ISSN 1330-3651 (Print), ISSN 1848-6339 (Online)
https://doi.org/10.17559/TV-20230614000733
Original scientific paper

Analyzing Site-Specific Tractor Draft Force in Different Passes during Plowing

Mateja ORTOPAN, Vojislav SIMONOVIĆ*, Nevena TASIĆ, Emil VEG, Ivan ZLATANOVIĆ, Nenad GUBELJAK

Abstract: The difference in draft force is analyzed for six different passes during longitudinal plowing of the plot. The force is measured indirectly using four strain transducers. Values of the force are obtained by calculation after previous calibration and then measurements in the experimental field. The strain readings on the sensors installed on the outside of the tractor lower links are used. Similar values are obtained on the other two sensors installed on the inside of the links. The biggest difference is observed between the first and second pass, respectively, the second and third one for which the value of effect size amounts to 0,824 and 0,835 respectively. The study highlights draft force in the function of soil resistance as an exceptionally important parameter in the analysis of agricultural soil and suggests the expansion of current routine in precision agriculture mapping.

Keywords: draft force; lower links; pass; strain transducer

1 INTRODUCTION

The task of precision agriculture is to detect and make use of the plot site-specificity. The most frequently employed parameters for the purpose are crop yield, crop condition and the content of chemical elements in the soil. Soil compaction is among the most significant soil physical properties of all. The measurements of this soil property involve the application of multiple methods of different complexity levels. The devices can have different constructions. The "stop-and-go" principle-based measurements utilize manual or automated vertical penetrometers. Required additional effort and time for measurements is common for all of them. If measurement is performed according to the "on-the-go" principle, horizontal penetrometers with one [1-4] or more measuring components [5-8] can be used. Besides, all soil tillage operations, especially plowing, are greatly suitable for simultaneous measurements of soil mechanical resistance by measuring the draft force. In this case, measurements can be done using universal measuring frames or instrumentalized tractors that have force transducers [9] placed on their hydraulic lift links. The three-point linkage transfers forces acting on the implement to the tractor during operation. Plowing is a highly power demanding soil tillage operation [10], comprehending cutting and turning up and over the surface soil layer enriched with minerals and decomposed organic matter, usually in the depth range of 15 - 30 cm. Going deeper increases the soil resistance and consumed energy. Beside the ploughing depth, soil reactions toward plow depend on the tractor speed, soil physical parameters and the plow design [11]. In this study, during plowing, a simple method of measuring draft force by 4 strain transducers was used. Agricultural tractor workload occurs in accordance with soil resistance caused by the soil-implement interaction during tillage. It means that the soil properties distribution according to the soil layer and tillage depth [12-14] are the key factors that have the greatest influence on the efficiency and mechanical loading of the agricultural tractors. Earlier studies of tractor loading were mainly conducted based on the tillage force prediction and analysis. Tillage force is the force required to pull an implement in the direction of tractor operation and it is mainly affected by the driving speed (i.e., gear selection), machine geometry, tillage depth and soil environment (e.g., soil texture, soil properties, water content) [15]. The major objective of measurement results analysis was to evaluate the difference levels in draft force measured values within control limits in the experimental field between six representative adjacent passes. Prior to the measurement system calibration, it is necessary to predict the expected pulling force during ploughing with a two-furrow plough 245 kg overall weight of the aggregated tractor 82 kW power. Variability of the soil properties imposes hard difficulties in the formulation of the general equations for the draft evaluation. Forces acting on the plough can be represented by the resulting three-dimensional force that acts at the point of application. The point of application is not fixed because it depends on variable soil resistance, plough adjustment and connecting plough to a three-point lift mechanism. Lateral force R_z originates from the soil. Vertical force R_y comes from the plough weight, vertical component of soil resistance and soil weight that the plough is carrying. Part of the vertical force can be taken over by the auxiliary wheel. There are several methods for defining the R_x horizontal draft of the tractor attachment. Investigation of differences between draft force values from one pass to another was conducted using the Mann-Whitney U test. Statistical significance was proved for differences in yield values between individual passes during harvest [16, 17]. Plowing is a more challenging operation in terms of measuring and analysis, primarily due to smaller working width and greater data variability but, at the same time, the draft force and soil force resistance mapping, respectively, generate multiple times better resolutions regarding data variability than during harvesting. This paper presents the conceptual solution of the procedure for measuring site-specific variability of soil compaction by means of measuring the draft force variability during soil tillage. Based on measured values, it is possible to generate site-specific draft force map. Pulling and draft force were measured indirectly through dilatation of the tractor lower links that a two-furrow plough was attached to.

