Comparison of Cargo Securing Requirements for Two Types of Off-Road Vehicles

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Abstract: The paper concerns the comparison of two off-road vehicles on three different types of surfaces with regard to cargo securing requirements. As primary data, the values of the acceleration coefficients are obtained from the transport experiments conducted on the Tatra 815 and the Tatra 810 trucks. The goal of the paper is to identify differences between the operations of both the vehicles in terms of cargo securing in the context of EN 12195-1:2010 standard requirements. An elementary statistical analysis was carried out to evaluate the measured data (values of the acceleration coefficients). Based on the results, there are statistically significant differences between the vehicles, and in several cases deviations from the EN 12195-1:2010 standard assumptions were identified as well. The conclusions above have an influence on the cargo securing selection, and primarily on the lashing capacity of the securing means used. The results are usable in the securing system optimisation for the tested vehicles aiming to prevent risk situations related to the loosening of the cargo during transport.

1. Introduction
Cargo transportation in terrain, or possibly on unpaved roads is not only the domain of armed forces, but also of the Integrated Rescue System (IRS) or agricultural and construction companies. For the transport in terrain or on unpaved roads, the vehicle itself (mainly of off-road type), and in particular the surface itself, which may, in addition, radically change its properties throughout a year, or in general due to the climate (especially rain, snow, hoarfrost, etc.), are the specifics. Given this the commonly applied requirements for the securing system, e.g. of EN 12195-1:2010 “Load Restraining on Road Vehicles – Safety – Part 1: Calculation of Securing Forces” [1] and [2], which is also referred to in European Best Practice Guideline on Cargo Securing for Road Transport Directorate-General for Mobility and Transport [3], also discussed in [4], may not correspond to the greatly differing transport conditions [5, 6].

The key aspect here is the normatively determined values of the acceleration coefficients that are experimentally measured and statistically evaluated (averaged) and should have general validity. Nevertheless, their general validity can only be assumed on the standard roads under normal conditions (e.g. without extremely damaged sections or sections under reconstruction). Often exceeding of
normatively set limits of the acceleration coefficients, especially more than double [7], can be risky for cargo securing, particularly in a case of the dangerous goods transport [8].

Due to the strong statistical relationship between the values of the acceleration coefficients, proved in the article [9] which can be confirmed experimentally by means of accurate accelerometers, and the values of inertia forces, or rather securing forces (from the securing system perspective) to be identified, the statistical evaluation of primary data can be used to formulate the conclusions and recommendations.

2. Transport experiment
For the comparison, two off-road vehicles commonly used in the Army of the Czech Republic and the Integrated Rescue System of the Czech Republic, were used. Specifically, these were:

- The Tatra 815-VVN 6×6 (further in the text only as the “Tatra 815”);
- The Tatra 810-V-1R0R26 6×6 (further in the text only as the “Tatra 810”).

For the purpose of the data (the values of acceleration coefficient) measurement, the training polygon (Figure 1) close to Podivice (District of Vyskov, South Moravian Region), having the length of 3,550 meters and comprising three surface types, was made by the use of:

- Green – granite cobbles (1,700 m);
- Blue – unpaved road (1,550 m);
- Red – concrete blocks (170 + 130 m).

The transport experiment was conducted without the cargo in order to provide comparable outcomes that can be considered as the least favourable if compared to a fully loaded vehicle. The polygon surface was dry, there was very good visibility and no rainfall during the transport experiment. The outdoor temperature ranged between 5 and 10°C [10].

For the purpose of recording the shocks – multiples of normal acceleration of gravity g, or possibly the values of the acceleration coefficients – the following measuring device was used: OMEGA-CP-ULTRASHOCK-5 with the measuring range of ±5g.

The acceleration coefficient for the longitudinal direction of the vehicle movement was formally denoted $c_x$, for the transverse direction $c_y$ and for the vertical direction $c_z$ [11].

![Figure 1. Experimental polygon close to Podivice.](image-url)
2.1 Data
In the framework of the transport experiment, each of the vehicles went round the polygon 10 times; the number of data collected to perform the subsequent statistical analysis is shown in Tables 1 and 2 for the sake of overview.

Simultaneously, the number of the data expresses the total time in seconds (t), from which the average lap speed can be determined. The sampling frequency was 512 Hz with the logging of the highest and lowest extremes per every second [10].

The total number of data obtained from those 10 laps for the Tatra 815 was 10,731 (3,577 per each axis); for the Tatra 810 it was 10,827 (3,609 per each axis).

| Road   | LAP (number of data) | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  |
|--------|----------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Green  | 134                  | 129 | 128 | 138 | 131 | 131 | 128 | 128 | 128 | 133 |
| Red    | 26                   | 22  | 22  | 25  | 27  | 26  | 23  | 23  | 24  | 26  |
| Blue   | 183                  | 186 | 188 | 183 | 182 | 180 | 186 | 186 | 187 | 185 |
| Red    | 16                   | 17  | 19  | 17  | 18  | 18  | 18  | 18  | 19  | 19  |
| t (s)  | 359                  | 354 | 357 | 363 | 358 | 356 | 355 | 356 | 358 | 361 |
| v (m·s⁻¹) | 9.9         | 10.0| 9.9 | 9.8 | 9.9 | 10.0| 10.0| 10.0| 9.9 | 9.8 |

From Table 1, it follows that the difference between the laps for the Tatra 815 is minimal; the deviation from the average time is below 1.3 %. The same applies to the deviation from the average lap speed, if unrounded values of the average speed are applied.

