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Analysis of truck braking using multiple simulations

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Abstract. In the field of road vehicles, the merging of mechanical assemblies and electronic computing architecture has become indispensable. In the present paper, a thorough study of the braking performance of heavy goods vehicles is presented. Operating conditions and other influencing factors during use create multiple combinations that influence the behavior and performance of braking systems in different ways. However, for such a speed of development, the dedicated means of research become insufficient, thus new study methods are needed to guarantee complex results with a minimum of consumed resources. Such a variant of the study is also addressed in this paper, where the results are obtained based on multiple simulations, carried out simultaneously, but in a much shorter time than in the experimental cases and with a large volume of data.

Keywords*:* brake, braking process, brake wear, commercial vehicles, truck brakes

1. Introduction

The main purpose of the simulations carried out in this work was to identify if the initial situations identified in practice and in some experimental studies can be validated and if they are also valid in other conditions, simultaneously with obtaining additional new analysis data about the main parameters at running and braking for different truck configurations and in different operating situations.

2. Analysis elements of braking processes by different methods

The complexity of motor vehicles brings to the fore the need for advanced methods of design, verification and analysis of component systems and subsystems. In this

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sense, the use of computer simulations becomes the most effective method of study and analysis. By transposing the phenomena into mathematical equations, graphs can be obtained that express their main parameters, thus making possible the comparative analysis of several variants and the combinations between variants and operating conditions or other influencing factors [1,2,3,4].

Such an approach is used in some studies [2], for the analysis parameters when braking with brake shoes. The main purpose exposed is the analysis of shoe braking efficiency by using a mathematical simulation model. Starting from simple calculation elements for the efficiency of shoe braking (with applications in the field of railway transport), Konstantin K, et al., [2], identify a not very complex formula that considers, among others, the dimensions of the shoes, total weight, and weight distribution. However, although the accuracy of the results depends to a large extent on the complexity of the input data, in this case, although simplifying assumptions were also used (ex. wind speed), the results present a general allure of the phenomenon, and the main conclusions can be found in other specialized papers too [5,6].

The problem of the complexity of the input data has a dual nature, being on the one hand beneficial because a high complexity of the entered data increases the accuracy of the results, but at the same time too many details complicate the model and make the final analysis difficult. In this context, the main problem becomes the calibration of the complexity ratio between the data entered and the results obtained, in order to obtain data with sufficient accuracy starting from minimal time resources, as in the case of Konstantin K, et al., in [2].

However, another study of wear on brake pads [7], complicates things and besides the fact that the simulation model is much more complex, an experimental analysis of the system's particularities is also introduced. The study addresses the issue of wear in the friction coupling between the brake pad and the brake disc, bringing to the fore the influence of the materials used. The mathematical model used is much more complex than in the previously analyzed case and provides much more complex results, but with a greater consumption of resources and with the use of a specialized simulation software.

If in the previous case [2], the results could be obtained relatively easily by creating a calculation formula in a spreadsheet, in the study [7], the results are generated based on the instructions in the ANSYS simulation software. However, without this additional complexity, the topic analyzed by Melkamu Yigrem, et al., [7], would be impossible to approach. The authors propose an analysis of the properties obtained when braking with brake pads made of different recycled materials, following two important directions: braking efficiency and reducing the impact on the environment. The simulation environment used provides data related to heat transfer, pressures, forces, and moments in the friction coupling. From this study it can be seen, an exposition of some more complex results, based on computer simulations and which are then validated by comparison with variants frequently used in real conditions.

A classic, but effective method for studying friction coupling processes, is presented by Dong Tan, et al., in the study [8]. In this study, a series of experimental tests is combined with a macroscopic analysis of the processes in the friction coupling, also with the aim of identifying new materials for brake pads. In this case, the focus falls on the experimental trials based on which a series of values were generated that were later processed and analyzed.