2 MATERIAL AND METHODS

Key elements of the measuring system for direct measurements of the plow draft force values in this study were strain transducers. These sensors are installed on the lower links of the tractor lift mechanism. They are placed on both sides of the two lower links facing each other longitudinally. Strain transducers of the HBM manufacturer, model SLB700A/06, are designed purely to measure static and dynamic strains within the load limits. A total of four sensors are installed, Fig. 1. Measurement signal from the sensor is processed using the data acquisition (DAQ) unit of the HBM manufacturer, model Quantum MX840A, which has eight inputs. Location positioning equipment of the manufacturer AG Leader Technology included the antenna model GPS1600 for Egnos signal reception and tractor monitor model Integra for monitoring the motion of the tractor-machine unit. The antenna signal was introduced simultaneously through a specially designed adapter into the tractor monitor (terminal) and into the computer.

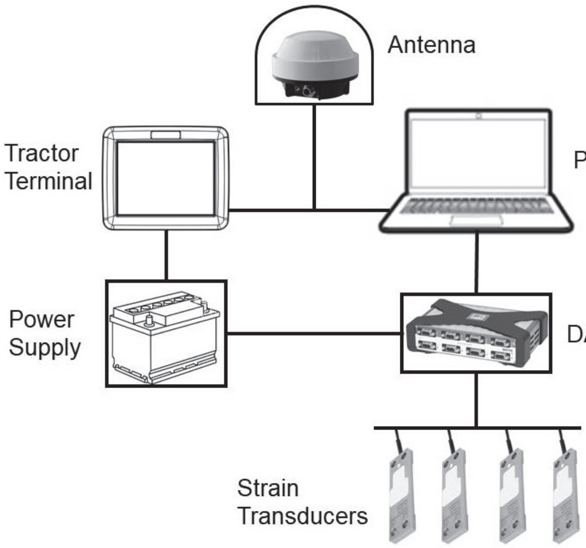

Figure 1 Scheme of installation for draft force measuring

The most suitable position for installing sensors on the tractor lower links was identified after the link strain state analysis. Prior to installing sensors, links were machined by milling on both sides and cleaned to provide smooth surface for the sensors to adhere to. Strain transducer is bolted to the measurement object with four standard M6 hexagon socket screws. For optimum measurement results, there are screws of property class 12,9; to be tightened in a diagonally opposite sequence with a torque of 16 Nm. On each link two sensors are installed on both sides of the link using the same screws. Strain transducer on the outside of the left link, viewed from the direction of motion, is designated by S1, while sensor on the inside of the same link is designated by S2. Strain transducer on the inside of the right link is marked with S3, while sensor on the outside of the same link is marked with S4. In Fig. 2 are shown sensors ST2 and ST4 from the inside of the left link and from the outside of the right link. The output of the transducer is expressed as mV/V. It shows the output voltage generated when 1 V is applied. Voltage and currently applied force can be calculated only indirectly.

For the purpose of calibration, force transducer of the manufacturer HBM, type U1/5MP, was used as calibrated in conformity with ISO 7500-1:2018. Calibration was carried out by successive loading of the force transducer and the tractor lift mechanism applying the axial force. The links were exposed to bending so that inside sensors were loaded in tension and outside sensors in pressure. This influenced the choice of a model for draft force calculation. The force was calculated using correction factors obtained by calibration and the summary displays of voltage output on the outside (S1 and S4) and inside sensors (S2 and S3), respectively.

