ASSESSMENT OF A TECHNIQUE FOR DETERMINING THE MASS CENTER OF VARIOUS VEHICLES

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Abstract: *Location of the center of gravity has a significant effect on the various performance characteristics of vehicles, especially ride comfort, stability and handling. Experimental determination of the center of gravity is not always possible. There is a known technique for calculating the center of gravity of a truck, built on the method of partitioning, which is based on the hypothesis that the center of gravity of the aggregates coincides with their geometric center. The author set the task to improve the accuracy of the proposed method by taking into account the mass of filling fluids in large units for various vehicles.*

Keywords: *cars; trucks; geometric characteristics; partitioning method; iterative method*

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1. INTRODUCTION

The position of the center of gravity of a vehicle is an extremely important parameter in the design and calculation of vehicles. For example, the longitudinal coordinate of the center of gravity has a significant effect on the smoothness of the ride [1–3]. The shift of the center of gravity towards the front axle increases the component of the centrifugal force acting on the steered wheels, which has a positive effect on handling [4–6]. The vertical coordinate of the center of gravity significantly affects the longitudinal stability [7–8], as well as the lateral stability on a slope [9] or during curvilinear motion [10–12]. An increase in the height of the center of gravity reduces the critical roll-over speed of the vehicle $v_{cr.h}$ [13–14]. In this case, it is advisable to take into account the displacement of the center of gravity relative to the longitudinal axis [15]:

$$v_{cr.h} = \sqrt{\frac{Rg}{h_g}\left(\frac{B}{2} \pm E_g\right)},$$

where R is the turning radius, m;

g=9,81 м/с^2 – acceleration of gravity;

h_g – height of the center of gravity, m;

B – reduced track, m;

E_g – transverse eccentricity of the center of gravity, m (the minus sign corresponds to the shift towards the roll).

Not only traffic density [16-17], class inequality [18], discrepancies in the Traffic Regulations [19] and inexperienced car-sharing drivers [20] affect the mental tension of road users [21], but also the braking efficiency of vehicles in case of emergency maneuvers, which forces the developers of Driver Attention Monitoring Systems (DAMS) to build in additional functions that record the psycho-emotional state and driving style of the driver [22–24]. Braking efficiency is especially important in the case of mutual longitudinal approach of vehicles [25–28], as well as during emergency braking [29], including in front of pedestrian crossings [30]. The longitudinal and vertical coordinates of the center of gravity have a significant effect on the redistribution of normal reactions on wheels during braking [31–38] and acceleration [39–40], as well as on the angles of the steered wheels [41–46]. At the same time, the difficulty lies in a decrease in the radius of the wheels with an increase in normal reactions (and vice versa), which, in turn, leads to a shift in the center of gravity. This cyclical problem is solved only by the iterative modeling method [47–51]. In addition, the distribution of vertical reactions along the axes of vehicles is an important factor affecting the wear of the road surface [52–54].

Usually, the center of gravity is determined by bench tests [55] using a standardized technique (Fig. 1–2). Various stands are known for performing such tests [56–59]. However, the experimental determination of the center of gravity at the design stage is very difficult. Therefore, to calculate the center of gravity, the author proposes to use a technique based on the method of partitioning and the use of initial reference data [60].

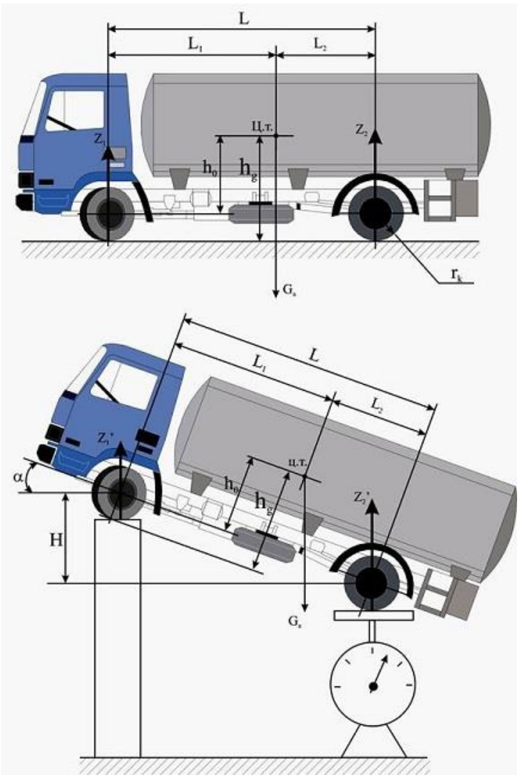

Fig. 1. *Experimental determination of the longitudinal coordinate of the vehicle center of gravity*

