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Department of Transport Engineering and Logistics

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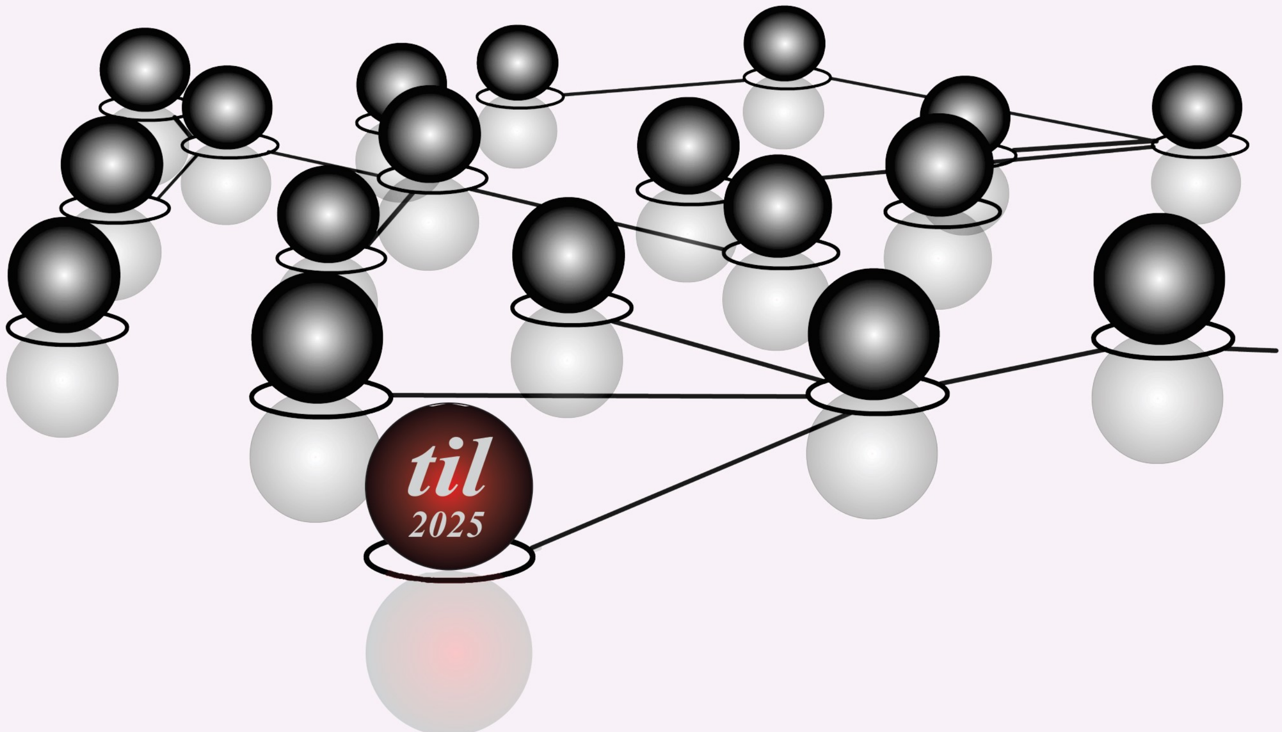
TRANSPORT & LOGISTICS

PROCEEDINGS



Niš, Serbia 5 December 2025

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TRANSPORT AND LOGISTICS

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Assoc. Prof. Dr. Predrag Milić

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Dr. Aleksandar Stanković
Dr. Jovan Pavlović
Jelena Mihajlović

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FOREWORD

The *International Conference on Transport and Logistics (TIL 2025)* marks a significant milestone, celebrating its tenth edition. The origins of this conference date back to 2004, when the first Serbian Seminar on Transport and Logistics (TIL 2004) was organized within the framework of a TEMPUS project funded by the European Commission. The project aimed to support the transfer of knowledge in the field of logistics from European universities to the Faculty of Mechanical Engineering in Niš, where the first generation of students had enrolled a year earlier in the newly established study profile Transport and Logistics.