Figure 2 Position of strain transducer sensors installed on the lower links

Draft force values F_o and F_i calculated in these two manners should be also approximately equal under conditions of draft force varying in the field during plowing, but should also correspond to the values obtained by means of standard ASABE Standard D497.4, 2003 [18]. For mapping and statistical analyses that followed, the F_o values were used.

3 RESULTS AND DISCUSSION

Soil analysis indicated that pH value is 7,27; P_2O_5 concentration 21,6 mg/100 g, K_2O concentration 21,2 mg/100 g, and humus content 3,56%. The soil EC is a measure of how easily an electric current flows through the soil. Soil EC responds to the amount of salt in the soil and indicates the soil composition the amount of sand, clay, organic matter and water content. The map of soil electromagnetic conductivity suggests a comparatively good soil conductivity and small variability of this conductivity across the experimental field. Draft force measurement was conducted in the experimental field of 1 hectare in size. However, the control limits were narrowed in relation to the field limits so that constant conditions apply along the entire pass length. This refers primarily to the tillage depth of 30 cm and tillage speed of 2 m/s. Soil moisture was uniform and there was no slip. Plow adjustment did not affect draft force. The plow had two plow bodies, overall working width per a single pass amounted to 70 cm, while each pass length within control limits was 120 m. In this study, the total of six representative tractor passes were chosen for analysis. Output voltage of strain transducers can be visualized through box plots. In Fig. 3, the horizontal line present inside the grey colour boxes refers to the median of the output voltage. The box covers 50% of the data referred to as the inter quartile range (IQR), and the median line divides the data in equal proportions. The vertical lines are drawn on either side of the box which is referred to as whiskers. The length of the whiskers is drawn, 1,5 times of IQR or drawn up to the last data point [19]. These whiskers cover most of the remaining data. However, the data which lies outside the whiskers are called outliers and are represented by dots. In Fig. 3, it is inferred that the strain transducer feature has different range distribution. As previous analyses also showed, sensors ST1 and ST4 have similar ranges, as well as sensors ST2 and ST3. Sensors on the right rod ST3 and ST4 have narrower ranges and less outliers than those on the left rod.

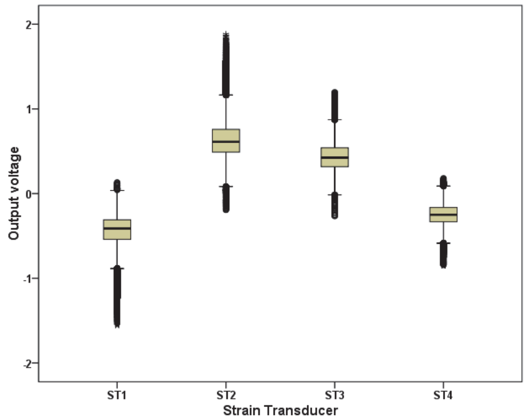

Figure 3 Output voltage box plot

Mean value of draft force, when it is calculated using sensors of the outside lower links, is F_o = 9,864. When sensors from the inside of lower links are used, draft force calculated value is F_i = 9,868. A slight deviation of the mean values justifies the pairing of the corresponding sensors when calculating draft force. For a big sample of voltage measured values and calculated draft forces, the distribution is approximately normal. In order to evaluate the significance of individual sensors for accurate determination of the draft force, correlation analysis was performed for all four sensors and the draft force that was calculated in two ways. The results are given in Tab. 1.