From Table 2 similar conclusions follow for the Tatra 810; the deviation from the average time is below 1.3 %. The same applies to the deviation from the average lap speed, if unrounded values of the average speed are applied.

The first dataset \(d_1\) contains the acceleration coefficient values measured on the Tatra 815; the other dataset \(d_2\) contains the data measured on the Tatra 810. Both the datasets are for practical reasons compared with the theoretical values of acceleration coefficients as per EN 12195-1:2010, formally denoted with index \(n\):

- \(c_{nx} = 0.8\);
- \(c_{ny} = 0.6\);
- \(c_{nz} = 1.0\);

and for the z-axis, the value of 2.0 applies due to the shift of the coordinate axis in the measuring device by \(1g\) [12].
2.2 Methods
In the paper, descriptive statistics were used, specifically the range, the arithmetic means of the absolute values of the acceleration coefficients, the standard deviation, the average time, and the speed were calculated. Furthermore, the probabilities of excess (\( \pi \)) of the normatively determined values as per EN 12195-1:2010. For practical reasons, even the double excess (\( \rho \)) of the normatively determined values as per the above-mentioned standard was taken into consideration.

Before the statistical analysis, normality tests were performed using skewness and kurtosis coefficients [13]. The significance level was \( \alpha = 0.05 \).

Although in some of the three axes (x, y, z) for both datasets \( d_1 \) and \( d_2 \) the distribution of the acceleration coefficients values was not normal, but symmetrical (which was verified by Q-Q plots, histograms, and skewness coefficients) and included outliers, further analysis was carried out assuming normal distribution. For the comparison of the \( d_1 \) and \( d_2 \) datasets, a parametric statistical analysis (one-sided t-test) was used at the significance level of \( \alpha = 0.01 \).

3. Statistical evaluation

3.1 Descriptive statistics
The experimental data measured in the three dimensions: longitudinal (x), transverse (y) and vertical (z) axis expressed by the values of the acceleration coefficients in the \( d_1 \) and \( d_2 \) datasets were statistically evaluated. Table 3 shows the descriptive statistics results, and it is clear that the \( d_1 \) and \( d_2 \) datasets differ to a great extent. It can be seen from Table 3 that the lowest arithmetic means of the absolute values of the acceleration coefficients (0.53) were measured in the x-axis, and y-axis of the \( d_2 \) dataset, respectively. Contrarily, in the \( d_1 \) dataset, the highest arithmetic means of the absolute values of the acceleration coefficients (2.44) was measured in the z-axis.

From Table 3 it also follows that while the average time and the average speed per lap on the polygon were comparable in the \( d_1 \) and \( d_2 \) datasets, it is not the case of the other descriptive characteristics. The standard deviation value is more than double in the z-axis in the \( d_1 \) dataset compared to the \( d_2 \) dataset.

|                  | \( d_1 \) (Tatra 815) | \( d_2 \) (Tatra 810) |
|------------------|-----------------------|-----------------------|
| Min              | x₁: -2.85, y₁: -2.13, z₁: 1.34 | x₂: -2.84, y₂: -2.16, z₂: 1.45 |
| Max              | x₁: 2.01, y₁: 4.82, z₁: 6.98 | x₂: 3.33, y₂: 3.26, z₂: 4.67 |
| Arith. Means ABS| x₁: 0.70, y₁: 0.76, z₁: 2.44 | x₂: 0.53, y₂: 0.53, z₂: 2.01 |
| Standard Deviation| x₁: 0.71, y₁: 0.70, z₁: 0.58 | x₂: 0.55, y₂: 0.43, z₂: 0.26 |
| Average Time     | x₁: 357.70, y₁: 357.70, z₁: 357.70 | x₂: 360.90, y₂: 360.90, z₂: 360.90 |
| Average Speed    | x₁: 9.93, y₁: 9.93, z₁: 9.93 | x₂: 9.84, y₂: 9.84, z₂: 9.84 |

In several cases, the arithmetic means of the absolute values exceed the normatively determined limit as per EN 12195-1:2010 (in \( y_1 \), \( z_1 \) and \( z_2 \)), which may be considered potentially dangerous. When comparing the two vehicles, the Tatra 810 shows “better” values of shocks in relation to cargo securing [14].

