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MOBILE DIAGNOSTICS OF VEHICLES AS A MEANS TO EXAMINE AND DEFINE SPEED LIMITS IN A ROAD

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Abstract

Speed limitations imposed upon vehicles using the road network are practically brought down to a road administrator defining a certain presupposed discrete value. The latter is typically dependent on the arrangement of linear road infrastructure elements and local development (visibility), the road pavement condition and the roadway geometry. Such a limitation is sometimes consequential to excessive noise or technical specificity of an infrastructure element, which is the case of bridges, tunnels etc. Every officially imposed speed limit set at a too high level against the legitimate requirements (needs) causes considerable losses in terms of traffic flow and affects (also negatively) the behaviour of drivers. From a cognitive perspective, a lower and unjustified speed limit causing irritation among vehicle drivers may not necessarily translate into increased traffic safety. Reduction of traffic flow in road network cross-sections stems from the fact that the permissible speed has been limited to a level below the free flow traffic speed, only based on discrete (step) values, and not always the appropriate ones. This article provides a discussion on a method for determining a legitimate speed limit for a road network based on mobile diagnostics of vehicles. It also touches upon the problem of dynamic adjustment of this specific road network parameter, which will prove crucial for intelligent transport systems (ITS) in the nearest future.

Keywords: speed limit, vehicle diagnostics, road pavement, road geometry, ITS

MOBILNA DIAGNOSTYKA POJAZDÓW W CELU ZBADANIA I OKREŚLENIA OGRANICZEŃ PRĘDKOŚCI W SIECI DROGOWEJ

Streszczenie

Ograniczenia prędkości pojazdów w sieci drogowej sprowadzają się w praktyce do określenia przez zarządcę drogi pewnej z góry ustalonej wartości skokowej. Wartości uzasadnionej na ogół konfiguracją elementów liniowych infrastruktury drogowej i zabudowy (widoczność), stanem nawierzchni drogi i geometrią jezdni. Czasem ograniczenie takie podyktowane jest nadmiernym hałasem bądź specyfiką techniczną elementu infrastruktury tak jak ma to miejsce w przypadku mostów, tuneli itp. Każde administracyjne ograniczenie prędkości ustalone na „zbyt wysokim" poziomie w stosunku do uzasadnionych wymogów (potrzeb) powoduje wymierne starty przepustowości i wpływa na zachowania (również negatywne) kierujących pojazdami. W ujęciu kognitywnym, mniejsza, nieuzasadniona prędkość wpływająca na zdenerwowanie kierujących niekoniecznie oznacza więc zwiększenie bezpieczeństwa ruchu. Zmniejszenie przepustowości przekrojów sieci wynika z faktu ograniczenia prędkości poniżej prędkości ruchu swobodnego w oparciu wyłącznie o skokowe i nie zawsze odpowiednie wartości. W artykule dyskutowany jest sposób wyznaczenia zasadnego ograniczenia prędkości w sieci drogowej na podstawie mobilnej diagnostyki pojazdów. Poruszono również problematykę dynamicznej regulacji tego parametru w sieci drogowej, która będzie kluczowa w najbliższej przyszłości w systemach ITS.

Słowa kluczowe: ograniczenie prędkości, diagnostyka pojazdu, nawierzchnia drogi, geometria drogi, ITS

1. INTRODUCTION

Speed limits in Polish roads are subject to an extensive and heated public discourse on account of the various controversies which typically arise on grounds of this topic. Despite strenuous efforts of multiple circles operating in Poland, the local road traffic safety (RST) indices are still among the worst in Europe [1÷4]. The controversies accompanying the process of speed limiting are substantial to the extent that, in the recent years, they have been the very reason for deregulation of speed limiting road signs. Among various consequences, it has also caused the General Directorate of National Roads and Motorways (GDDKiA) to increase the permissible speed in most road network cross-sections managed by this authority [5]. With regard to the foregoing, it is justified to seek a research methodology which would make it possible to define speed limits applicable in the network of Polish roads in an objective manner, based on studies of vehicle traffic parameters.