Table 1 Pearson correlation coefficients between measured and calculated values

Variable						
ST1	-	−0,975**	−0,423**	0,328**	−0,893**	−0,851**
ST2		-	0,497**	−0,380**	0,900**	0,904**
ST3			-	−0,973**	0,775**	0,820**
ST4				-	−0,718**	−0,730**
Fo					-	0,975**
Fi						
** $p < 0{,}01$ level (2-tailed)						

The results presented in Tab. 1 confirm several facts. First, there is a strong correlation between value readings of the output voltage on those sensor pairs located on the same tractor lower links, $r = -0{,}975$ for ST1 and ST2 on the left lower link, $r = -0{,}973$ for ST3 and ST4 on the right lower link. Negative value of the Pearson coefficient suggests reverse sensor strain also shown in real time graphs. Then, a high value of the Pearson coefficient $r = -0{,}975$ for different models of draft force calculations F_o and F_i suggest equal use value of both calculation formulas. Finally, the sensor which independently represents best the value of draft force isa strain transducer ST2. Strong positive correlation was calculated between output voltage on this sensor and pulling force F_i, $r = 0{,}904$, $n = 195040$, $p < 0{,}05$, therefore a high 81% of common variance is obtained. The frequency of draft force sampling amounted to 50 Hz. Draft force data was stored, visualized and then analyzed using software CatmanEasy 4.2.2.14, HBM manufacturer, Fig. 4. Prior to measurement, zero balance of all sensors was done while tractor was in an idle state with a plough lowered to the ground.

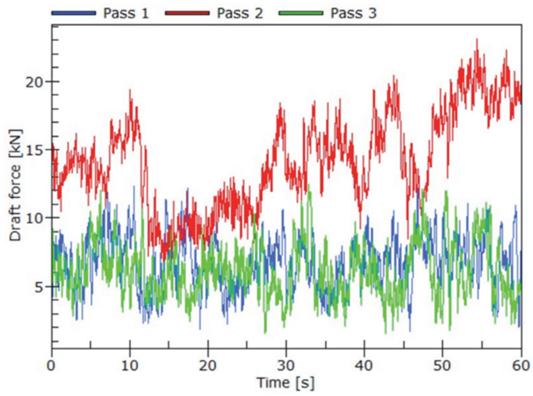

Figure 4 Representative real-time graphs of pulling force and soil resistance inside control limits for passes 1, 2 and 3

Draft force values during each of the six observed passes were mapped in Fig. 5. Ordinal numbers for passes are specified from 1 to 6 in the north direction, i.e., from the bottom to the top in the Fig. 5. Measurement in adjacent passes was performed for tractor motion in the same direction.

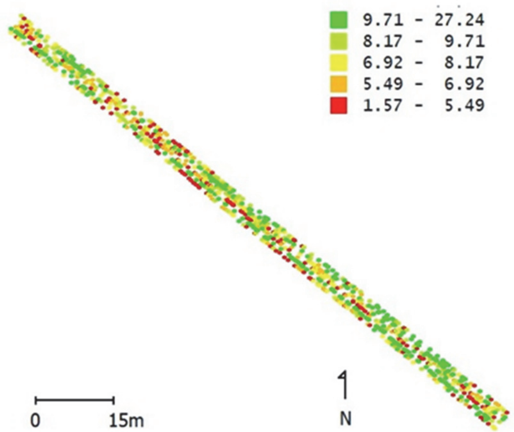

Figure 5 Representation of site-specific draft force, kN, software SMS Advance by AG Leader Technology

Additional data processing was done with software SMS Advance by AG Leader Technology, for mapping and with software SPSS Statistics 21 by IBM, for statistical data analysis. Tab. 2 will display medians for all six analyzed passes, where more detailed analyses, i.e., comparison of individual passes will follow.

Table 2 Mean value, number of samples, standard deviation and median of draft force for 6 different consecutive passes

Pass Num	Mean	N	Std. Deviation	Median
1	6,73943	3091	1,944380	6,7980
2	14,32600	3283	3,513320	14,3500
3	6,17743	3130	1,964906	5,9445
4	7,49458	2989	1,849926	7,3690
5	11,37020	2940	3,488540	11,1600
6	8,99572	2869	3,214581	8,5720

In addition to information on atypical points, a rectangular diagram represents the shape of the draft force distribution of different passes, Fig. 6. It indicates the variability of results within each pass and provides a visual survey of differences between the groups. This possibility will be employed in the analysis of draft force variability for adjacent passes on the same plot.

