration coefficients) even at about half the average transport speed. At higher speeds on a lower quality road, even greater differences in shocks can be expected. Generated shocks can be quantified as inertial forces that act not only on the cargo but also on the vehicle and the driver.

The graphical comparisons show a different distribution of values for each type of road. Primarily the graphical view of their variance in single intervals of 0.5g differs significantly. Whereas for dataset 1 and 2 there is an average variance at 6 intervals, for datasets 3 and 4 it is almost at 9 intervals.

## 4 CONCLUSIONS

The shocks generated by trucks significantly influence the life of the road and the vehicle. In the short term, there is a key impact on the cargo, that can be released or damaged by the effect of the shocks (the magnitude of the acceleration coefficients exceeding normative values according to EN 12195-1:2011). In addition, the unfastening of the cargo may carry secondary risks such as damage to the vehicle, other technical means on the vehicle, cause a traffic accident involving personal injury, damage to the environment or other property damage (Vlkovský et al., 2017).

The results of the analysis presented by the article can be mainly used to optimize the fastening of cargo by choosing a more suitable fastening system, or fasteners with the corresponding lashing capacity. Lashing capacity must correspond to actual shocks (the magnitude of the acceleration coefficients, respectively resulting inertial forces), rather than simply theoretical assumptions of the standards.

A specific area of transport is the shipping of dangerous items, especially those that are directly affected by the shocks. These primarily include various types of explosives (Vlkovský and Rak, 2017), that are transported by the army using their own or contracted vehicles. Transportation of various fragile cargoes can also be considered as problematic in this respect. Despite the use of special packaging and vehicles for transport, types of cargo more vulnerable to the negative effects of shocks are mentioned.

In further research, the spectral analysis enable to transform the data (signal) of the time series into a frequency domain, which allows examination of other aspects of transport – cargo securing (Grzesica and Wiecek, 2016).

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