Another more complex study method is based on combining mathematical models with simulations and experimental tests. Such studies consume a larger volume of resources, but overlaying the results of several analyzes is an alternative for obtaining complex results. Such an analysis is addressed by Mariani, V., et al., [9], where the experimental part is doubled by an analytical part of calculation and simulation. The central subject of this study is based on braking energy recovery, a concept of major importance in the current context and which has potential (by improving the energy balance) regardless of the energy used for propulsion.

Based on these studies, it can be highlighted that the simulation of processes is necessary for outlining complex results and if they are also validated through experimental tests, then the accuracy of the results increases significantly. It should also be emphasized the close connection between the complexity of the model and the results obtained for most cases. Validation of simulation results through experimental trials is often encountered and provides complex results in studies [10,11], but it brings a high degree of complexity and requires large resources, both temporary and financial. At the same time, the most important advantage of the simulations expressed through the significant reduction of costs (fuel consumption, wear and tear, availability, etc.) and the allocated time is emphasized.

3. The simulation environment and the configuration of the trucks

After establishing the test routes and cycles, the configurations of the trucks were created according to the model and structure of those from the experimental studies and from the specialized literature. For the current study, the AVL Cruise variant was used [12].

Figure 1 shows the configuration of a truck intended for towing semi-trailers used in the study. Two test cycles with specific characteristics were used for each truck in the study, which include the basic conditions for urban (Urban_Delivery, figure 2) and extra-urban traffic (Regional_Delivery). In addition to 4 of the configurations, two more cycles (Long_Haul and Municipal_Ut) were used. A single repeated braking test cycle (UDC) was used for one of the configurations. The role of each test cycle is to generate data relating to the braking process under certain conditions specific to that route.

For each truck in the study, the configuration of the type shown in figure 1 can include data on: engine, clutch, gearbox, cardan transmission, differential, final transmission, main or auxiliary braking system, number of axles and their type, influence and the presence of a trailer/semi-trailer, masses and dimensions, external parameters, etc. The combinations of the test cycles (Regional, Urban, Long,

Municipal and UDC), the configuration of each truck (Vehicles and Veh.Type) and the analyzed parameters (noted from 1 to 41), are shown in table 1.
In the current study, 8 different truck configurations (table 1) and 4 test cycles were used (UrbanDelivery, RegionalDelivery, MuniciplaUt, LongHaul). These were grouped in certain series, with the aim of following the parameters identified and analyzed in the practical experiments [5,6,11] but also in other studies from the specialized literature. During the simulation, other aspects were also monitored: braking forces and moments; values, distribution and frequency of accelerations and decelerations; masses and weights; the number of brakes; the amount and distribution of loads on wheels and axles; the influence of leadership style; the influence of the route on braking performance; aspects related to the use of auxiliary braking systems.

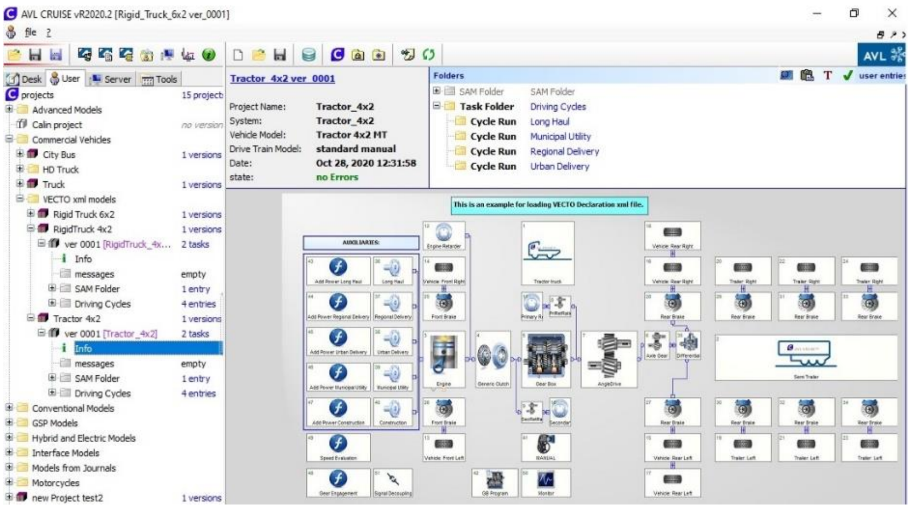


Fig. 1. Configuration variant for a truck with a semi-trailer.