The members of the Department of Transport Engineering and Logistics express their special gratitude to the former Head of the Department, Prof. Dr. Vinko Jevtić, whose visionary insight made it possible to bring together leading experts in logistics from across the European Union. His efforts played a crucial role in the establishment of a new academic orientation that, at that time, had not been taught at mechanical engineering faculties in Serbia.

Since 2004, the conference has undergone continuous development, evolving from an academic seminar and a national conference with international participation into the *International Conference on Transport and Logistics*. This evolution reflects both the growing scientific maturity of the event and the increasing importance of transport and logistics as key disciplines in modern engineering, economics, and society.

The Proceedings of the *International Conference on Transport and Logistics* include a total of **40 peer-reviewed papers**, authored by researchers from **Bosnia and Herzegovina, China, Croatia, Germany, Greece, Italy, Lithuania, Poland, Serbia, Slovenia, and Turkey**. The conference serves as an international forum for researchers, academics, and practitioners to exchange knowledge, experiences, and recent advances in the broad field of transport and logistics.

The conference focuses on contemporary challenges and emerging trends in transport systems, logistics, mobility, traffic engineering, vehicle technology, and related interdisciplinary areas. Particular emphasis is placed on sustainable transport solutions, intelligent transportation systems, logistics optimization, and the interaction between academia and industry.

We would like to thank all authors for their valuable contributions, as well as the members of the Organizing and Scientific Committees for their dedication and efforts in ensuring the successful realization of the conference. Special thanks are extended to the supporting institutions and partners whose cooperation made this event possible.

We hope that this volume will serve as a useful reference for future research and professional practice and will stimulate further discussion and collaboration in the field of transport and logistics.

Chair of the Scientific Committee
Assoc. Prof. Dr. Predrag Milić

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EXPERIMENTAL INVESTIGATION OF VEHICLE DECELERATION USING THE TAGUCHI METHOD TO IMPROVE TRAFFIC SAFETY

***Bojana BOŠKOVIĆ*1, *Nadica STOJANOVIĆ*[2], *Ivan GRUJIĆ*[2], *Jovanka LUKIĆ*[2], *Jasna GLIŠOVIĆ*[2], *Danijela MILORADOVIĆ*[2]**

[1)]Academy of Professional Studies Šumadija, College Trstenik
[2)] Faculty of Engineering, University of Kragujevac, Kragujevac, Serbia

ORCID iDs: Bojana BOŠKOVIĆ https://orcid.org/0000-0001-8622-9874
Nadica STOJANOVIĆ https://orcid.org/0000-0002-4199-0587
Ivan GRUJIĆ https://orcid.org/0000-0003-0572-1205
Jovanka LUKIĆ https://orcid.org/0000-0002-5893-3976
Jasna GLIŠOVIĆ https://orcid.org/0000-0002-8251-1722
Danijela MILORADOVIĆ https://orcid.org/0000-0003-1427-9789

Abstract

This paper presents a study on the influence of braking operating parameters on vehicle deceleration using the Taguchi method of experimental design. The experiment was conducted with 16 measurements, where the input parameters were the initial speed, the quartervehicle mass, and the brake system pressure. The output variables observed were the brake disc temperature, braking distance, and vehicle deceleration. The results show that the initial speed has the greatest influence on the braking distance, while the brake system pressure significantly affects the stability of deceleration and the increase in brake disc temperature. This approach enables efficient optimization of the braking process with a minimal number of experiments.