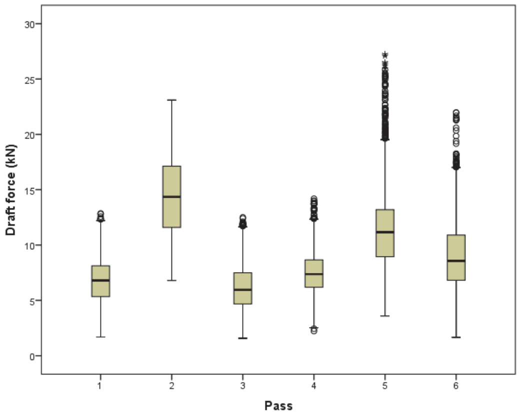

Figure 6 Box plot for six-pass draft force

In the case of comparing draft force between pass 1 and pass 2, $z_{12} = -65,783$ and $N = 6374$, therefore r_{12} amounts to 0,824. This would be considered as a large effect according to Cohen's criterion [20-22]. In Tab. 3 is show cross-presentation of effect r_{ij} values for all six observed passes, where statistically significant difference was previously observed, i.e., the p value was below 0,05.

Table 3 Value of effect size r_{ij} for passes where draft force is statistically significantly different

r_{ij}	1	2	3	4	5	6
1		0,824	0,153	0,176	0,674	0,371
2	0,824		0,835	0,796	0,402	0,632
3	0,153	0,835		0,330	0,722	0,470
4	0,176	0,796	0,330		0,600	0,245
5	0,674	0,402	0,722	0,600		0,346
6	0,371	0,632	0,470	0,245	0,346	

In the case of draft force comparison between adjacent passes during plowing the effect size was relevant. The largest difference is observed between passes 1 and 2 as well as between 2 and 3, because the value of effect size is 0,824 and 0,835, respectively. These values suggest a large difference in draft force between the cited passes. The smallest difference is noted between passes 1 and 3 because the value of effect size r equals 0,153. This value suggests a small difference in draft force between the cited passes. The values presented here are given in Tab. 3 and correspond completely with real-time graphs of pulling force and soil resistance shown in Fig. 4.

4 CONCLUSION

Draft force maps are more suggestive if they are represented as base maps instead of contour maps, and even grid maps. This is a consequence of evident and logical fact that soil structure on production plots is mostly ruined by tractor-machine units that tread the soil, and that this phenomenon is expressed longitudinally, the direction of tractor motion. This is the reason why differences in soil structure are even more pronounced across the field width. Any zoning of draft force tends to produce a false image. Hence, such maps of soil compaction draft force are visually hardly comparable with other maps, e.g., of yield or crop scouting. Yet, at the level of raw maps with source data, the maps of draft force can be compared with all other maps in the domain of precision agriculture by applying different analytical and statistical methods. Knowledge of certain draft forces, their values and way they affect tractor operation is a starting point for appropriate aggregation of tractors and working machines. By mapping draft forces when applying different working machines aggregated with the tractor, data useful for precision agriculture can be obtained but also optimal decisions can be made regarding the choice of working tools on attachment machines and their adjustment. For example, it is possible to make a more proper choice of the type of mouldboard, or adjustment of the operating plough, or a better choice of the type of teeth and adjustment of their inclination on the harrow. For mapping of pulling force and soil resistance, respectively, and consequently soil compaction by applying the described method, two sensors are sufficient. Average value of forces F_o and F_i is approximately very equal for given conditions and in given measured range, therefore either only outside or only inside sensors can be employed. Output voltage signals on sensors installed on the same links are of similar absolute values but different sign. Signal diagrams and statistical analysis have shown a significant need for data filtering. This way, too large amplitudes of output voltage and pulling force can be avoided and thus more reliable maps obtained. After the previous thorough analysis based on the Mann-Whitney U test principles, it is arrived at the conclusion that Z statistics applied to draft force during a pass when plowing can be used as a good indicator of the plot site-specificity in terms of soil compaction and other physical properties being observed indirectly by measuring exactly the draft force. The procedure and principles of the analysis of force variability and site-specificity of the plot applied in the described experimental field during plowing are applicable for any other field or any other tillage operation. Statistical analysis of obtained draft force values per pass proves to be an extremely rewarding tool for understanding site specificity of the plot. Calculation procedure, i.e., the procedure presented in this study is very simple. However, the measurement procedure requires caution, primarily in calibration and measurement during plowing.