Speed limitations are introduced by a traffic (typically the given road) managing body, i.e. the Director of GDDKiA, a provincial governor (marszałek), a district governor (starosta) etc. The above authorities apply speed limitations on account of various factors, such as the arrangements of linear infrastructure elements at junctions and intersections, condition (usually poor) of road pavement, variable road geometry (profiles) etc. It is far less frequent that the decision on introducing a speed limit is caused by excessive noise emission or technical specificity of road infrastructure (e.g. limited load-bearing capacity of a bridge). With regard to the subject of interest addressed in this article, it should be noted that such constraints may also be limited to individual vehicle types, which is the case, however, in specific road network cross-sections. From such a perspective, it is the vehicle which constitutes the speed limiting criterion for roads.

Each time, a proposal to regulate speed in the given road is subject to an official opinion issued by the police: either the provincial or the district headquarters, depending on the scope of authority. In terms of reviewing the proposals, the police mainly follow the principles of safety of vehicle and pedestrian traffic in the given road. The bodies which also play crucial parts in the speed regulation process for Polish roads are Traffic Safety Councils. All decisions made in this respect must comply with the Regulation of the Minister of Infrastructure on detailed technical conditions for road signs and signals as well as road traffic safety devices and conditions for their siting in roads (referred to as the red book). Grounds for placing speed limit signs in the road network are provided by an approved and officially reviewed draft plan of traffic organisation changes. The speed limitation is static in nature, since it only applies to one speed, which is also the case of e.g. sign B-33 [5].

With reference to the foregoing, one may claim that road traffic speed regulation is a complex process in which various official bodies are involved. Moreover, it should be noted that all these bodies use different information, and equally disparate are their particular interests. The road administrator is mainly concerned about maintaining the highest attainable traffic flow rate, especially in toll roads. The police are mostly preoccupied with traffic safety assurance and/or penalising those who violate speed limits. In the event of pathology of the speed control and regulation system, the fiscal aspect may be exactly the predominant one. Also drivers, who perceive the matter of speed purely subjectively, play a part in the clash of very diverse needs reported by individual parties to the process of speed regulation in the road network. Their perspective depends on such factors as, for instance, the vehicle they own, the age structure, the route of travel, the motivation for travelling, the state of being delayed in the network, weather conditions, the psychophysical condition etc. [6÷11].

The overall body of problems related to speed regulation in the road network has been limited in this article to only two, yet particularly important aspects connected with the road pavement condition and road geometry. The reason for the foregoing is that these two aspects may be linked with the physical parameters of vehicle traffic which can be diagnosed (also by mobile means [12÷19]). Other aspects related to noise, technical specificity of infrastructure and their impact on speed limitations have only been briefly addressed in the section of conclusions. The same applies to cognitive aspects, being a subject which requires separate more extensive studies.

2. DIAGNOSTICS OF SELECTED VEHICLE TRAFFIC PARAMETERSCHAPTER

The value of speed limitation pertaining to road traffic (in a cross-section) is heavily dependent on such variables as visibility, pavement condition, weather conditions and geometry. Certain influence is also exerted in this respect by the noise generated by vehicles and the composition of traffic. The nature of all these variables is very different. Road pavement condition is a random variable. In terms of vertical and horizontal deformations, road pavement condition changes in longer periods of time (on a seasonal basis). With regard to weather conditions, the overall state is subject to short-term changes (also sudden changes in intervals of less than 1 h). Weather conditions are (if applicable) reflected in the road signs linked with speed limits. Another parameter, i.e. road geometry, is only seemingly pre-determined from the perspective of speed regulation in the road network. This is only a feature of narrow traffic lanes with the width of 2.5 m, in which vehicles follow a nearly invariable trajectory. For wider roads and lanes, some vehicles tend to divert from the lane (road) axis to a certain extent depending on the traffic conditions (the manoeuvres being made, like overtaking) and the driver's driving style (e.g. there are drivers who prefer driving very close to the middle of the road). What also varies is the composition of the traffic stream, affecting the speeds attainable to individual vehicles in the road. A considerable share of heavy vehicles slow down the entire traffic regardless of the legally imposed limitations applicable in this respect. Therefore, organisation of the transit traffic may contradict the speed limits introduced in the road network.

