Cargo Securing During Transport Depending on the Type of a Road

Martin Vlkovský¹, Michal Šmerek¹, Jaroslav Michálek¹

¹University of Defence, Kounicova 65, 662 10 Brno, Czech Republic

martin.vlkovsky@unob.cz

Abstract. The article is concerned with the evaluation of a transport experiment conducted in the Czech Republic in order to prove the inappropriateness of the input data used for the purpose of cargo securing in vehicles. For the experiment, a TATRA truck was used. In a statistical evaluation, an overview of basic statistical characteristics, including an interpretation of significant values, is provided. In the article, a model of loading is presented illustrating the problem associated with the application of average – normative – values of acceleration coefficients when calculating inertial forces acting during transport on different types of roads.

1. Introduction
Cargo securing is a key factor of each transport. In the Czech Republic, 400,000 tons of material are conveyed every year [1]: the material needs to be secured in order to be prevented from shifting during transport. For this purpose, various securing means are used having different capacity. Among the means most commonly used, there are textile lashing straps. The choice of a type and capacity of a lashing strap mainly depends on the inertial forces potentially acting during transportation (resulting from the load weight, technical condition of a vehicle, road quality etc.). In order to simplify the securing process (the entire loading), software applications are currently employed making use of input data characterising the load and transport, and taking into account the requirements of respective standards (e.g. ČSN EN 12195-1:2011 Load restraining on road vehicles – Safety – Part 1: Calculation of securing forces). The goal of the article is to practically prove the inappropriateness of the application of averaged data from empirical studies (part of respective standards – see above). For this purpose, data from a transport experiment conducted using a TATRA T-810 vehicle will be used.

2. Transport experiment
The subject of measuring and statistical evaluation was a drive that took place on 14th October 2016 in the Czech Republic. For this purpose, a training polygon (refer to Figure 1) in the Military region and training area Březina (close to the town of Vyškov) was used. The experiment was conducted on an unsurfaced road (in the terrain). The measurements were taken on a TATRA T-810 truck of AUT.T810 6X6.1R VALNÍK type having effective weight of 5700 kg [2] without load. The vehicle was in a good technical condition with the mileage slightly below 100 thousand km. The vehicle was driven by a professional driver between the city of Brno and the town of Vyškov.
During the transport experiment, there were ideal climatic conditions with dry terrain, excellent visibility and no rainfall. The vehicle was driven by 6 drivers who were undergoing training in driving vehicles in the terrain. For the article and statistical evaluation, a comparison of acceleration coefficients under various conditions – on the road and a training polygon in the terrain – was crucial, and made the road assessment possible. For the measuring, 4 OM-CP-ULTRASHOCK-5-CERT accelerometers with a datalogger, including a calibration certificate, were used. The measuring equipment (accelerometers) measured acceleration (acceleration coefficients) in all axes (x – longitudinal, y – transversal and z – vertical). These are dimensionless coefficients specifying the acceleration as a multiple of gravitational acceleration. The highest/lowest values of the acceleration coefficients were recorded every second at the frequency of 512 Hz [4] for each axis.

3. Statistical evaluation

3.1. Statistical methods
The goal of the evaluation was to conduct a statistical analysis of the acceleration coefficient values obtained, to make point and interval estimations of parameters of individual partial datasets, and to compare the parameter estimates of individual statistical datasets. For each individual axe, the acceleration coefficients, obtained from a set of measurements taken on the road and on the training polygon (in the terrain) were compared. Before the statistical analyses, tests of normality were performed. Normality was verified graphically; using Q-Q plots [5], skewness and kurtosis were determined for the purpose of the normality testing (Neubauer et al., 2016). In these tests, minor deviations from normal distribution were identified, in particular when testing the kurtosis; the graphical analysis, however, did not show any substantial deviations from normality; theoretical quantiles and corresponding empirical quantiles lay approximately in a line. For the sake of illustration, the Q-Q plots for the datasets related to the drive on a training polygon and the acceleration coefficients measured in x and y axes are shown in Figures 2 and 3.
Figure 2. Q-Q plot: measured acceleration coefficient values in X coordinate during the drive on a training polygon (in the terrain)

Figure 3. Q-Q plot: measured acceleration coefficient values in Y coordinate during the drive on a training polygon (in the terrain)

For this reason and with regard to the size of the datasets compared (the extent of compared selections exceeded 5000), asymptotic confidence intervals and asymptotic statistical test, based on the assumptions of asymptotic normality of the characteristics monitored [5, 6], were also used. For the purpose of calculation, Stat1 application was used [6].