Fig. 2. Urban test cycle configuration.

Table 1. The parameters analyzed for each truck, the test cycles and the main notations used.

	Vehicles	Veh. Type	Cycles					Measured parameters																
			Reg	Urb	Long	Municipal	UDC	1	2	3	4	...	30	31	32	33	34	35	36	37	38	39	40	41
1	VehicleClass01_camion	A	x	x				x	x	x	x	...	x	x	x									
2	VehicleClass03_camion2	A	x	x				x	x	x	x	...	x	x	x									
3	VehicleClass05_02_cap_tr-SR	B -	x	x				x	x	x	x	...	x	x	x									
4	VehicleClass05_02_cap_tr+SR	B +	x	x				x	x	x	x	...	x	x	x									
5	WTruck_cam_3axe - without RET	C					x	x	x	x	x	...	x	x	x									
6	RigidTruck4x2Cam	A	x	x	x	x		x	x	x	x	...	x	x	x	x	x	x	x	x	x	x	x	x
7	RigidTruck4x2T+SR	B+	x	x	x	x		x	x	x	x	...	x	x	x	x	x	x	x	x	x	x	x	x
8	RigidTruck6x2	D	x	x	x	x		x	x	x	x	...	x	x	x	x	x	x	x	x	x	x	x	x

4. Results obtained through simulations

4.1. Graphs and general simulation results

Figure 3 shows the graphs of accelerations and decelerations measured on two of the main test cycles. Significant differences are observed both in the obtained values and in the distribution and frequency of accelerations and decelerations, which highlights from the beginning a series of additional demands in the case of urban cycles/routes.

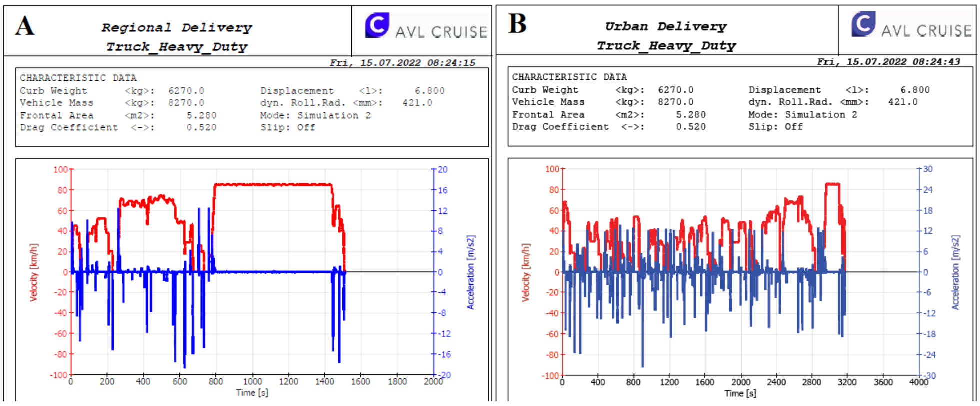


Fig. 3. The accelerations and decelerations obtained on the two regional (A) and urban (B) test cycles, for a 4x2 truck configuration with a mass of 8270kg.