One may assume that for purposes of optimum utilisation of the road network flow capacity, speed limits should be established in a dynamic manner, proportionally to the typical behaviours displayed by drivers in periods when no incidents usually take place in roads. Contemporarily, an obstacle in the pursuit of this goal is the fixed vertical road signs which preclude taking the dynamics of traffic condition changes into account. The only way to adjust the speed limit in a dynamic manner is currently the use of variable message signs (VMS). In the future, it will be possible by means of virtualised vertical signs featuring LED panels. In relation to the foregoing, the parameters which affect the running speed of vehicles have been defined as time-dependent variables. Therefore, a function which establishes the value of speed limit in a traffic lane may be noted as the following equation:.

$$V(t) = f(RS(t), RAC(t), \overline{PR}(n), N(t), RIL) \qquad (1)$$

where:

RS – road pavement conditions [sets of measurements],
RAC – weather conditions on the road [sets of measurements],
PR – average vehicle trajectory for all the n^{th} road users [sets of 3D points],
N – overall noise [dB],
RIL – road infrastructure limitations [t].

Equation (1) does not regard such properties of the traffic stream as the traffic structure, since they are limitations unrelated directly to the given road, but rather connected with traffic organisation across the entire road network. All of the parameters included in equation (1) which affect the adjusted speed are variable in nature, although they vary to a different extent. In this article, it has been proposed that two of them should be subject to diagnostic examinations, namely the road pavement condition and the average vehicle trajectory (especially for older roads, since they were inappropriately profiled or their profiles have changed in a longer period of time due to soil mechanics or workmanship defects). For that purpose, MEMS and GPS units can be installed in vehicles running in the given road section in order to record their linear accelerations and trajectories. Such studies are currently limited to installing mobile applications on smartphones (devices featuring GPS and MEMS units) used by the persons forming the survey sample, which should be immobilised in a specific position against the vehicle body (for instance, using a stable holding bracket) while the vehicle is running. Owing to simplicity of the measuring system, one can determine linear accelerations in every vehicle axis in a precisely defined reference system and with a very small measuring interval (e.g. in the trial test: 10 ms). For a vehicle stream speed of 50 km/h, it means that a single sample is obtained every 18 cm, whereas at a speed of 20 km/h – every 5 centimetres (see tab. 1).

Table 1. Sample resolutions

No.	Intersection speed [km/h]	Space interval [cm]
1	10	2,78
2	20	5,56
3	30	8,33
4	40	11,11
5	50	13,89
6	60	16,67
7	70	19,44
8	80	22,22
9	90	25,00

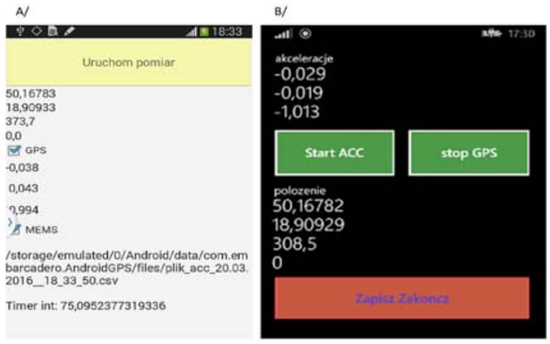

Fig. 1. Sample test application running on:
a) Android, b) Windows Phone
Source: author's own materials