3.2. Description of obtained data

For the purpose of statistical evaluation, average values from all 4 measuring devices (accelerometers) were used. These values were then compared with the basal variant (vector) of acceleration coefficients specified in the norm ČSN EN 12195-1:2011: (0.8; 0.6; 2.0). The normative value for z axis is 1g; however, the recording for this axis does not start at 0g, but at 1g, which is why the axis shift is included in the basal variant in 2g [7].

Consolidated data from the measurements is stated in graphs in Figures 4, 5 and 6.

The graphs in Figures 4, 5 and 6 show a part of the transport from Brno to Vyškov (between 6:57:25 – 8:13:59). In order to prevent the result distortion, two pauses were excluded from the data – at a petrol station and the time before the training began. Between 8:14:00 and 9:51:34, individual drivers were driving the vehicle. In the graph, the moments of driver swapping – short pauses – can be seen. At 9:51:35, there was a short pause and then the vehicle drove back to Brno. The transport experiment was terminated at 10:41:43. 12,233 values were obtained for each axis, i.e. 36,699 values of acceleration coefficients in total.
Furthermore, it is clear from the graphs in Figures 4, 5 and 6 that there is a difference between the Brno–Vyškov and Vyškov–Brno drive and the terrain drive, where there are extreme variations. The greatest variations are mainly found on $z$ axis, where even the highest value of acceleration coefficient was measured ($c_z = 5.4225$, which corresponds to 4.4225g).

Figure 4. Average values of acceleration coefficients (x axis)

Figure 5. Average values of acceleration coefficients (y axis)

Figure 6. Average values of acceleration coefficients (z axis)
Out of the total number of 36,699, 3502 values were outside the normative limits (refer to the basal vector specified in ČSN EN 12195-1:2011), which accounted for 9.54% of the values. A relatively significant amount of the values – 247, which accounted for 0.67% of the total number, even double exceeded the basal vector. The greatest number of values above/below the normative limits is in y axis. This is primarily caused by the lower bound set in the standard (cy = 0.6); extreme values are generally more statistically significant in z axis.

3.3. Statistical characteristics of the entire dataset
For the sake of clarity, the values of the basic statistical characteristics are stated in Table 1.

| Day of measurement | 2016-10-14 |
|-------------------|------------|
| Axes              | x          | y          | z          |
| Mean              | 0.0230     | -0.1144    | 1.4774     |
| Modus             | 0.0550     | -0.1000    | 1.0175     |
| Median            | 0.0150     | -0.1275    | 1.4575     |
| Variance          | 0.2053     | 0.2156     | 0.0892     |

It follows from Table 1 that most basic characteristics are within the standard values, i.e. they fully correspond to the standard’s requirements for maximum/minimum values of the acceleration coefficients. The extremes measured in individual axes are more important (refer to Table 2), from the perspective of securing of a cargo, because even when isolated (extreme) fluctuations, may cause damage or release of cargo, respectively damage to other elements (e.g. lashing straps). The largest number of these values can be found in z axis.

| Day of measurement | 2016-10-14 |
|-------------------|------------|
| Axes              | x          | y          | z          |
| Highest values    | 4.9675     | 2.3500     | 4.4225     |
| Lowest values     | -5.4000    | -4.1825    | *          |

* missing value in the z axis is caused by measuring range of the accelerometer; the measuring range of the z axis is in range from 1 g, i.e. identifying of the lowest value is irrelevant