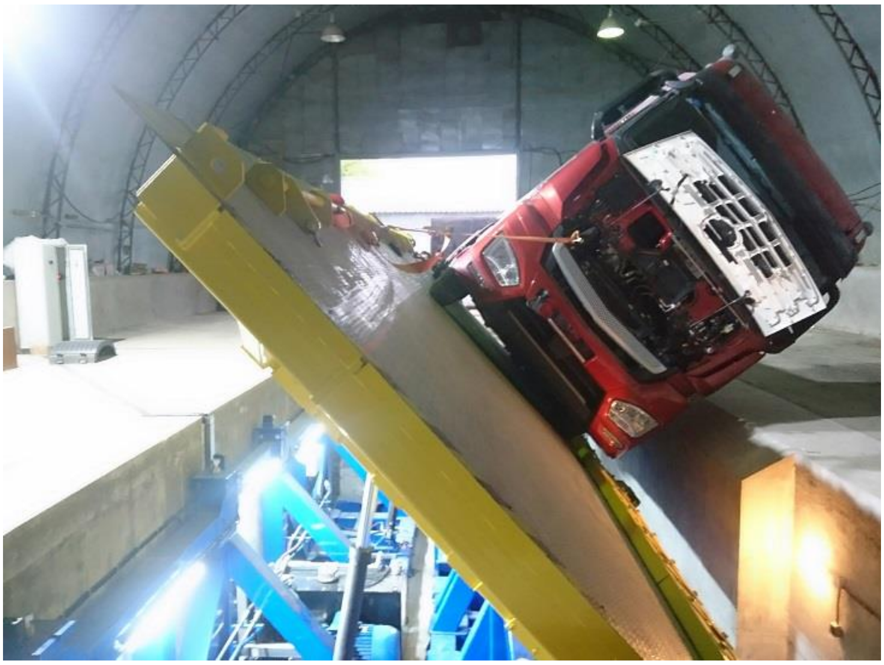

Fig. 2. *Experimental determination of the transverse coordinate of the vehicle center of gravity*

The accuracy and adequacy of this technique can be increased if we take into account the mass of filling fluids in large units, such as the engine, gearbox, transfer case, axle housings. The filling volume of the power steering, hydraulic brake drive, shock absorbers, and the washer fluid reservoir, as a rule, is an order of magnitude less, so they can be attributed to the residual mass. The author of the article set the goal to check the adequacy of the refined methodology for determining the center of gravity of a wheeled vehicle.

2. TECHNIQUE FOR DETERMINING THE MASS CENTRE

The algorithm of the refined methodology for determining the center of gravity of a vehicle includes the following steps.

1. According to the reference book [61], the following parameters are determined:

– total mass m_f and its distribution along the axes m_{f1}, m_{f2}, kg;

– curb weight m_c and its distribution along the axes m_{c1}, m_{c2}, kg;

– carrying capacity m_{wc}, kg;

– longitudinal coordinate of each axis L_1, L_2, L_3, m;

– mass of the engine with clutch m_{eng}, kg;

– mass of the gearbox m_{gb}, kg;

– mass of the transfer case m_{trc}, kg (if any);

– mass of the cardan transmission m_{crd}, kg;

– mass of the front, second and third axles m_{ax1}, m_{ax2}, m_{ax3}, kg;

– body (platform) mass m_{bod}, kg;

– mass of the cabin m_{cab}, kg;

– mass of the tail m_{hd}, kg (with a bonnet arrangement);

– mass of the frame m_{frm}, kg;

– mass of front and rear suspension (spring) m_{sp1}, m_{sp2}, kg;

– mass of the radiator m_{rad}, kg;

– mass of the winch m_{win}, kg (if available);

– mass of the fifth wheel coupling m_{fw}, kg (for truck tractors);

– mass of a wheel with a tire m_{wt}, kg;

– volume of the fuel tank V_{ft}, l;

– volume of the engine cooling system V_{cs}, l;

– volume of the engine lubrication system V_{ls}, l;

– volume of the gearbox housing V_{gb}, l;

– volume of the transfer case crankcase V_{trc}, l;

– crankcase volume of each axle V_{ax1}, V_{ax2}, V_{ax3}, l.

2. The mass of the driver and passengers is calculated as the total mass of the vehicle minus the unladen mass and the mass of the cargo, kg:

$$m_{hum} = m_f - m_c - m_{wt}.$$

3. The mass of a wheel with a tire must be multiplied by the number of slopes k_w for each axle:

$$m_{wt1} = k_{w1} m_{wt}; \; m_{wt2} = k_{w2} m_{wt}; \; m_{wt3} = k_{w3} m_{wt},$$

where k_{w1}=2, k_{w2} and k_{w3} can be 2 or 4.