Keywords: *braking operating parameters, vehicle deceleration, initial speed, brake system pressure, Taguchi experimental design*

1 INTRODUCTION

The braking system, from the standpoint of a vehicle technical condition, represents a subsystem that directly influences the safe participation of the vehicle in traffic. Its primary function is to decelerate and/or bring the vehicle to a complete stop, thereby enabling adaptation to prevailing traffic conditions and ultimately preventing the occurrence of traffic accidents. In addition, the braking system serves to prevent any movement of the vehicle when it is parked, ensuring that it remains in a stationary state.Systems designed to ensure the safe deceleration of a vehicle and to prevent the occurrence of hazardous situations continue to evolve at a rapid pace. The primary objective of any braking system is to reduce the vehicle speed. Various constraints imposed on braking systemssuch as minimum stopping distance, reliability under different operational conditions and similar factorshave become central considerations in the design of modern vehicles. As with any engineering design process, calculations of deceleration begin with certain assumptions that are subsequently validated or modified. Traffic safety, in addition to the technical condition of the vehicle, is influenced by the operating parameters of braking: vehicle speed, vehicle mass and the brake system pressure. Depending on these parameters, the amount of heat generated in disc brakes will vary, which directly affects the value of the friction coefficient [1]. The friction coefficient is directly related to the resulting deceleration. Moreover, the magnitude of vehicle deceleration varies across different vehicle types. These differences arise from factors such as vehicle mass, the structural design of the braking system and other related characteristics.Vehicles of identical mass that travel at higher speeds at the moment of brake activation exhibit longer braking distances, meaning they require more time to come to a complete stop [2]. In addition to braking parameters, the driver's psychophysical condition also affects braking distance. Here, the term “driver” refers to whether the individual is a professional test driver or not. For non-professional test drivers, braking distance is typically 20% to 30% longer [3].Another factor that influences braking distance is the rise in disc brake temperature. As temperature increases, the friction coefficient decreases, which has a direct impact on braking distance. Experimental study [4] have shown that at the beginning of the braking process, the friction coefficient rises with increasing temperature within the range of 100°C to 180°C, it typically varies between 0.4 and 0.6. However, a further increase in temperature up to 350°C leads to a reduction of the friction coefficient to approximately 0.2, which directly affects braking distance. Vehicles are expected to achieve minimal braking distance (i.e., maximum deceleration) in unexpected situations without compromising vehicle stability or overall traffic safety. The challenges encountered during the braking process, as outlined above, have provided the motivation for the present research.

$$d = \frac{\Delta V}{\Delta t} \quad (1)$$

2 ANALYSIS OF THE INFLUENCE OF OPERATING PARAMETERS ON DECELERATION USING THE TAGUCHI METHOD

The braking system is the most important safety-related subsystem of a vehicle, responsible for decelerating, fully stopping, or maintaining the vehicle in a stationary position under various conditions.
For many years, engineers have sought through both experimental and numerical methods to identify which operating parameters influence the braking process and to determine which of them is most significant. To establish these relationships, various analytical methods are used

today. Among the methods most widely applied to determine the dependency of operating parameters in brake systems is the Taguchi method. The Taguchi method defines the relationship between input and output parameters, thereby facilitating the optimization of output variables, i.e. system responses. In this way, the total number of required experiments is reduced [5].Various studies have employed the Taguchi method to investigate the influence of different operating parameters on braking systems. Authors[6]used the Taguchi approach to examine the effects of load, sliding speed, and contact surface diameter on the wear rate of brake pads. In another study [7]applied the Taguchi method to define the impact of various parameters on the concentrations of $PM_{2.5}$ and PM_{10} particles generated by different brake pads. Additionally, Stojanović et al. [8]investigated how different brake disc parameters such as the number of ribs, density, Young's modulus, and Poisson's ratio affect brake noise using the Taguchi method.The application of the Taguchi method significantly reduces the number of measurements required, identifies the factors that influence output, and decreases both the time needed to conduct experiments and the associated costs.

3 EXPERIMENTAL INVESTIGATION OF THE INFLUENCE OF OPERATING PARAMETERS ON VEHICLE DECELERATION

Design of Experiments (DOE) is a powerful statistical technique introduced by R. A. Fisher in England during the 1920s to study the effects of multiple variables simultaneously. In his early applications, Fisher sought to determine how factors such as rainfall, water, fertilizer, sunlight, and other variables influenced crop yield to achieve the optimal harvest.