Figure 1 illustrates the applications used to measure linear accelerations of a vehicle combined with recording of the MEMS unit position in a geocentric system by means of the GPS for each sample [12÷19]. While measuring linear accelerations, also road irregularities are measured indirectly, whereas the running trajectory of each of the drivers tested is measured in a direct manner. Road irregularities are recorded in such a measuring system on account of the vehicle body tilting (limited by the vehicle's suspension system). The measurement data obtained for linear accelerations comprise components originating from the engine vibrations, the vehicle suspension system characteristics as well as the irregularities affecting the vehicle while it is moving on the road. Values of these components are not only dependent on the suspension system and the road irregularities, but also on the individual person's driving style. It is assumed that the measurement of linear accelerations applies to a sample of vehicles covering the given road section multiple times, and that technical condition of their suspension and power transmission systems is not subject to considerable changes in a short time horizon. Following these assumptions, it is not the absolute values of linear accelerations that one may use to indirectly establish the road pavement condition, but a reference to their variance in a short period of time for specific vehicle types. The structure of the study may further improve when driving style is taken into consideration. By that means, in individual groups of vehicles assigned different traction characteristics or driving styles, based on the observation of variance in the values of linear accelerations and for the given road section, one can establish adjusted running speed V_a^k:

$$V_a^k = f(\Delta a_x(\Delta t), \Delta a_y(\Delta t), \Delta a_z(\Delta t)) \qquad (2)$$

where:

a_x – linear acceleration in the x-axle perpendicular to lane axis [m/s^2],
a_y – linear acceleration in the y-axle parallel to lane axis [m/s^2],
a_z – linear acceleration in the z-axle

perpendicular to lane surface [m/s²],

Δt – basic measuring interval [µs].

K – structure element in the population of drivers using the lane for which homogeneous characteristics are being determined (drivers, vehicles - similar) [-].

The speed limit applicable to the given section should be the minimum speed value established in individual type groups after rejecting extreme values (atypical for the traffic):

$$V_a^I(\Delta t) = \min\{V_a^K(\Delta t)\} \quad (3)$$

where:

I – road cross-section in which the speed limit sign is situated [m]

In the set of speed values established for all the analysed groups, one can reject, for instance, two extreme deciles. The basic measuring interval should be adjusted to the average speeds observed in the road being studied (the higher the speed, the smaller the interval). It should also be noted that the drivers' profile is measured with pre-assumed diversion from the traffic lane axis, and hence the divergent characteristics of linear accelerations (stemming from that reason exactly). The vehicles which divert from the lane axis encounter various obstacles. And by that means, by way of a simple measurement, a three-dimensional function is described characterising linear accelerations for different momentary vehicle positions. At each discrete point of such a function, components of three linear accelerations a_x, a_y, a_z are given. Linear accelerations in the x-axis describe forces acting transversely to the vehicle driving direction (pavement irregularities, tuning manoeuvres, responses of the suspension system etc.). The y-axis accelerations describe forces acting in the vehicle motion axis (mainly acceleration, braking and the related responses of the suspension system). The z-axis accelerations, on the other hand, describe forces perpendicular to the vehicle motion direction (gravitation, road pavement irregularities and responses of the vehicle suspension system). Figure 2 illustrates sample changes in the vehicle motion characteristics observed in a road section. One can conclude from the graph that, on a constant characteristic curve of the suspension system in short periods of time, the variance of linear acceleration values in an equivalent measurement section indirectly implies changes to the road pavement condition (on a fixed vehicle trajectory). The figure shows two cases of characteristic curves (change of accelerations with the same trajectory).

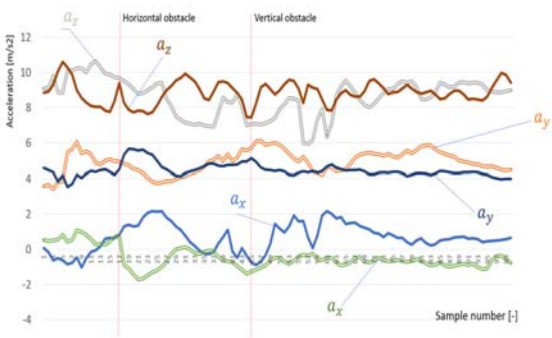

Fig. 2. Sample characteristic curves of linear accelerations in an automotive vehicle Source: author's own materials

Linear accelerations are measured in a reference system of geocentric coordinates for a pre-defined smartphone position against the vehicle body (Fig. 3). Road irregularities are reflected in the values of all linear accelerations recorded by this method. In points where traffic stream speed is typically regulated, the highest values of linear accelerations are recorded primarily in axes X and Z.