The spare wheel mass m_{wts} is taken into account separately.

4. The mass of filling fluids is determined according to the well-known formula, kg:

$$m_{liq} = 10^{-3} \cdot V_u \cdot \rho_{liq},$$

where V_u is the volume of this unit, l;

ρ_{liq} – density of liquid, kg/m^3.

In the calculations, the following averaged density values were taken:

– for gasoline ρ=760 kg/m^3, for summer diesel fuel ρ=860 kg/m^3;

– for antifreeze ρ=1080 kg/m^3;

– for engine oil ρ=900 kg/m^3;

– for transmission oil ρ=915 kg/m^3.

5. To determine the centers of gravity of people and units, it is advisable to use the overall layout drawing of the vehicle in the computer-aided design (CAD) system "KOMPAS" [62–64], while the origin along the longitudinal axis X coincides with the front dimension, and along the vertical axis Z – with the level of the supporting surface (Fig. 3).

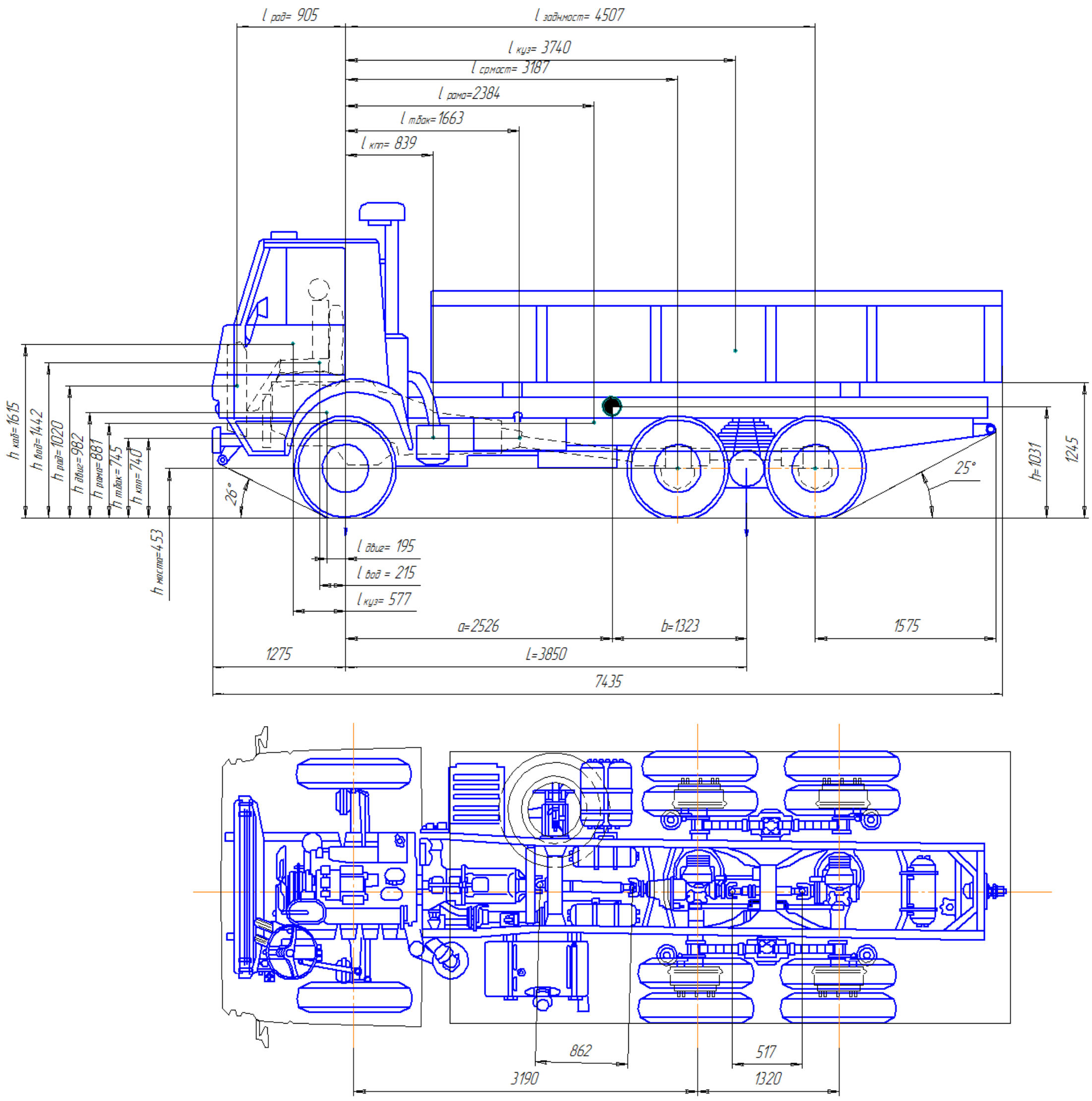

__Fig. 3.__ Determination of the coordinates of the centers of the vehicle units according to the outline drawing in CAD "KOMPAS"

6. The centers of gravity of bridges and wheels (except for the spare) coincide with the axes of rotation. The longitudinal coordinates of the axes L_1...L_3 are known, and the vertical coordinate can be equated to the static radius of the wheel, which is also determined from the reference book for a given tire size [65].