Acknowledgements

This work was supported by the National Research Projects of the Republic of Serbia Ministry of Education, Science, and Technological Development, Project of Technological Development under Grant (Contract number 451-03-47/2023-01/ 200105 from 03.02.2023.).

5 REFERENCES

[1] Hall, H. E. & Raper, R. L. (2005). Development and conceptual evaluation of an on-the-go soil strength measurement system. *T. ASAE*, *48*(2):469-477. https://doi.org/10.13031/2013.18311

[2] Raper, R. L. & Hall, H. E. (2003). Soil strength measurement for site-specific agriculture. *U.S. Patent No. 6647799*.

[3] Naderi-Boldaji, M., Sharifi, A., Jamshidi, B., Younesi-Alamouti, M., & Minaee, S. (2011). A dielectric-based

combined horizontal sensor for on-the-go measurement of soil water content and mechanical resistance. *Sensor. Actuator.*, *171*, 131-137. https://doi.org/10.1016/j.sna.2011.07.021

[4] Topakci, M., Unal, I., Canakci, M., Celik, H. K., & Karayel, D. (2010). Design of a horizontal penetrometer for measuring on-the-go soil resistance. *Sensors*, *10*, 9337-9348. https://doi.org/10.3390/s101009337

[5] Chukwu, E. & Bowers, Jr. C. G. (2005). Instantaneous multiple-depth soil mechanical impedance sensing from a moving vehicle. *T. ASAE*, *48*(3), 885-894. https://doi.org/10.13031/2013.18492

[6] Andrade-S'anchez, P., Upadhyaya, S. K., Jenkins, & B. M. (2007). Development, construction, and field evaluation of a soil compaction profile sensor. *T. ASABE*, *50*(3), 719-725. https://doi.org/10.13031/2013.23126

[7] Hemmat, A., Binandeh, A. R., Ghaisari, J., & Khorsandia, A. (2013). Development and field testing of an integrated sensor for on-the-go measurement of soil mechanical resistance. *Sensor Actuator*, *198*, 61-68. https://doi.org/10.1016/j.sna.2013.04.027

[8] Sharifi, A. & Mohsenimanesh, A. (2011). Soil mechanical resistance measurement by an unique multi-cone tips horizontal sensor. *Int. Agrophys.*, *26*(61-64). https://doi.org/10.2478/v10247-012-0009-7

[9] Kostić, M., Malinović, N., Meši, M., & Belić, M. (2012). Application of GPS and GIS technology in mechanical soil resistance measurement. *Cotemporary agricultural engineering*, *38*(3), 219-229.

[10] Fröba, N. (1995). Benötigte Traktor Motorleistung bei landwirtschaftlichen Arbeiten, *KTBL Arbeitsblatt Nr. 0255 in Landtechnik*, *50*(5), 277-282.

[11] Cerović, V., Milković, D., Grbović, A., Petrović, D., & Simonović, V. (2020). 2D Analytical Model for Evaluation of the Forces in the Three-point Hitch Mechanism, J*ournal of Agricultural Sciences Tarim Bilimleri Dergisi*, *26*(3), 271-281. https://doi.org/10.15832/ankutbd.493339

[12] Jabro, J. D., Stevens, W. B., Iversen, W. M., & Evans, R. G. (2010). Tillage Depth Effects on Soil Physical Properties, Sugarbeet Yield, and Sugarbeet Quality. *Commun. Soil Sci. Plant Anal*., *41*, 908-916. https://doi.org/10.1080/00103621003594677