3.4. Estimation of parameters
From the data obtained, two statistical subsets were considered. The first dataset contained the acceleration coefficient values for individual x, y, and z axes, obtained from road measurements; the times of pauses were excluded. This dataset will be referred to as dataset 1 hereinafter, and the parameters of the set will be marked by index 1. The size of dataset 1 was n1 = 6148. The second subset contained corresponding acceleration coefficient values obtained on the training polygon; the time of pauses was excluded, and similarly to dataset 1, it is referred to as dataset 2 hereinafter. The parameters of the dataset will be marked by index 2. The size of dataset 2 was n2 = 5257. For both the subsets, basic characteristics of the mean value and sample standard deviation were determined as the estimation of expected value µ and standard deviation σ. In addition, the frequency of values exceeding the normative values was determined for individual axes; the respective relative frequency was an estimation of parameter θ specifying the probability of excess. Again, the characteristics
estimated were marked in accordance with the datasets as index 1 (the first dataset, obtained from road measurements), and index 2 (the second dataset, obtained from measurements on the polygon). The estimations were supplemented with 95% confidence intervals for individual parameters. The results for the dataset measured on the road are stated in Table 3, and the results for the dataset measured on the polygon are stated in Table 4.

The values of estimated individual parameters allow the comparison and assessment, how the datasets differ within individual axes in terms of their mean value, variability and probability of the normative value excess. Nevertheless, for a detailed comparison of the datasets, statistical tests based on confidence intervals were employed. Such a comparison is provided in subchapter 3.5.

3.5. Statistical comparison of datasets describing the road and training polygon drives

The comparison of both the datasets, i.e. one dataset measured on the road (dataset 1) and the other measured on the training polygon (dataset 2), was made by comparing standard deviations $\sigma_1$ and $\sigma_2$, mean values $\mu_1$ and $\mu_2$ and probabilities $\theta_1$ and $\theta_2$.

### Table 3. Measurement results – road

| Acceleration measurement in the axes | X | Y | Z |
|--------------------------------------|---|---|---|
| $\sigma_1$ | PE | 0.446 | 0.459 | 0.253 |
|           | LB | 0.438 | 0.451 | 0.249 |
|           | UB | 0.454 | 0.467 | 0.258 |
| $\mu_1$   | PE | 0.023 | −0.130 | 1.510 |
|           | LB | 0.012 | −0.141 | 1.503 |
|           | UB | 0.035 | −0.118 | 1.516 |
| $\theta_1$ | PE | 0.0519 | 0.2025 | 0.0350 |
|           | LB | 0.0463 | 0.1925 | 0.0304 |
|           | UB | 0.0574 | 0.2126 | 0.0396 |

### Table 4. Measurement results – polygon

| Acceleration measurement in the axes | X | Y | Z |
|--------------------------------------|---|---|---|
| $\sigma_2$ | PE | 0.493 | 0.502 | 0.325 |
|           | LB | 0.485 | 0.493 | 0.319 |
|           | UB | 0.502 | 0.511 | 0.331 |
| $\mu_2$   | PE | 0.031 | −0.117 | 1.502 |
|           | LB | 0.018 | −0.130 | 1.493 |
|           | UB | 0.044 | −0.103 | 1.511 |
| $\theta_2$ | PE | 0.0660 | 0.2182 | 0.0506 |
|           | LB | 0.0593 | 0.2070 | 0.0447 |
|           | UB | 0.0727 | 0.2293 | 0.0565 |

### Table 5. Statistical tests of equality

| Acceleration measurement in the axes | X | Y | Z |
|--------------------------------------|---|---|---|
| $\sigma_1/\sigma_2$ | PE | 0.904* | 0.914* | 0.778* |
|           | LB | 0.881 | 0.891 | 0.758 |
|           | UB | 0.928 | 0.938 | 0.799 |
| $\mu_1−\mu_2$ | PE | −0.008 | −0.013 | 0.008 |
|           | LB | −0.0251 | −0.0305 | −0.0028 |
|           | UB | 0.0097 | 0.0050 | 0.0188 |
| $\theta_1−\theta_2$ | PE | −0.0141* | −0.0157* | −0.0156* |
|           | LB | −0.0228 | −0.0307 | −0.0231 |
|           | UB | −0.0054 | −0.0007 | −0.0081 |

Note – Table 3, 4, 5:
PE Parameter estimation
LB Lower bound of 95% confidence interval
UB Upper bound of 95% confidence interval
* means significant difference between parameters of the first and the second dataset at 5% significance level
95% confidence intervals were constructed for the ratio of standard deviations and for the differences in the mean values, and also for the differences in the probabilities of exceeding the normative value. All three comparisons were made for each axis. Using these confidence intervals, statistical tests were then conducted at 5% significance level for the comparison of individual pairs of the parameters. The confidence intervals were constructed based on the methodology described in [5, 6]. The resulting 95% confidence intervals are stated in Table 5. Using the confidence intervals, statistical tests of equality of matching parameters were conducted.