7. For trucks, it is assumed that the load is evenly distributed over the body volume. Then the center of gravity of the load is at the geometric center of the body.

8. The center of gravity of the driver and passengers coincides with the qi-hai point, the coordinates of which are determined taking into account their landing on the seats.

9. The longitudinal coordinate of the center of gravity of the spring for a single axle coincides with the center of the axle, and for a two-axle bogie it lies between the middle and rear axles. The mass of the springs is multiplied by 2, since they are located on both sides of the vehicle.

10. After taking into account all the listed mass elements m_u the residual mass of the vehicle is calculated, kg:

$$m_{res} = m_c - \sum m_u .$$

The coordinates of the residual mass are taken in the geometric center of the vehicle, m:

$$X_{res} = \frac{L_{ov}}{2};$$

$$Z_{res} = \frac{h_{cab} + h_{gr}}{2},$$

where L_{ov} – overall vehicle length, m;

h_{cab} – cabin height, m;

h_{gr} – ground clearance, m.

11. The calculated coordinates of the center of gravity at the total mass are found by the formulas based on the partitioning method, m [66]:

$$X_{gf} = \frac{\sum m_u X_u + m_{res} X_{res} + m_{wt} X_{wt} + m_{hum} X_{hum}}{m_f};$$

$$Z_{gf} = \frac{\sum m_u Z_u + m_{res} Z_{res} + m_{wt} Z_{wt} + m_{hum} Z_{hum}}{m_f}.$$

The same with the curb weight:

$$X_{gc} = \frac{\sum m_u X_u + m_{res} X_{res}}{m_c};$$

$$Z_{gc} = \frac{\sum m_u Z_u + m_{res} Z_{res}}{m_f}.$$

3. ADEQUACY OF THE TECHNIQUE

To confirm the adequacy of the proposed method, the experimental longitudinal coordinate of the center of gravity was determined based on the distribution of the total and equipped mass along the axes:

$$\lambda_{gf.exp} = L_1 + L\frac{m_{f2}}{m_f};\ \lambda_{gc.exp} = L_1 + L\frac{m_{c2}}{m_c},$$

where L_1 – front overhang, m;

L – vehicle wheelbase, m.

In addition, a comparison was made with the known reference values of the longitudinal ($\ell_{gf.ref}$, $\ell_{gc.ref}$) and vertical ($h_{gf.ref}$, $h_{gc.ref}$) coordinates of the center of gravity [67].

The results of calculations according to the above method for various vehicles at full weight are given in table 1, with the curb weight – in table 2.

Table 1. *The results of calculations for the total mass of vehicles*

Vehicle	X_{gf}, m	$\ell_{gf.exp}$, m	$\ell_{gf.ref}$, m	Z_{gf}, m	$h_{gf.ref}$, m
ZAZ-11022	1,86	1,81	1,948	0,565	0,569
VAZ-2106	1,984	1,972	1,918	0,591	0,58
VAZ-2105	1,991	1,972	2,021	0,58	0,56
VAZ-2108	2,038	2,001	2,045	0,576	0,58
Moskvich-412	1,992	1,975	1,955	0,598	0,596
GAZ-24-10	2,219	2,219	2,236	0,612	0,62
VAZ-2121	1,837	1,84	1,835	0,734	0,75
UAZ-31512	2,003	2,042	2,07	0,762	0,769
UAZ-2206	2,125	2,271	2,25	0,918	0,9
RAF-2203-01	2,549	2,597	2,52	0,872	0,732
PAZ-3201	3,481	3,47	3,47	1,269	1,2
LAZ-695N	4,769	4,843	4,85	1,076	0,83
LAZ-42021	5,273	5,398	5,43	1,242	0,7
Izh-2715-01	2,197	2,141	2,105	0,794	0,65
Izh-27151-01	2,17	2,141	2,105	0,626	0,6
GAZ-53-12	3,734	3,682	3,666	1,073	1,14
ZiL-433100	4,399	4,223	3,533	1,227	1,26
ZiL-133GYa	5,104	5,278	4,536	1,444	1,2
KamAZ-53212	4,273	4,601	4,575	1,362	1,3
GAZ-66-11	2,926	2,897	2,83	1,241	1,15
ZiL-131N	4,039	3,988	4,097	1,211	1,16
KrAZ-260	5,159	5,184	5,08	1,621	1,5