[13] Lee, K. S., Park, J. G., Cho, S. C., Noh, K. M., & Chang, Y. C. (2007). Physical Properties of Hardpan in Paddy Fields. *J.Biosyst. Eng*., *32*, 207-214. https://doi.org/10.5307/JBE.2007.32.4.207

[14] Chung, S. O. & Sudduth, K. A. (2006). Soil failure models for vertically operating and horizontally operating strength sensors. *Trans. ASABE*, *49*, 851 863. https://doi.org/10.13031/2013.21725

[15] Kim, Y. S., Lee, S. D., Baek, S. M., Baek, S. Y., Jeon, H. H., Lee, J. H., Kim, W. S., Shim, J. Y., & Kim, Y. J. (2022). Analysis of the Effect of Tillage Depth on the Working Performance of Tractor-Moldboard Plow System under Various Field Environments. *Sensors*, *22*, 2750. https://doi.org/10.3390/s22072750

[16] Simonović, V., Marković, D., Marković, I., & Kirin, S. (2016). Impact of sensor readings of grain mass yield on combine speed. *Technical Gazete*, *23*(1), 157-162. https://doi.org/10.17559/TV-20141019192801

[17] Simonović, V., Marković, D., & Marković, I. (2016). Testing of sitespecific yield in diferent harvest passes. *Technical Gazete*, *23(*2), 499-503. https://doi.org/10.17559/TV-20140930145702

[18] ASAE Standard D497.4, (2003). Agricultural Machinery Management Data, *ASAE, St. Joseph, Michigen, USA*.

[19] Zuperl, U., Kovačič, M., & Brezočnik, M. (2022). An ANFIS-Mechanistic Simulator of Tool Loads in Ball-End Milling of Layered Metal Materials. *Int. Journal of Simulation Modelling*, *21*(4), 639-650.

[20] Ellis, P. D. (2010). The Essential Guide to Effect Sizes: An Introduction to Statistical Power, Meta-Analysis and the Interpretation of Research Results. *United Kingdom: Cambridge University Press.* https://doi.org/10.1017/CBO9780511761676

[21] Cohen, J. (1988). Statistical Power Analysis for the Behavioral Sciences (second ed.). *Lawrence Erlbaum Associates.*

[22] Lipsey, M. W., Puzio, K., Yun, C., Hebert, M. A., Steinka-Fry, K., Cole, M. W., Roberts, M., Anthony, K. S., & Busick, M. D. (2012). Translating the Statistical Representation of the Effects of Education Interventions Into More Readily Interpretable Forms. *United States: U.S. Dept of Education, National Center for Special Education Research, Institute of Education Sciences,NCSER 2013-3000*.

Contact information:

Mateja ORTOPAN, PhD Student
University of Belgrade, Faculty of Mechanical Engineering,
Kraljice Marije 16, 11120 Belgrade, Serbia
E-mail: mortopan@mas.bg.ac.rs

Vojislav SIMONOVIĆ, Associate Professor
(Corresponding author)
University of Belgrade, Faculty of Mechanical Engineering,
Kraljice Marije 16, 11120 Belgrade, Serbia
E-mail: vsimonovic@mas.bg.ac.rs

Nevena TASIĆ, PhD Student
University of Belgrade, Faculty of Mechanical Engineering,
Kraljice Marije 16, 11120 Belgrade, Serbia
E-mail: ntasic@mas.bg.ac.rs

Emil VEG, Associate Professor
University of Belgrade, Faculty of Mechanical Engineering,
Kraljice Marije 16, 11120 Belgrade, Serbia
E-mail: eveg@mas.bg.ac.rs

Ivan ZLATANOVIĆ, Associate Professor
University of Belgrade, Faculty of Mechanical Engineering,
Kraljice Marije 16, 11120 Belgrade, Serbia
E-mail: izlatanovic@mas.bg.ac.rs

Nenad GUBELJAK, Full Professor
University of Maribor, Faculty of Mechanical Engineering,
Smetanova ul. 17, 20000 Maribor, Slovenia
E-mail: nenad.gubeljak@um.si