Regional Cycle

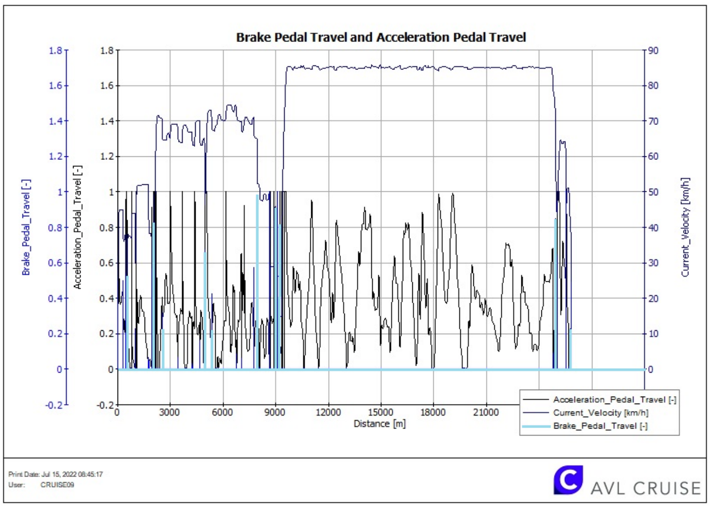


Fig. 4. The relationship between the brake pedal stroke and its acceleration on regional test cycle

Figures 4 and 5 show the graphs obtained for the ratio between the brake pedal travel and its acceleration on the two main cycles (regional and urban). The acceleration of the brake pedal (or pressing speed) denotes the type of braking (emergency braking, sudden braking, slow braking).

Urban Cycle

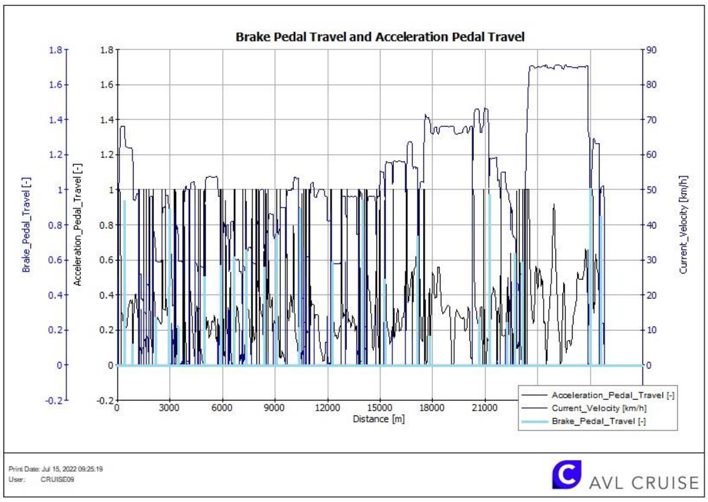


Fig. 5. The relationship between the brake pedal stroke and its acceleration on urban test cycle.

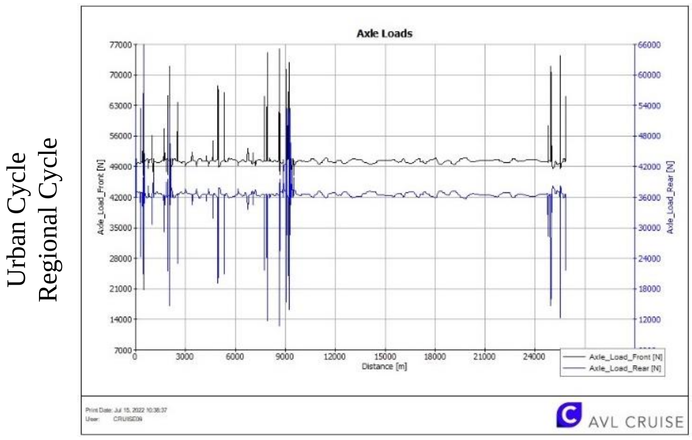
It has been observed that the most pronounced wear occurs when the brakes are under high stress and this is favored by two main factors: traffic conditions and driving style. In this case (fig. 4 and 5), the problem arises of highlighting the influence of the mentioned factors on braking performance by analyzing and comparing the two cycles.

Although there are much fewer actuations on the regional cycle, the brake pedal travel frequently has values close to the maximum value. It was also found that on extra-urban routes, in the area of high speeds, the stroke and acceleration of the brake pedal are higher than in urban cases, where the frequency of pressing the brake pedal is much higher but at strokes lower than 60% of the stroke total.