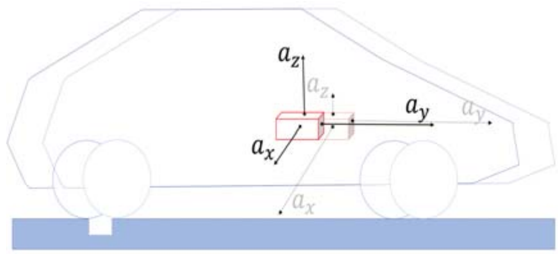

Fig. 3. Linear accelerations recorded by means of a smartphone; changes in forces caused by decreasing thickness of the pavement surfacing. Source: author's own materials

Linear vehicle accelerations are recorded in such a study at nearly all points of the vehicle trajectory (for low Δt values, it is a quasi-continuous characteristic):

$$RS(x, y, z, t) = f(a_x, a_y, a_z, t) \quad (4)$$

where:

x, y, z – coordinates of momentary vehicle position in a geocentric system.

Due to the limited accuracy of the vehicle GPS position measurement, where even on application of the AGPS technology the accuracy is close to variability in the width of road lanes in the Polish road network (2.5÷4.2 m), the position values taken into account in equation (4) are averaged in a traffic lane. By that means, for the given lane, one formulates a conventional average vehicle traffic stream trajectory for which accelerations and their variance, and consequently also the permissible traffic speed are established. Figure 4 illustrates the concept of measurement of linear acceleration values for different vehicle trajectories.

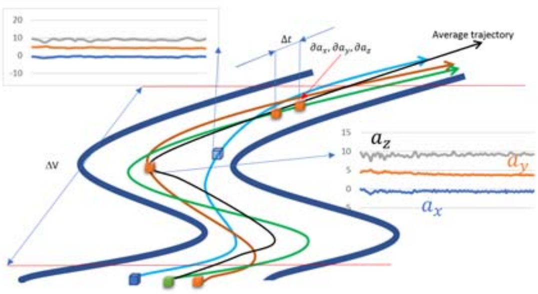

Fig. 4. Set of characteristic road cross-section points forming different trajectories. Source: author's own materials

As shown in Fig. 4, both sectional speed and its changes in individual cross-sections of a road section are determined based on changes in the variance of linear acceleration values established for resultant vehicle trajectories in individual groups of vehicle and driver types. Having measured n runs of the same vehicle in the given road section, one can determine variance of linear accelerations in individual measuring axes. Values of variance are averaged for m test vehicles in each of the pre-defined type groups. One may assume certain thresholds of permissible changes in linear acceleration values for test vehicles. By that means, each level of the linear acceleration variance change in a test sample corresponds to a speed limit change for a road section:

$$V_j \propto \left(\{\Delta a_x\}, \{\Delta a_y\}, \{\Delta a_z\}\right) \quad (5)$$

where:

V_j – regulated speed in the j^th road cross-section [m/s].

By application of the proposed methodology, one can establish a quasi-continuous function of speed limit changes for a road section depending on changes of linear acceleration values in individual axes. In this respect, it is a valid question for what purpose one should apply nearly continuous values of speed limitations considering the restrictions to their implementation in real road networks. In light of the increasing integration in the vehicle-road system in intelligent transport systems, it is possible to adjust the vehicle running speed more and more accurately (especially in autonomous vehicles) as well as to regulate it in such a manner that its value is as close as possible to the permissible speed limit set for the given road section. On account of the foregoing, one may expect a nearly optimum utilisation of the entire available flow capacity of the road network. Figure 5 illustrates the concept of mobile diagnostics of vehicles as a means to examine and define speed limits in a road.