It follows from Table 5 that the mean values of the acceleration coefficients in each axis (x, y, z) do not differ significantly in statistical terms at 5% significance level in the datasets obtained on the road and on the training polygon.

However, the variability of the datasets compared in each axis differs significantly in statistical terms; the variability of the acceleration coefficients obtained on the road is considerably lower than the variability obtained on the training polygon.

Also, the probabilities of exceeding the normative value differ significantly in statistical terms in each of the axes. As expected, the probabilities are higher on the training polygon.

4. A model loading and securing of a cargo for transport

The influence of extreme values of acceleration coefficients on resulting inertial forces (F_T) can be illustrated by means of a model loading. The input value for the acceleration coefficient will be the highest measured extreme value (c_x = −5.400). The values of other acceleration coefficients (c_y and c_z) are taken from the same second of measuring. For the sake of clarity, other input values of the model are stated in Table 6.

| Variable | Value | Unit | Note |
|----------|-------|------|------|
| F_T      | ?     | N    | Tension force |
| F_Tn     | ?     | N    | Tension force (norm) |
| c_x      | −5.400 | −  | Coefficient of acceleration (x) |
| c_y      | −0.5925 | −  | Coefficient of acceleration (y) |
| c_z      | −1.1075 | −  | Coefficient of acceleration (z) |
| µ        | 0.4   | −    | Coefficient of friction |
| m        | 1600  | kg   | Mass of cargo |
| g        | 9.81  | ms⁻² | Gravitational acceleration |
| f_s      | 1.25  | −    | Safety factor |
| n        | 1     | pcs  | Number of lashing straps |
| α        | 85    | °    | Angle – among strap and floor |

The calculation of an inertial force (F_T) is made for one piece of a lashing strap; in real conditions, more pieces may be substituted in the formula. For the sake of comparison, an inertial force (F_Tn) is also calculated using normative values of acceleration coefficients.

For the substitution in formula (1), values specified in standard ČSN EN 12195-1:2011 are used; m and α are substituted for model values 1600 kg (two pallet units of 800 kg next to each other) and 85 degrees, corresponding to common transport conditions and standard method of cargo securing in the cargo space of a vehicle.
The weight and angle are not crucial for the calculations using normative values and the values of measured acceleration coefficients, as the proportion between the calculated values of inertial forces $F_T$: $F_{Tn}$ that is crucial for the conclusions remains unchanged. The relationship for the determination of $F_{Tn}$ is identical; what differs is the input data of the acceleration coefficient values. The input values are stated in Table 7.

It follows from the calculations that when $c_x$ is substituted for a high value, value $F_T$ (for longitudinal direction, x axis) is, in consequence of other acceleration coefficients ($c_y$ and $c_z$), very high, i.e. 48,443 N.

Although the value of the acceleration coefficient $c_x$ is 6.75-times ($5.4/0.8$) higher than the normative value, the inertial force in x axis is, if compared to the assumed (normative) value of the inertial force, almost 12.4-times higher. For the sake of better understanding, a load of 1.6 tons acts as a 5-ton load.

### Table 7. Output values of the model loading

| Variable | Value   | Unit | Note       |
|----------|---------|------|------------|
| $F_T$ (for $c_x$) | 48,443 | N    | absolute value |
| $F_T$ (for $c_y$) | 1461   | N    | absolute value |
| $F_{Tn}$ (for $c_x$) | 3909   | N    |            |
| $F_{Tn}$ (for $c_y$) | 1955   | N    |            |
| $F_T : F_{Tn}$ (for $c_x$) | 12.39  | –    |            |
| $F_T : F_{Tn}$ (for $c_y$) | 0.75   | –    |            |

In y axis, the intensity of the inertial force determined is not statistically significant; it is even lower than the normative value. This is caused by very low values of acceleration coefficients in y and z axes ($c_y$ and $c_z$).