Since then, the technique has evolved significantly within the academic sphere and has also generated numerous applications in manufacturing. The implementation of DOE requires careful and rational experimental planning as well as expert analysis of the results. Building on years of research and application, Taguchi standardized methods for each step in the DOE process. Consequently, DOE using the Taguchi approach has become a highly attractive tool for engineers and scientists in practice and it is therefore employed in this study.DOE, when applied using the Taguchi approach, can economically satisfy the needs of problemsolving projects and the optimization of product or process design. By learning and applying this technique, engineers, scientists, and researchers can significantly reduce the time required for experimental investigations.DOE provides an efficient means to optimize product and process design, study the effects of multiple factors (e.g. variables, parameters, components, etc.) on performance and resolve production issues through the objective design of experiments. It enables the examination of individual factor impacts on performance and the identification of factors with greater or lesser influence. Insights derived from the experiments guide the allocation of resources for quality assurance based on objective data, facilitating the combination of various factors to achieve optimal results [9].

In this research, the Taguchi method was used for experimental planning, with variations in initial vehicle speed, quarter vehicle mass and braking system pressure. A fractional factorial L16 orthogonal array was applied, significantly reducing the number of required experimental runs.

Table 1 Experimental planning using the Taguchi method

Number of measurement	Initial speed [km/h]	Quarter vehicle mass [kg]	Brake preassure [MPa]
1	20	200	2
2	20	250	3
3	20	300	4
4	20	350	5
5	40	200	3
6	40	250	2
7	40	300	5
8	40	350	4
9	60	200	4
10	60	250	5
11	60	300	2
12	60	350	3
13	80	200	5
14	80	250	4
15	80	300	3
16	80	350	2

4 RESULTS AND DISCUSSION

The following section presents the results obtained using the Taguchi method, analyzing the influence of individual parameters on the observed process. Based on these results, a detailed discussion will be conducted with the aim of identifying optimal conditions and gaining a better understanding of the factors that contribute to the overall improvement of system performance.

Table 2 illustrates overview of the results from the optimization of braking process parameters using the Taguchi method. The input parameters defined in Table 1 (initial speed, quartervehicle mass and brake pressure)directly shape the behavior of the output parameters presented in Table 2, which include braking time, brake temperature, braking distance and deceleration. Among all input variables, initial speed emerges as the dominant factor. Increasing the speed from 20 to 80 km/h leads to a systematic rise in both braking time and braking distance, as well as to a significant increase in temperature due to higher thermal loading. At the same time, higher initial speeds result in greater deceleration, since larger braking forces are required to dissipate the increased kinetic energy. The quartervehicle mass, although included as an experimental factor, exhibits a stable but comparatively weak influence.

Variations in braking time and distance caused by changes in mass are present but considerably less pronounced than the effects attributed to speed. Brake pressure exerts a moderate yet clearly observable impact on the output parameters.Its increase generally shortens braking time and distance and raises the deceleration value, while temperature increases in accordance with intensified friction.

Overall, the comparison between Table 1 and Table 2 indicates that initial speed primarily governs the braking dynamics, brake pressure acts as a significant corrective factor and the influence of mass is the least prominent among the examined parameters.