Another aspect monitored during the simulations was related to the loads on the wheels and axles and more precisely their distribution according to the configuration of the truck and the analysis of the influences introduced by the traveled route. Figure 6 shows the average of the dynamic stresses on the axles during travel on the two routes. It is observed that deceleration significantly loads the front axle, and acceleration loads the rear axle, which produces a migration of values between the two depending on the road conditions. In the case of urban routes, the variations increase significantly, and the differences in the stresses measured at the axles and wheels are much more visible.

In contrast to the conditions above, the UDC test cycle supplements the analysis with punctual details for tests consisting of repeated acceleration and braking. The distribution of speeds and accelerations on this cycle are shown in figure 7. In this case the maximum value of the decelerations is only -0.92 m/s^2, which is a low value compared to the results of the previous simulations, but a first aspect that must be emphasized is the value of the maximum speed on this cycle, which does not exceed 50 km/h.

The deceleration values are capped at a constant value, which will lead to a high braking time. From the point of view of braking, the question arose whether a long braking at a constant value of deceleration can extend to a significant degree the duration of use of the wear elements in the system. However, this method of practical tests on urban routes cannot be used frequently in operation due to road conditions and the need for rapid braking in most situations. In this context, this simulation at low and constant decelerations becomes essential in the case of retarder/intarder auxiliary braking systems.



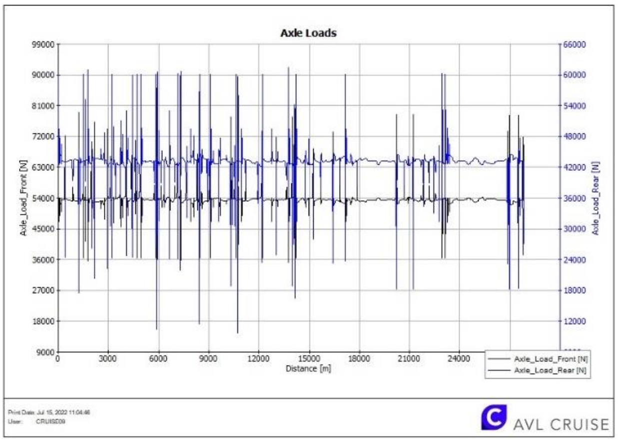


Fig. 6. Average axle loads [N] over the two test cycles.

The difference between the three stages of braking in figure 7 (which are initiated from different speeds) consists in the braking time of: 6 seconds, 12 seconds, and 21 seconds (divided into two stages of 8 seconds and 13 seconds respectively and without the time lost at constant speed between the two stages). If the first two steps are analyzed, it can be said that with an increase in travel speed from 15 to 32 km/h, to obtain the same deceleration of approximately 1 m/s^2, a doubling of the braking time from 6 to 12 seconds is required.

For an increase in speed from 32 to 35 km/h, the braking time increases from 12 seconds to 13 seconds. This can be interpreted as follows: for an increase in travel speed of approx. 2 km/h to achieve the same deceleration, the braking time increases by one second.

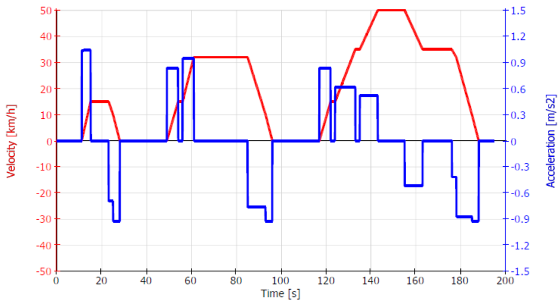


Fig. 7. Main speed conditions, accelerations and decelerations recorded on the UrbanDeliveryCycle.