### 5. Conclusion

The transport experiment represents a partial contribution to proving the differences in cargo securing during transport on a common road and in the terrain. The comparison of differences among drivers, unloaded and fully loaded trucks and possibly among other aspects of transportation are the preconditions of further research.

It follows from the statistical analysis of the experiment conducted that the mean value of acceleration coefficients in individual axes does not differ significantly in statistical terms at 5% significance level. Statistically significant deviations between both the datasets can be seen when comparing the variability of acceleration coefficients and when comparing the probabilities of exceeding normative values in individual axes. It has thus been proved that it is the individual maximum values of measured acceleration coefficients that is crucial for load transportation. The impact of individual values of acceleration coefficients is nullified when average values are used. Hence, it would be recommendable to adhere to the theory of extreme values [8], when assessing transport safety and drafting the respective standard.

Further research shall be based on the employment of other statistical tools, or operational research tools so that the hypotheses proposed, e.g. in relation to accidents resulting from inappropriate cargo securing [9], can be verified.

The tools employed for the identification of inertial forces acting during transport clearly proved that particularly at extreme deviations of the acceleration coefficient function the values of inertial forces can significantly exceed assumed values derived from the normative values of acceleration coefficients. Specifically, 0.67 % (247) of values more than double exceeding the normative limits of
acceleration coefficients pose a potential risk for the cargo and its securing. The model proved inertial force acting in x axis that is over twelve times higher than the value calculated using normative acceleration coefficients. Especially, when transporting hazardous items, in army conditions, e.g. ammunition [10], appropriate cargo securing is of great importance.

Acknowledgement
The paper was written with the support of specific research project no. SV16-FVL-109-VLK, funded by the Ministry of Education, Youth and Sports.

References
[1] Ministry of Transport – Transport Yearbook. Goods transported by road 5.2.3.1. [online]. c2015. [vid. 2016-12-09]. Available at <http://www.sydos.cz/cs/rocenka-2014/yearbook/htm/uk14520310.html>. (Czech)
[2] Kolmaš V. et al. 2007. Catalog of automobile and tracked vehicles used in ACR. Ministry of Defence of the Czech Republic, Prague. 222 p. ISBN 978-80-7278-382-3. (Czech)
[3] Seznam – Mapy. Vyškov training area. [online]. c2016. [vid. 2016-12-10]. Available at <https://mapy.cz/zakladni?x=16.9675302&y=49.3309453&z=16&base=ophoto&source=muni&id=5924&q=vy%C5%A1kov>. (Czech)
[4] Omega. Accelerometer – Datalogger [online]. c2015. [vid. 2016-12-09]. Available at <http://www.omega.com/das/pdf/OM-CP-ULTRASHOCK.pdf>.
[5] Johnson, R.A. and Wichern, D.W. 1992. Applied multivariate Statistical Analysis. Prentice-Hall International, Inc. Englewood cliffs.
[6] Neubauer, J. et al. 2016. Elementary Statistics. 2nd extended edition. Praha: Grada. (Czech)
[7] ČSN EN 12195-1. Load restraining on road vehicles – Safety – Part 1: Calculation of securing forces. Czech Office for Standards, Metrology and Testing (2011). Czech Office for Standards, Metrology and Testing. Prague. 48 p. (Czech)
[8] De Haan, L. and Ferreira, A. 2006. Extreme value theory. New York: Springer.
[9] Grzesica, D. 2016. Identification of the cyclical component in modeling road accidents. In Olja Čokorilo (ed.), Third international conference on traffic and transport engineering; Proc. ICTTE, Belgrade, 24-25 November 2016. Belgrade: City Net Scientific Research Center.
[10] Šilinger, K. et. al. 2015. The evidence of ballistic characteristics of artillery ammunition using barcodes within the automated system of artillery fire control. Czech Military Review, 24 (56), No. 4, p. 38-46. ISSN 1210-3292. (Czech)