Table 2. The results of calculations for the equipped mass of vehicles

Vehicle	X_{gc}, m	$\ell_{gc.exp}$, m	$\ell_{gc.ref}$, m	Z_{gc}, m	$h_{gc.ref}$, m
ZAZ-11022	1,638	1,581	1,933	0,559	0,559
VAZ-2106	1,896	1,782	1,708	0,566	0,56
VAZ-2105	1,866	1,747	1,761	0,552	0,55
VAZ-2108	1,8	1,742	1,835	0,559	0,56
Moskvich-412	1,822	1,759	1,655	0,577	0,562
GAZ-24-10	2,091	2,066	2,106	0,599	0,586
VAZ-2121	1,635	1,604	1,605	0,712	0,7
UAZ-31512	1,725	1,758	1,766	0,703	0,735
UAZ-2206	2,095	2,102	2,103	0,833	0,822
RAF-2203-01	2,475	2,415	2,32	0,932	0,75
PAZ-3201	3,141	3,089	3,09	1,16	1,1
LAZ-695N	4,96	4,964	4,99	0,988	0,63
LAZ-42021	5,506	5,532	5,52	1,161	0,55
Izh-2715-01	1,81	1,755	1,81	0,659	0,629
Izh-27151-01	1,688	1,687	2,329	0,542	0,56
GAZ-53-12	2,659	2,907	2,906	0,758	0,82
ZiL-433100	3,117	3,198	2,663	0,919	0,95
ZiL-133GYa	4,125	4,31	3,746	0,922	0,8
KamAZ-53212	3,832	3,708	3,715	1,067	0,9
GAZ-66-11	2,356	2,411	2,33	0,929	0,763
ZiL-131N	3,418	3,4	3,397	0,96	0,758
KrAZ-260	3,903	4,137	4,17	1,022	1,15
KamAZ-5410	3,081	3,012	2,485	0,837	0,9
MAZ-64221	3,159	3,218	3,26	1,069	1,1

The error of the calculated values relative to the experimental and reference data was calculated using the formulas:

$$\Delta X_{exp} = \frac{\left|X_g - \lambda_{g.exp}\right|}{X_g} \cdot 100\%;$$

$$\Delta X_{ref} = \frac{\left|X_g - \lambda_{g.ref}\right|}{X_g} \cdot 100\%;$$

$$\Delta X_{ref/exp} = \frac{\left|\lambda_{g.ref} - \lambda_{g.exp}\right|}{\lambda_{g.ref}} \cdot 100\%;$$

$$\Delta Z_{ref} = \frac{\left|Z_g - h_{g.ref}\right|}{Z_g} \cdot 100\% .$$

The results of assessing the adequacy of the proposed technique are shown in table 3.

Table 3. *Error of calculated values*

Vehicle	Full mass				Curb mass			
	ΔX_{exp}	ΔX_{ref}	$\Delta X_{ref/exp}$	ΔZ_{ref}	ΔX_{exp}	ΔX_{ref}	$\Delta X_{ref/exp}$	ΔZ_{ref}
ZAZ-11022	2,69	4,73	7,08	0,71	3,48	18,01	18,21	0,00
VAZ-2106	0,60	3,33	2,82	1,86	6,01	9,92	4,33	1,06
VAZ-2105	0,95	1,51	2,42	3,45	6,38	5,63	0,80	0,36
VAZ-2108	1,82	0,34	2,15	0,69	3,22	1,94	5,07	0,18
Moskvich-412	0,85	1,86	1,02	0,33	3,46	9,17	6,28	2,60
GAZ-24-10	0,00	0,77	0,76	1,31	1,20	0,72	1,90	2,17
VAZ-2121	0,16	0,11	0,27	2,18	1,90	1,83	0,06	1,69
UAZ-31512	1,95	3,34	1,35	0,92	1,91	2,38	0,45	4,55
UAZ-2206	6,87	5,88	0,93	1,96	0,33	0,38	0,05	1,32
RAF-2203-01	1,88	1,14	3,06	16,06	2,42	6,26	4,09	19,53
PAZ-3201	0,32	0,32	0,00	5,44	1,66	1,62	0,03	5,17
LAZ-695N	1,55	1,70	0,14	22,86	0,08	0,60	0,52	36,23
LAZ-42021	2,37	2,98	0,59	43,64	0,47	0,25	0,22	52,63
Izh-2715-01	2,55	4,19	1,71	18,14	3,04	0,00	3,04	4,55
Izh-27151-01	1,34	3,00	1,71	4,15	0,06	37,97	27,57	3,32
GAZ-53-12	1,39	1,82	0,44	6,24	9,33	9,29	0,03	8,18
ZiL-433100	4,00	19,69	19,53	2,69	2,60	14,57	20,09	3,37
ZiL-133GYa	3,41	11,13	16,36	16,90	4,48	9,19	15,06	13,23
KamAZ-53212	7,68	7,07	0,57	4,55	3,24	3,05	0,19	15,65
GAZ-66-11	0,99	3,28	2,37	7,33	2,33	1,10	3,48	17,87
ZiL-131N	1,26	1,44	2,66	4,21	0,53	0,61	0,09	21,04
KrAZ-260	0,48	1,53	2,05	7,46	6,00	6,84	0,79	12,52
KamAZ-5410	2,69	4,73	7,08	0,71	2,24	19,34	21,21	7,53
MAZ-64221	0,60	3,33	2,82	1,86	1,87	3,20	1,29	2,90