4.2. General interpretation of the results

Figure 8 shows the average travel speeds of each truck, on each test cycle. Average speed values vary over a wide range, from low travel speeds characteristic of urban sectors to high travel speeds characteristic of long-haul routes. There are also test cycles that combine urban and extra-urban sectors (Municipal Delivery). On urban cycles the average travel speed is in the range of 30...45 km/h and on extra-urban cycles the average travel speed most often has values between 55 and 65 km/h but there are also a few exceptions on very long routes with high travel speeds close to 85km/h.

If the accelerations and decelerations on each cycle are analyzed, it can be stated that the maximum values of the decelerations were obtained in the case of light configurations (low mass), and with the increase of the mass, the decelerations decrease to the value of -6.5 m/s^2. The mean values of the accelerations were in all cases lower than those of the decelerations. Starting from these aspects, it was found that the obtained decelerations are generally 6 m/s^2 higher than the accelerations.

Starting from the analysis of the decelerations, it was found that depending on the test cycle, the distribution of braking at maximum capacity has a high frequency with the increase of travel speeds. In this sense, the braking mode was also monitored by the value of the braking force when the brake pedal was pressed. In figure 9, the heavy braking relative to the total number of braking for each simulation is highlighted. It has been observed that there is an average of approximately 15% of the total number of braking, where the braking is performed at full capacity. The percentage also increases significantly on routes with urban sectors where it frequently exceeds 25% of the total number of braking. This aspect explains the increased wear and a much greater stress on the braking system on urban routes.

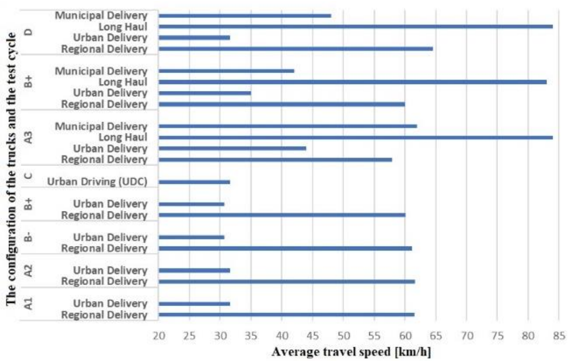


Fig. 8. Average travel speed for each configuration and on each km/h cycle.

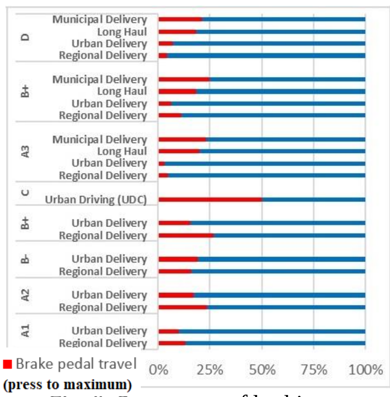


Fig. 9. Percentage of braking at maximum capacity, out of the total number of braking.