Table 2 Overview of the results from the optimization of braking process parameters using the Taguchi method

Number of measurement	t_b[s]	T [ºC]	S_b [m]	d [m/s^2]
1	1,62	27,08	5,85	2,46
2	1,97	28,23	5,86	1,81
3	1,54	28,83	5,02	2,53
4	0,99	25,57	3,15	2,87
5	1,10	27,06	3,42	1,60
6	3,25	30,81	19,93	2,78
7	1,75	31,12	11,20	3,79
8	2,11	31,28	14,32	3,93
9	2,25	32,49	21,53	5,18
10	2,08	32,78	21,80	5,52
11	5,52	34,29	47,84	2,69
12	3,74	37,01	35,29	3,88
13	2,67	35,49	34,86	6,74
14	3,18	38,84	40,98	5,83
15	4,25	40,76	51,26	4,45
16	6,49	43,21	77,99	3,17

Figure 1 illustrates the variation of deceleration as a function of time for a total of 16 conducted measurements, with each measurement represented by a distinct curve. All curves start from a zero valueand then rise to a certain maximum deceleration before gradually decreasing until the vehicle comes to a complete stop.The differences in the height and shape of the curves reflect variations in maximum deceleration, braking duration and the dynamics of the braking process for each individual measurement. Some measurements reach higher peak deceleration values and maintain elevated levels for longer periods, indicating more effective and intensive braking. Other measurements display lower maximum values or a faster decline in deceleration, reflecting different braking conditions. The diagram enables a direct visual comparison of all 16 measurements, providing insight into which conditions resulted in stronger, longer-lasting, or more stable deceleration.

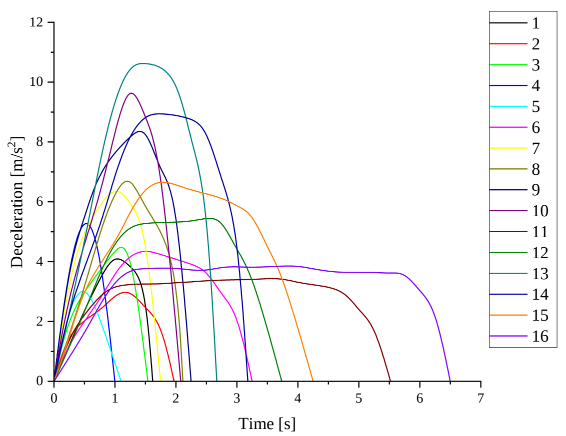
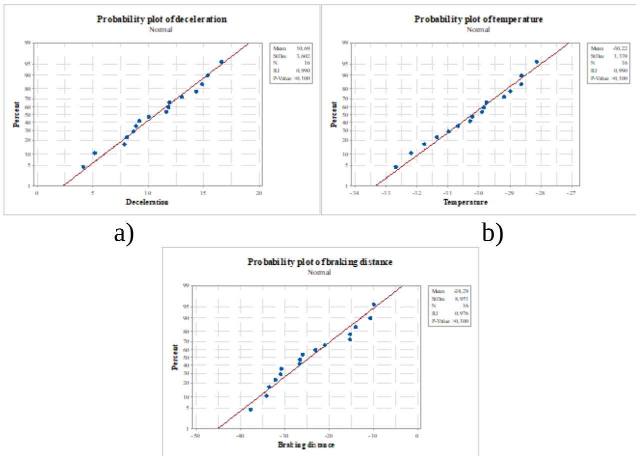


Fig. 1Comparative representation of deceleration for 16 measurements

4.1 Testing the null hypothesis

In order to determine the rank of input parameters and the percentage contribution of each parameter, the first step is to test the null hypothesis. The null hypothesis essentially represents whether the output parameters lie along a defined line with minimal deviation. Testing the null hypothesis is performed by calculating the p-value, which defines the probability that the observed result occurred by chance [10].

The null hypothesis can be considered valid if the p-value is greater than 0.05. Conversely, if the null hypothesis is not confirmed, the obtained results are rejected, and analysis of those data cannot be conducted. In this study, the null hypothesis was tested using the Ryan-Joiner test, which is similar to the Shapiro-Wilk test. On the resulting graph (Figure 2), the p-value is greater than 0.100, therefore, the null hypothesis is not rejected, as $p > 0.05$.