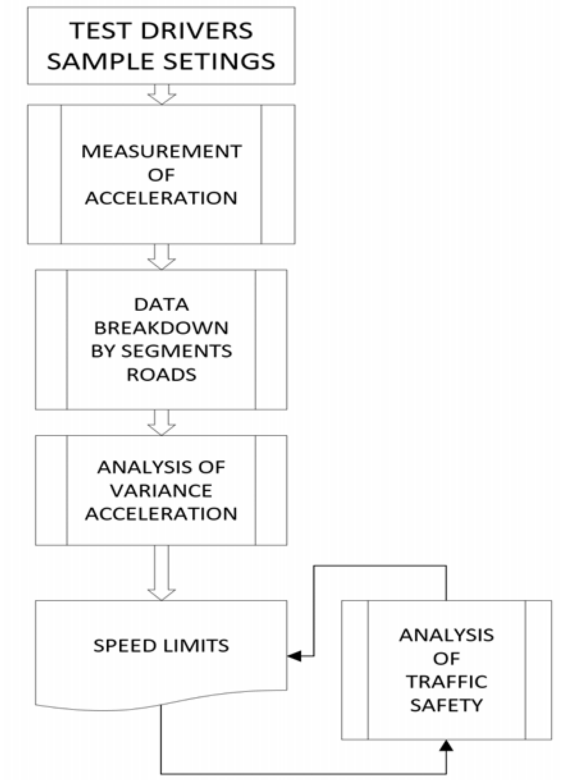

Fig. 5. Concept of mobile diagnostics of vehicles as a means to examine and define speed limits in a road. Source: author's own materials

3. CONCLUSIONS

One of the problems related to the proposed method of linear acceleration measurement and, by that means, of limiting the running speed in a well-grounded manner is making an appropriate selection of the sample of vehicles subject to testing of linear accelerations. This selection should be oriented towards ensuring uniform characteristics of vehicle suspension systems in the type groups studied. Values of regulated speed should result from delimitation of the range of observed linear acceleration variances into uniform ranges. The sample structure may also reflect different types of vehicle drivers. In this article, selected preliminary observations pertaining to the matter in question have been discussed. The problem as such concerns the notion of Big Data and requires extensive research to be undertaken.

Speed regulation depending on the variables describing noise and specificity of the infrastructure requires that linear acceleration values should be analysed with reference to parameters of local settlements and the accompanying commercial facilities. For that purpose, one can apply a method of the road network indexing using data retrieved from OSM type maps. Examples of such indexing have been discussed in several articles [19].

What may also be studied by application of the method proposed besides linear acceleration values is some other characteristics of vehicles, such as emission of harmful substances. Yet another interesting area of research entails tests conducted using the eye tracking technology, since reduction of running speed may be accompanied by declining attention among vehicle drivers. Consequently, in the course of such studies, one may also observe the effect of speed limitation on the level of drivers' attentiveness. In some cases, determining reasonable speed limits on the road network involving mobile vehicle diagnostics may in fact change road traffic safety. In some cases, it may deteriorate road traffic safety. Speed is one of five risk factors (others: child restraints, drink driving, helmets, seat-belts). It is therefore necessary to feedback between the results methods (speed limits) and the diagnosis of road traffic safety (Fig. 5).