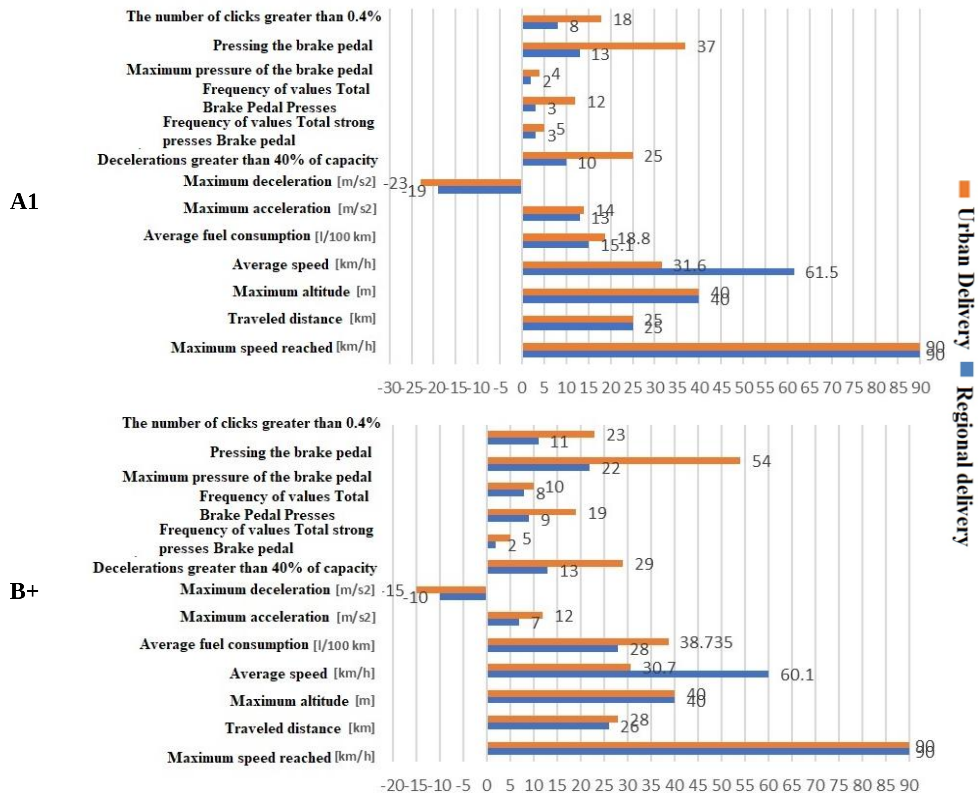


Fig. 10. Dynamic parameters and frequency of braking on the urban and regional cycle for two truck configurations.

The graph in figure 10 shows aspects related to the number of braking performed by two trucks (A1 - 4x2 truck, and B+ - head-tractor combination with semi-trailer) on the urban and extra-urban cycle. On average, 47.5 braking/cycle were recorded on the urban route, and only 17.5 braking/cycle were recorded on the regional route. The difference between the number of braking on the urban and the regional route is an average of 30 braking per cycle, given the same distance traveled.

In the same vein, the number of braking at maximum and average values was also analyzed. On the graph, the frequency of BP values represents the number of braking that falls between 50 and 80% of the maximum braking capacity, and the frequency of high BP values represents braking at more than 80% of the braking capacity. And these values show significant variations by route and configuration. In the case of average braking, the difference in the number of braking on the urban route compared to the regional one is almost 50% higher. This aspect shows that in the urban environment, there is not only a double increase in the number of braking compared to extra-urban routes, but also a doubling of the number of medium and heavy braking.

The distribution of values in figure 10 underlines a significant increase in the demands on the braking system according to two main factors: the mode of operation and the configuration of the truck. Along with the increase in accelerations and average travel speeds, there are also important changes in the distribution and values of decelerations, but also in the way of braking. These variations, so pronounced and sensitive to the mentioned factors, favor the appearance and evolution of wear in the main braking system.

5. Conclusions

In this study, an analysis was carried out by simulating the driving and braking behavior for 8 truck configurations, on 5 urban and extra-urban routes.
At the same time, results from practical works were combined with data obtained by simulation in AVL Cruise. In the first phase, the average travel speeds were followed, and then aspects related to the values, distribution and frequency of accelerations and decelerations on the established routes were analyzed.
Reducing the mass of the truck led to an increase in acceleration and implicitly in travel speeds, but the demands on braking also increased significantly. It was found that an additional mass puts more pressure on the powertrain, which leads to lower accelerations of the truck, and the influence on the deceleration is significantly less. So, the braking system must be capable of greater decelerations than the accelerations delivered by the engine group, but at the same time it must cope with the demands imposed by the mass of the truck.
It can be said that with an increase in travel speed from 15 to 32 km/h to achieve the same deceleration of about 1 m/s2, a doubling of the braking time from 6 to 12 seconds is required. For an increase in travel speed of 3 km/h, the braking time increases by one second.
It has been observed that there is an average of approximately 15% of the total number of braking, where the braking is performed at full capacity. The percentage of heavy braking in relation to the total number of braking increases significantly on routes with urban sectors, frequently exceeding 25% of the total number of braking. This aspect explains the increased wear and a much greater stress on the braking system on urban routes. It was also observed that these percentages of braking in the area of maximum braking capacity have lower values by up to 10%, for trucks with two axles compared to those with three axles. On average, there were 47.5 braking per cycle on the urban route, and only 17.5 braking per cycle on the regional route.
The analysis of driving and braking behavior provides important and essential data in the study of improving braking systems, but it consumes a significant number of resources. In this sense, the combination of computerized analysis techniques with elements from the practical side works perfectly to achieve an optimal ratio between the resources used and the results obtained. The study identifies the most fragile situations with a high failure potential and then points out the main elements that favor these situations. Among the most important analyzed factors can be listed: travel speed, accelerations/decelerations, and the number of brakes per cycle. All these factors are analyzed in different situations and on different