4. CONCLUSION

The algorithm of the proposed method for determining the center of gravity can be used not only in design and verification calculations of vehicles, but also in the functional logic of preventive motion control system [68–69] and autonomous control systems [70–75]. The error of the technique relative to the experimental values does not exceed 3%, and relative to the reference values 7% and 10% along the longitudinal and vertical coordinates, respectively, which generally confirms its adequacy. However, the reliability of the reference values is questionable, since, although their average error relative to the experimental data on the longitudinal coordinate did not exceed 6%, in some cases the error reached 16…28%. It was not possible to estimate the reference values for the height of the gravity center due to the lack of similar experimental data. For buses, the average error along the vertical coordinate reaches 23%, which indicates the need to clarify the methodology in terms of placing passengers relative to the body.

References

1. Pavlov V.V. Proektirovochnye raschjoty transportnyh sredstv special'nogo naznachenija [Design calculations of special vehicles]. Moscow, MADI, 2014, 116 p.

2. Kuvshinov V.V., Pavlov V.V. Vestnik MADI, 2016, issue 3, pp. 55–62.

3. Malinovskij M.P., Kuvshinov V.V., Fjodorov A.A., Bedzhanov G.A. Jenergo- i resursosberezhenie: promyshlennost' i transport, 2018, no. 3, pp. 10-13.

4. Zheleznov E.I., Revin A.A. Avtomobili. Teorija jekspluatacionnyh svojstv [Cars. Performance theory]. Volgograd, VolgGTU, 2015, 170 p. 4.

5. Tarasik V.P. Vestnik Belorussko-Rossijskogo universiteta, 2019, no. 2, pp. 44-53.

6. Demić M., Željko Š., Djordje D. Science journal of transportation, 2020, no. 10, pp. 50-61.

7. Tjurin Ja.I., Mandrovskij K.P. Vestnik MADI, 2018, issue 4, pp. 34-38.

8. Malinovsky M. Science journal of transportation, 2011, no. 3, pp. 62-66.

9. Husainov A.Sh., Selifonov V.V. Teorija avtomobilja [Car theory]. Ul'janovsk, UlGTU, 2008, 121 p.

10. Gladov G.I., Malinovskij M.P. Izvestija vysshih uchebnyh zavedenij. Mashinostroenie, 2007, no. 11, pp. 36-46.

11. Malinovskij M.P. Vestnik MADI, 2016, issue 1, pp. 51-56.

12. Malinovskij M.P., Kuvshinov V.V., Smolko E.S. Vestnik MADI, 2020, issue 4, pp. 43-54.

13. Kul'ko P.A., Kul'ko A.P., Galicyna T.A. Izvestija Volgogradskogo gosudarstvennogo tehnicheskogo universiteta. Serija: Nazemnye transportnye sistemy, 2010, vol. 3, no. 10, pp. 58-61.

14. Rjabov I.M., Hanin D.M., Mamakurbanov M.M. Izvestija Volgogradskogo gosudarstvennogo tehnicheskogo universiteta. Serija: Nazemnye transportnye sistemy, 2013, vol. 6, no. 10, pp. 30-33.

15. Malinovskij M.P. Metod povyshenija aktivnoj bezopasnosti putem preduprezhdajushhego upravlenija dvizheniem avtopoezda [Method of active safety improvement by preventive motion control of articulated vehicle], Ph.D. thesis, Moscow, MADI, 2009, 157 p.