Table 3 further shows the highest and the lowest values of shocks measured within the \( d_1 \) and \( d_2 \) datasets. For both the vehicles and all the axes, the extremes measured more than double exceeding of the normatively determined limits. The highest measured value \( (z_1 = 6.98) \) even exceeds the
normatively determined limit six times, and the cargo of a model weight of 1,000 kg would thus “act” as having the weight of almost 6,000 kg during the transport.

In Table 4 the probabilities of excess and double excess of the standard values based on the experimentally measured data are shown. Again, the significant excess values can be observed, in particular in the \( d_1 \) dataset.

### Table 4. The probabilities of excess and double excess of the standard values.

|                  | \( d_1 \) (Tatra 815) | \( d_2 \) (Tatra 810) |
|------------------|------------------------|------------------------|
| Excess of the    |                         |                        |
| standard values  | No. of excesses        | 6,407                  |
|                  | Total no. of data      | 10,731                 |
| \( \pi \) (%)    | 59.71                  | 21.65                  |
| Double excess of |                         |                        |
| standard values  | No. of excesses        | 574                    |
|                  | Total no. of data      | 10,731                 |
| \( \rho \) (%)   | 5.35                   | 0.79                   |

Table 4 shows a significant difference between both the datasets. In the \( d_1 \) dataset, the total of 6,407 values (out of 10,731 measured) exceeded the normatively determined values in at least one axis. In spite of the fact that the \( z \)-axis prevailed (2,858 values out of the total number of excesses), the number of excesses in the \( y \)-axis was also high (2,562 values). The probability of an excess of the normatively determined values was (\( \pi_1 = 59.71 \% \)); in a case of the double excess it was (\( \rho_1 = 5.35 \% \)). In the \( d_2 \) dataset, the total of 2,344 values (out of 10,827 measured) exceeded the normatively determined values in at least one axis. Once again, the \( z \)-axis prevailed (1,493 values out of the total number of excesses), and the number of excesses in the \( y \)-axis was also higher (726 values). Hence, the probability of the excess of the normatively determined values is (\( \pi_2 = 21.65 \% \)), and the probability of the double excess of the normatively determined values is (\( \rho_2 = 0.79 \% \)).

#### 3.2 Vehicle comparison

A one-sided \( t \)-test was carried out for the comparison of the \( d_1 \) and \( d_2 \) datasets. The test was performed in all three axes at a significance level of \( \alpha = 0.01 \). The results of the performed tests are shown in Table 5. In the first column of this table, the relevant acceleration coefficients are listed. In the second column (\( AH_t \)), the alternative hypothesis of the one-sided \( t \)-test is shown. In column \( t \), the test statistics of the \( t \)-test assuming heteroscedasticity is shown. And finally, the column denoted \( p \) contains the \( p \)-values of the \( t \)-test assuming heteroscedasticity.

### Table 5. Results of the one-sided \( t \)-test in all the axes.

| Acceleration coefficients [-] | \( AH_t \) | \( t \) | \( p \) |
|-------------------------------|------------|--------|-------|
| \( c_x \)                     | \( \mu_1 > \mu_2 \) | 35.07* | 0.00* |
| \( c_y \)                     | \( \mu_1 > \mu_2 \) | 41.55* | 0.00* |
| \( c_z \)                     | \( \mu_1 > \mu_2 \) | 39.97* | 0.00* |

*indication of the values of relevant statistics, when the related null hypothesis was rejected at the 1 \% significance level.

From the results in Table 5 it is evident that there are statistically significant differences between the both military trucks at the significance level of \( \alpha = 0.01 \) in all the axes. These results point to very different values of the shocks generated by the Tatra 815 (\( d_1 \) dataset) and by the Tatra 810 (\( d_2 \) dataset).
The Tatra 810 thus on average generated smaller shocks than the Tatra 815. As far as the securing system is concerned, securing means with greater lashing capacity shall be used on the Tatra 815.

4. Conclusions

The results of the one-sided t-test stated in Table 5 prove that the absolute values of the acceleration coefficients in all the axes measured for the Tatra 810 are statistically smaller than for the Tatra 815, i.e. in terms of the generated shocks the more up-to-date vehicle Tatra 810 shows much better results. This fact is also confirmed by the probabilities of the excess/double excess of the normatively determined values of the acceleration coefficients. From the perspective of the arithmetic means of the acceleration coefficients values, the assumptions of the EN 12195-1:2010 standard are only met for the Tatra 810 vehicle, with a minor deviation in the z-axis. For the Tatra 815 vehicle, the arithmetic means of the acceleration coefficients values exceed the normatively determined limits rather significantly in the y-axis a z-axis, which has a considerable impact on the selection of the cargo securing system, and in general on the operation economy – in particular the maintenance and the frequency of the vehicle repairs [15].

In further research, the surfaces selected for the transport experiment shall be analysed by the means of the capability analysis [16], Six sigma algorithm [17], Extreme Value Theory [18], spectral analysis. [19, 20] or other mathematical methods [21, 22], and individual laps driven by the respective vehicles shall be evaluated and compared.

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