configurations. These aspects allowed a complex analysis of the braking phenomenon.

References

[1] Burnete N. V., Burnete N., *Motoare cu ardere internă și termodinamică. Noțiuni fundamentale*, Editura UT Press, ISBN 978-606-737-539-8 (eBook), 2021, https://biblioteca.utcluj.ro/files/carti-online-cu-coperta/539-8.pdf.
[2] Konstantin Kornienko et all., *Study of the efficiency of brake shoes*, Transportation Research Procedia 63 (2022) 386–393, ScienceDirect.
[3] Mohamed N. Elghitany, Farid Tolba, Adham Mohamed Abdelkader, *Low Vehicle Speeds Regenerative Anti-lock Braking System*, Ain Shams Engineering Journal, **13**, 2022, 101570, www.sciencedirect.com.
[4] M.H. Pranta, et all., *A computational study on structural and thermal behavior of modified disk brake rotors*, Alexandria Engineering Journal, **61**, 2022, p. 1882–1890, www.elsevier.com/locate/aej, www.sciencedirect.com.
[5] Popa Mădălin-Florin, Burnete Nicolae-Vlad, *Study of Brake System Parameters for Commercial Vehicles*, AMMA 2018, Print ISBN 978-3-319-94408-1, Cluj-Napoca, 2018.
[6] Popa Mădălin, Capătă Dorin, Burnete Nicolae, *Aspects of wear braking process on brake discs and brake pads in the construction of commercial vehicles*, IMT Oradea, Mai 2019, http://www.imtuoradea.ro/auo.fmte/.
[7] Melkamu Yigrem, O. Fatoba, Sheferaw Tensay, *Tensile strength, wear characteristics and numerical simulation of automotive brake pad from waste-based hybrid composite*, Materials Today: Proceedings, **62**, 2022, p. 2954–2964, www.elsevier.com/locate/matpr.
[8] Dong Tan, et all., *Evaluation of the wear resistance of aluminium-based hybrid composite brake discs under relevant city rail environments*, Materials & Design, **215**, 2022, 110504, www.elsevier.com/locate/matdes.
[9] V. Mariani, G. Rizzo, F.A. Tiano, L. Glielmo, *A model predictive control scheme for regenerative braking in vehicles with hybridized architectures via aftermarket kits*, Control Engineering Practice, **123**, 2022, 105142, www.elsevier.com/locate/conengprac.
[10] P.S.Bokare, A.K.Maurya, *Acceleration-Deceleration Behaviour of Various Vehicle Types*, Transportation Research Procedia, **25**, 2017, p. 4733–4749, www.sciencedirect.com.
[11] Popa Mădălin, Capătă Dorin, Burnete Nicolae, *Experimental Research on Brake Behavior for Different Types of Commercial Vehicles*, SMAT 2019, The 30th SIAR International Congress of Automotive and Transport Engineering, p. 406–413, Craiova, 2020.
[12] *** AVL website, https://www.avl.com/, last accessed in 26.12.2022.