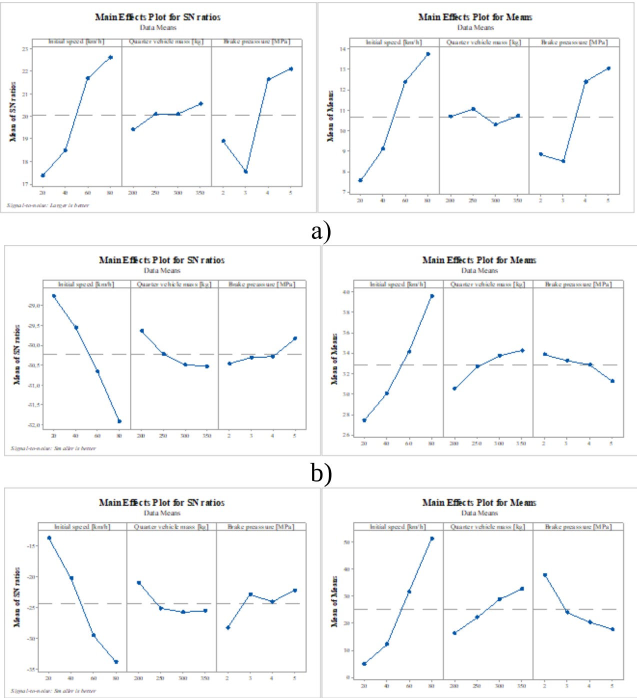
a) b) c)

Fig. 2Normality test: a) deceleration, b) temperature c) braking distance

Using the Taguchi method within the *MINITAB* software, the ranking of input parameters with respect to deceleration was performed. Determining the rank of input parameters is crucial, as it aids in the design and optimization of the braking system by identifying which parameters exert the greatest influence on deceleration.

Through the application of Taguchi experimental design and subsequent analysis, data regarding the influence of braking factors on deceleration were obtained.The presented diagrams represent main effects plots for both S/N ratios and mean values (Figure 3), commonly used in the Taguchi method to analyze the impact of multiple factors on system response. Each set of diagrams (a, b and c) shows how three factors: initial vehicle speed, quarter vehicle mass and brake pressureaffect the measured outcomes. In the diagrams on the left of each group, the S/N ratios are shown, indicating system stability and reliability (higher values correspond to greater resistance to variation), while the diagrams on the right display the mean response values, representing the average effect of each factor level.

By observing the slopes of the lines, the magnitude of each parameterinfluence can be determined. Steep lines indicate a strong effect, whereas gentle slopes indicate little or negligible influence. In all cases presented, initial speed has the strongest impact, evident from the pronounced changes in its plots. Quarter vehicle mass has a relatively stable and weak influence, while brake pressure exhibits a moderate but clearly noticeable effect on the response. Differences among cases a, b and c on Figure 3, arise from different optimization criteria (e.g. "*larger is better*" "*smaller is better*"and "*target value*"), which alter the shape of the S/N plots, yet the trends of speed dominance and the lesser significance of mass remain consistent across all versions.



a)

b)

c)

Fig. 3 Analysis of the influence of observed factors using the Taguchi method:a) deceleration, b) temperature, c) braking distance

Based on the results presented in Table 3, a clear hierarchy of the influence of the input parameters on the braking process can be identified. Initial vehicle speed consistently occupies the first position in terms of its impact on all three output parameters. This outcome is expected, as higher initial speed directly increases the required braking energy, which manifests as higher deceleration, more intensive heating of the braking system, and an extended stopping distance.

Quarter vehicle mass exhibits a relatively weaker and more stable influence. For deceleration and braking distance, it is ranked as the third contributing factor, while for temperature it takes the second position, indicating that its role is more pronounced in the thermal aspect of braking than in the dynamic response. This aligns with the physical characteristics of the process, since greater mass increases the instantaneous load on braking components, thereby contributing more to thermal buildup, although not necessarily exerting a proportional effect on deceleration.

Brake pressure is ranked as the second most influential factor for deceleration and braking distance, whereas for temperature it appears as the least influential parameter. This suggests that increasing brake pressure primarily affects the effective deceleration and the reduction of braking distance, while contributing to temperature rise to a lesser extent compared with the other parameters.