16. Malinovskij M.P., Zhuravleva A.Ju. Nauka i tehnika v dorozhnoj otrasli, 2015, no. 1, pp. 10-14.

17. Malinovsky M., Solntsev A., Juravleva A., Makovski S. Transportation Research Procedia, 2017, vol. 20, pp. 751-755. DOI 10.1016/j.trpro.2017.01.121.

18. Malinovskij M.P. Avtomobil'. Doroga. Infrastruktura, 2017, no. 2, p. 3.

19. Malinovskij M.P. Avtotransportnoe predprijatie, 2016, no. 6, pp. 17-21.

20. Malinovskij M.P., Arakeljan T.K. Avtomobil'. Doroga. Infrastruktura, 2018, no. 3, p. 2.

21. Malinovskij M.P. Avtomobil'. Doroga. Infrastruktura, 2018, no. 4, p. 3.

22. Malinovskij M.P. Vestnik MADI, 2014, issue 4, pp. 22–31.

23. Malinovskij M.P., Smolko S.E. Vestnik MADI, 2019, issue 1, pp. 17-23.

24. Malinovsky M. Science journal of transportation, 2016, no.7, pp. 153-159.

25. Malinovskij M.P., Gladov G.I. Avtomobil'naja promyshlennost', 2009, no. 9, pp. 21-26.

26. Gladov G.I., Malinovskij M.P. Zhurnal avtomobil'nyh inzhenerov, 2009, no. 2, pp. 30-33.

27. Ivanov A.M., Kristal'nyj S.R., Popov. N.V. Sistemy avtomaticheskogo jekstrennogo tormozhenija [Automatic emergency braking systems]. Moscow, MADI, 2018, 180 p.

28. Sidorova P.A., Popov N.V. Avtomobil'. Doroga. Infrastruktura, 2020, no. 2, p. 10.

29. Malinovskij M.P., Smolko E.S., Lukyanov D.V. Patent RU 2724944 C1, 26.06.2020.

30. Malinovskij M.P., Zhuravleva A.Ju. Avtomobil'. Doroga. Infrastruktura, 2016, no. 4, pp. 10.

31. Malinovskij M.P. Vestnik MADI, 2016, no. 4, p. 68–74.

32. Malinovskij M.P., Luk'janov D.V., Petrov A.A. Avtomobil'. Doroga. Infrastruktura, 2017, no. 2, p. 6.

33. Malinovskij M.P., Lukyanov D.V., Petrov A.A. Vestnik MADI, 2018, issue 2, pp. 54–61.

34. Malinovskij M.P., Smolko S.E. Vestnik MADI, 2019, issue 4, pp. 55-63.

35. Smolko E.S. Avtomobil'. Doroga. Infrastruktura, 2019, no. 4, p. 13.

36. Malinovskij M.P., Smolko S.E. Remont. Vosstanovlenie. Modernizacija, 2020, no. 2, pp. 33-38.

37. Malinovsky, M.P. Science journal of transportation, 2020, no. 10, pp. 62-72.

38. Malinovskij M.P., Smolko E.S. Avtomobil'naja promyshlennost', 2020, no. 7, pp. 27-32.

39. Kotovich S.V. Vestnik MADI, 2004, issue 3, pp. 27-33.

40. Malinovskij M.P. Vestnik MADI, 2020, issue 1, pp. 43-51.

41. Balakina E.V. Izvestija Volgogradskogo gosudarstvennogo tehnicheskogo universiteta. Serija: Nazemnye transportnye sistemy, 2004, no. 3, pp. 81-85.

42. Balakina E.V., Zotov N.M. Avtomobil'naja promyshlennost', 2012, no. 2, pp. 17-19.

43. Balakina E.V., Kozlov Ju.N. Avtomobil'naja promyshlennost', 2012, no. 8, pp. 15-19.

44. Malinovskij, M.P. Sistemy upravlenija koljosnyh mashin [Control systems of wheel vehicles]. Moscow, MADI, 2018, 100 p.