REFERENCES

1. Buttler I. Road accidents in Poland. IATSS Research 2005; 29: 102-105. http://dx.doi.org/10.1016/S0386-1112(14)60123-0
2. National Road Safety Council. National road, safety programme 2013-2020. From: http://www.krbrd.gov.pl/
3. Jamroz K, Smolarek L. Driver Fatigue and Road Safety on Poland's National Roads. International Journal of Occupational Safety and Ergonomics 2013; 19(2): 297–309.
4. Europen Transport Safety Council. Ranking EU progress on road safety, 2016. From: http://etsc.eu/wp-content/uploads/10-PIN-annual-report-FINAL.pdf
5. General Directorate for National Roads and Motorways. Raport z przeprowadzonej weryfikacji oznakowania w zakresie obowiązywania znaku B-33 ograniczenie prędkości na sieci dróg krajowych zarządzanych przez Generalną Dyrekcję Dróg Krajowych i Autostrad. Polish. From: http://www.gddkia.gov.pl/en/1001/contact-us
6. Bunn TL, Slavova S, Struttmann TW, Browning SR. Sleepiness/fatigue anddistraction/inattention as factors for fatal versus nonfatal commercial motor vehicle driver injuries. Accident Anal Prev. 2005; 37(5): 862–9.
7. Macioszek E. The road safety at turbo roundabouts in Poland. Archives of Transport 2015; 33: 57-67
8. O'Neill B. Improving U.S. highway safety: Have we taken the right road? TR News 2005; 329
9. Duperrex O, Bunn F, Roberts I. Safety education of pedestrians for injury prevention: a systematic review of randomised controlled trials. British Medical Journal 2002; 324: 1129-1134.
10. Wang Y. National road safety action plan in China. Sixth SHRP 2 Safety Research Symposium. Washington, DC.: Transportation Research Board 2011
11. TRB. Achieving traffic safety goals in the United Sates, Special Report 300. Washington, DC.: Transportation Research Board of the National Academies 2011.
12. Burdzik R, Celiński I, Czech P. Optimization of transportation of unexploded ordnance, explosives and hazardous substances - vibration issues. Vibroeng. Procedia 2016; 10: 382-386.
13. Młyńczak J, Burdzik R, Celiński I. Research on dynamics of shunting locomotive during movement on marshalling yard by using prototype of remote control unit. Dynamical systems: theoretical and experimental analysis, Łódź, Poland, December 7-10, 2015. Ed. Jan Awrejcewicz. Berlin: Springer International Publishing, 2016; 279-292.
14. Młyńczak J, Burdzik R, Celiński I. Research on vibrations in the train driver's cab in the course of shunting activity. Dynamical systems. Mechatronics and life sciences. Eds. Jan Awrejcewicz, Marek Kaźmierczak, Jerzy Mrozowski, Paweł Olejnik. Łódź: Wydaw. Politechniki Łódzkiej, 2016; 353-364.
15. Niziński S, Wierzbicki S. Zintegrowany system informatyczny sterowania pojazdów. Diagnostyka. 2004; 30:47-52.
16. Młyńczak J, Celiński I, Burdzik R. Effect of vibrations on the behaviour of a vehicle driver. Vibroeng. Procedia 2015; 6: 243-247.
17. Surma S, Młyńczak J, Celiński I, Warczek J. Mobile analysis of railway traffic safety. Vibroeng. Procedia 2015; 6: 238-242.
18. Młyńczak J, Burdzik R, Celiński I. Remote control operation using mobile devices of the train driver with monitoring of locomotive's movement dynamics during maneuvers. 13th Conference on Dynamical Systems Theory and Applications. DSTA 2015, Łódź, December 7-10, 2015, Poland. 2015; 217.
19. Młyńczak J, Burdzik R, Celiński I. Remote monitoring of the train driver along with the locomotive motion dynamics in the course of shunting using mobile devices. Dynamical systems. Control and stability. Eds. Jan Awrejcewicz, Marek Kaźmierczak, Jerzy Mrozowski, Paweł Olejnik. Łódź: Wydaw. Politechniki Łódzkiej, 2015; 411-422.
20. Celiński I. Transport network parameterisation using the GTAlg tool. Contemporary challenges of transport systems and traffic engineering. 13th Scientific and Technical Conference "Transport Systems. Theory and Practice 2016", Katowice, Poland, September 19-21, 2016. Selected papers. Eds. Elżbieta Macioszek, Grzegorz Sierpiński. Cham: Springer, 2017; 111-123.

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