Overall, the analysis shows that the braking process is predominantly governed by initial vehicle speed, whereas vehicle mass and brake pressure exert secondary but distinct influences. Mass is primarily affecting thermal loading and brake pressure influencing the dynamics of the stopping process.

Table 3 Ranking the influence of input parameters on vehicle deceleration

Input parameters	Output parameter	Influence rank
Initial vehicle speed	Deceleration	1
Quarter vehicle mass		3
Brake pressure		2
Initial vehicle speed	Temperature	1
Quarter vehicle mass		2
Brake pressure		3
Initial vehicle speed	Braking distance	1
Quarter vehicle mass		3
Brake pressure		2

4.2 Analysis of variance (ANOVA)

Analysis of variance (ANOVA) is used to determine the percentage contribution of each input parameter to the output parameter. To establish the percentage contribution, the analysis is conducted at a 95% confidence level, corresponding to a significance level of 5%.The *ANOVA* was performed to examine the influence of initial vehicle speed, quarter vehicle mass and brake system pressure on the investigated system response, i.e. vehicle deceleration. Three factors with four levels each were considered in the analysis: initial speed (20 km/h, 40 km/h, 60 km/h, and 80 km/h), quarter vehicle mass (200 kg, 250 kg, 300 kg, and 350 kg) and brake pressure (2 MPa, 3 MPa, 4 MPa, and 4.5 MPa).

Table 4 Results of *ANOVA* analysis for vehicle deceleration

	DF	Adj SS	Adj MS	F-Value	P-Value
Initial speed	3	97,563	32,521 0	6,66	0,024
Quarter vehicle mass	3	1,121	0,3736	0,08	0,970
Brake preassure	3	66,661	22,220 3	4,55	0,055
Error	6	29,289	4,8816		
Total	15	194,634			

The *ANOVA* results, presented in Table 4, indicate that initial speed has a statistically significant effect on the outcome (p=0.024), meaning that changes in the speed at the start of braking significantly affect the observed deceleration. Brake system pressure exhibits a marginally significant effect (p=0.055), suggesting a correlation between increased pressure and changes in system response. On the other hand, quarter vehicle mass does not have a significant effect on the outcome (p=0.970).The coefficient of determination R^2 is 84.95% indicating that the model explains approximately 85% of the total variation in the results, while the adjusted R^2 (62.38%) confirms a good fit of the model to the experimental data.Based on these results, it can be concluded that initial speed is the most influential factor, vehicle mass has the least impact on the analyzed response and brake system pressure also exhibits some effect, though it is at the threshold of statistical significance.

5 CONCLUSION

By applying the Taguchi design of experiments and the subsequent analysis, data were obtained regarding the influence of braking factors on the deceleration value. In all cases, the initial speed exhibits the strongest effect, the quarter vehicle mass shows a relatively stable and weak influence, while the brake pressure demonstrates a moderate but clearly observable effect on the response.

Therefore, the factor with the greatest impact on deceleration is the initial speed, followed by the quarter vehicle mass, and finally the brake system pressure.

The ANOVA analysis indicates that the initial speed has a statistically significant effect on the outcome, meaning that changes in the speed at which the braking process begins substantially influence the observed response. The brake system pressure exhibits a borderline significant effect, suggesting a relationship between pressure increase and the change in response, i.e. its influence on deceleration. Conversely, the quarter vehicle mass does not show a statistically significant impact on the outcome.

The coefficient of determination is 84.95%, indicating that the model explains approximately 85% of the total variation in the results, while the adjusted coefficient of determination confirms the model's strong agreement with the experimental data.

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Contact address:
Bojana Bošković
Academy of Professional Studies Šumadija
College Trstenik
37240Trstenik
Radoja Krstića 19
E-mail: bboskovic@asss.edu.rs