45. Malinovsky M.P. Vestnik MADI, 2018, issue 3, pp. 21-29.

46. Malinovsky, M.P. Science journal of transportation, 2019, no. 9, pp. 101-112.

47. Malinovskij M.P. Avtomobil'naja promyshlennost', 2011, no. 5, pp. 33-35.

48. Malinovsky M.P., Gladov G.I. Traktory i sel'hozmashiny, 2015, no. 8, pp. 17-19.

49. Malinovskij M.P., Gladov G.I. Avtomobil'naja promyshlennost', 2015, no. 11, pp. 35–39.

50. Malinovskij M.P., Smolko E.S. Trudy NAMI, 2020, no. 1, pp. 36-47.

51. Malinovskij M.P. Avtomobil'. Doroga. Infrastruktura, 2020, no. 3, p. 12.

52. Kaljonova E.V., Lugov S.V. Nauka i tehnika v dorozhnoj otrasli, 2014, no. 2, pp. 23-25.

53. Fotiadi A.A., Rezunov Ju.V., Kozorezov N.V. Avtomobil'. Doroga. Infrastruktura, 2016, no. 4, p. 6.

54. Gorjachev M.G., Lugov S.V., Kaljonova E.V. Vestnik MADI, 2018, issue 1, pp. 76-80.

55. Ivanov A.M., Kristal'nyj S.R., Popov N.V., Spinov A.R. Ispytaniya kolyosnyh transportnyh sredstv [Tests of wheeled vehicles]. Moscow, MADI, 2018, 124 p.

56. Gurov M.M., Ipatov L.D., Petrenko A.M., Sveranovskij R.S., Shahmatov O.N. Patent SU 160608 A1, 31.01.1964.

57. Kohanovskaja Z.S., Vasil'ev Ju.N., Pelenkov A.I., Terehov V.Ja. Patent SU 522433 A1, 25.07.1976.

58. Mjagkov A.T., Komlev V.N., Balandin S.M. Patent SU 1293504 A1, 28.02.1987.

59. Ploshhadnov A.N., Zejgerman A.S., Jakovlev P.Ju., Kursov I.V., Marshalov Je.S. Patent RU

2426088 C1, 10.08.2011.

60. Malinovskij M.P. Avtomobil'. Doroga. Infrastruktura, 2020, no. 4, p. 3.

61. Ponizovkin A.N. et al. Kratkij avtomobil'nyj spravochnik [Quick automobile reference]. Moscow, Transkonstalting, NIIAT, 1994, 779 p.

62. Malinovskij M.P. Komp'juternaya grafika v Compas. Ch. 1: Konstruktorskaya dokumentatsiya [Computer graphics in Compas. Chapter 1: Design documentation]. Moscow, MADI, 2015, 108 p.

63. Malinovskij M.P. Komp'juternaja grafika v Compas. Ch. 2: Oformlenie chertezhej [Computer graphics in Compas. Chapter 2: Drawing design]. Moscow, MADI, 2015, 124 p.

64. Malinovskij M.P., Malahov D.Ju. Komp'juternoe modelirovanie transportnyh sredstv special'nogo naznachenija: Primenenie bibliotek i raschjotnyh prilozhenij KOMPAS [Computer modeling of special-purpose vehicles: Application of libraries and computational applications KOMPAS]. Moscow, MADI, 2020, 164 p.

65. Malinovskij M.P., Bazeev K.V., Baljasnikov I.V. Avtomobil'. Doroga. Infrastruktura, 2020, no. 2, p. 8.

66. Gladov G.I., Petrenko A.M. Special'nye transportnye sredstva: Proektirovanie i konstrukcii [Special purpose vehicles: Design and construction]. Moscow, Akademkniga, 2004, 320 p.

67. Kisljakov Ju.D., Kuznecov O.G., Zhanabaev T.M. Spravochno-informacionnye dannye dlja analiza dorozhno-transportnyh proisshestvij [Reference data for the analysis of road traffic accidents]. Almaty, RMNIC BDD, 1998, 108 p.

68. Malinovskij M.P. Trudy NAMI, 2017, no. 1, pp. 53–59.

69. Malinovsky M.P. Vestnik MADI, 2017, issue 2, pp. 121–128.

70. Ivanov A.M., Shadrin S.S. Izvestija Volgogradskogo gosudarstvennogo tehnicheskogo universiteta. Serija: Nazemnye transportnye sistemy, 2013, vol. 7, no. 21, pp. 74-77.

71. Belousov B.N., Gladov G.I., Ksenevich T.I., Malinovskij M.P. Intellektual'nye mashinnye tehnologii i tehnika dlja realizacii Gosudarstvennoj programmy razvitija sel'skogo hozjajstva, Moscow, VIM, 2015, pp. 62-66.

72. Belousov B.N., Gladov G.I., Ksenevich T.I., Malinovskij M.P., Osipkov V.O. Avtomobil'naja promyshlennost', 2016, no. 2, pp. 14–19.

73. Malinovskij M.P. Trudy NAMI, 2018, no. 1, pp. 51–60.

74. Malinovsky M., Vorobyev A., Zabudsky A. Transportation Research Procedia, 2018, vol. 36, pp. 472-479. DOI 10.1016/j.trpro.2018.12.130.

75. Malinovsky M., Vorobyev A., Pakhomov S. Transportation Research Procedia, 2018, vol. 36, pp. 480-486. DOI 10.1016/j.trpro.2018.12.132.