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Modelling of Vehicles Movements for the Design of Parking Spaces

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Abstract. Nowadays, in all cities there is an acute problem of lack of parking spaces. The number of vehicles is significantly growing not only in megacities but also in small cities, and there are no more parking places. The pace of solving this problem is several times slower than the speed of transport growth among the citizens. Presented research is focused on determination of the optimum sizes of parking place for designed vehicles as an element of the roads. On example of passenger cars and trucks are determined optimum parking places. The results of research on dimensioning parking spaces are recommendations that should be used for the design of objects of transportation infrastructure.

Keywords: Passenger car · Truck · Auto train · Trajectory · Parking space · Turning radius of vehicles

1 Introduction

Trends in the size of cars in traffic flow, an acute shortage of parking space requires a more careful attitude to the design of the size of parking place and parking space [1–3]. Unfortunately, the design of parking does not take into account the composition of the traffic flow that takes shape on a specific road, transport infrastructure object (requirements are obvious here, in the USA where the size of cars is larger than in Europe, the size of parking space is larger), the duration of parking is not taken into account short-term parking near shops, banks, etc., requires more space for maneuvering upon arrival and departure from the parking space than during long-term parking) [4–7]. The most acute problem manifested itself when a ban was imposed on the transit movement of vehicles weighing more than 12 tons in the daytime along the Moscow Ring Road (Resolution of the Mayor of Moscow dated November 15, 2012 No. 650-PP "On Amendments to Legal Acts of the Government of Moscow" [8]). According to the Moscow mayor's office, more than 150 thousand trucks with a maximum weight of more than 3.5 tons are moving through the city streets during the daytime. About 40 thousand trucks arriving daily from the regions.

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At the Moscow Ring Road, large trucks make up 30% of the flow, half of which are transit and do not serve the needs of the capital [9]. At this time, there was no experience in designing parking place for cars arriving in Moscow or following in transit.

In the domestic regulatory and procedural documents, the dimensions of parking spaces for road infrastructure facilities are defined in the Methodological Recommendations of the SRC MDRS MIA [10], IRM 218.4.005-20101 и SS P 52289-20042. The dimensions in these documents were borrowed from the Handbook for Automobile Transportation and Traffic Management [11] published in the USSR in 1981, which, in turn, was a translation of the American Road Traffic Management Handbook of 1965 and the recommendations given in the third edition of the Transportation and Traffic Engineering Handbook [12].

Requirements for parking geometry in regulatory documents contain ambiguous, sometimes contradictory information that may adversely affect the level of road safety [13]. Thus, in the "Methodological recommendations on the design and equipment of highways to ensure traffic safety" [14], the turning radius of passenger cars is 8 m, and for truck is 9–12 m. When approximate calculation of the total area of coverage in parking place, including the area of maneuvering and parking, it is recommended to proceed from the average area per one passenger car of 25 m^2, on a truck −40 m^2. At the same time, in the album of typical projects "Cross-sectional profiles of highways passing through settlements" (TP503-0-47.86) 4, the average parking area for a truck should be 92.4 m^2, not 40 m^2, as stated in the methodological recommendations. The dimensions of the parking space given in the Regulations for the placement of multifunctional zones of road service on roads [15] take into account the size of modern cars, but this is not enough to develop a complete planning solution, since the parking maneuvers are not taken into account, and only the dimensions of the parking space are given. The passenger car and truck sizes used in the United States correspond to a parking angle of 45°, while it is indicated that at angles of 30°, the width of the passages can be reduced to 6.0 m, and the width of each parking space - by 30 cm. For large trucks, the length of the longitudinal parking space must be at least 41 m, width by 5.2 m. The same values are specified in the regulations of the United Arab Emirates for large trucks on parking spaces [16].

At the Department of Survey and design of roads MADI have been conducted research to justify the size of parking spaces for vehicles, taking into account the characteristics for modern traffic on the roads of the Russian Federation.

This research work included: monitoring parking maneuvers, studying the real situation when setting up parking spaces and modeling parking maneuvers of passenger cars and trucks using the AutoTURN software, which allows to simulate the movement and maneuvering of vehicles at speeds up to 60 km/h, and also to model three-dimensional movement on a 3D surface, localize modeling for various groups of vehicles; graphically represent the dynamic dimensions indicating the dynamic dimensions of the vehicles (external and internal wheels, characteristic points of the body); create vehicle reversal patterns [17]. In the study of the authors, it was found that the difference in AutoTURN data of the values of these parameters in comparison with the experimental values does not exceed 4.07%, that in the presence of a very similar nature of those and other curves, it can be considered valid and this makes it

possible to use the results obtained on the software AutoTURN, and use this program when determining the dynamic size of cars.

Parking space for vehicles includes parking spaces for vehicles and a maneuvering area, designed for the entrance to parking spaces, exit and setting cars. The dimensions of the parking space must ensure unhindered entry, opening the doors of the vehicles, unloading or loading luggage, and then unimpeded exit without hitting other vehicles [18].

The dimensions of the car parking space determine its type and size (length, width, turning radius of the inner rear wheel, overhang, base, gauge). To be able to bypass and open the doors of the car, the parking dimensions should be 0.5 m larger than the corresponding dimensions of the designing vehicles [19–22].

The "Methodological guidelines for the design and equipment of highways to ensure traffic safety" [23] indicated that parking at large recreation areas, at roadside catering establishments, motels and campgrounds should be placed between the highway and buildings with vehicle separation by types and sizes. Parking areas for trucks and passenger cars should be demarcated and provide for each type of vehicle a separate entrance to the appropriate temporary parking area.

In this case, passenger cars and buses are recommended to have on the left, and trucks on the right in the direction of travel [24].

It is recommended to place the parking of trucks parallel to the axis of movement, while parking of passenger cars mainly should be arranged according to an oblique angle at an angle of 45°–60°. For long stays in the parking place, as well as in cramped conditions, when the parking place have one exit, it is recommended to install vehicles perpendicular to the direction of the axis of movement. Recommendations are given for the designation of the average area of coverage for one vehicle, taking into account the area of the exit and entry zones and the area of the parking space itself.

2 Modelling of the Movement of Vehicles

The dimensions of the parking spaces of cars are determined depending on the type of car and its parameters (length, width, radius of rotation of the inner rear wheel, the outer point of the front bumper, base, and gauge). To be able to bypass and open the doors of the car, the parking dimensions must be 0.5 m larger than the corresponding dimensions of the design vehicle. To determine the width of the maneuvering of parking spaces, the authors took into account the minimum turning radius of the design vehicle and its dynamic size. To do this, studies have been conducted by authors, which allowed us to determine these characteristics [25, 26]. In the study, the width of the passage was determined as follows. When designing the parking space and the entrance vehicles at parking spaces, the following schemes and provisions were applied in the calculations:

1. the road train leaves the parking space in the forward direction;
2. auto train drives backwards in a parking space;
3. road train drives forward;
4. the road train leaves the parking space in reverse.

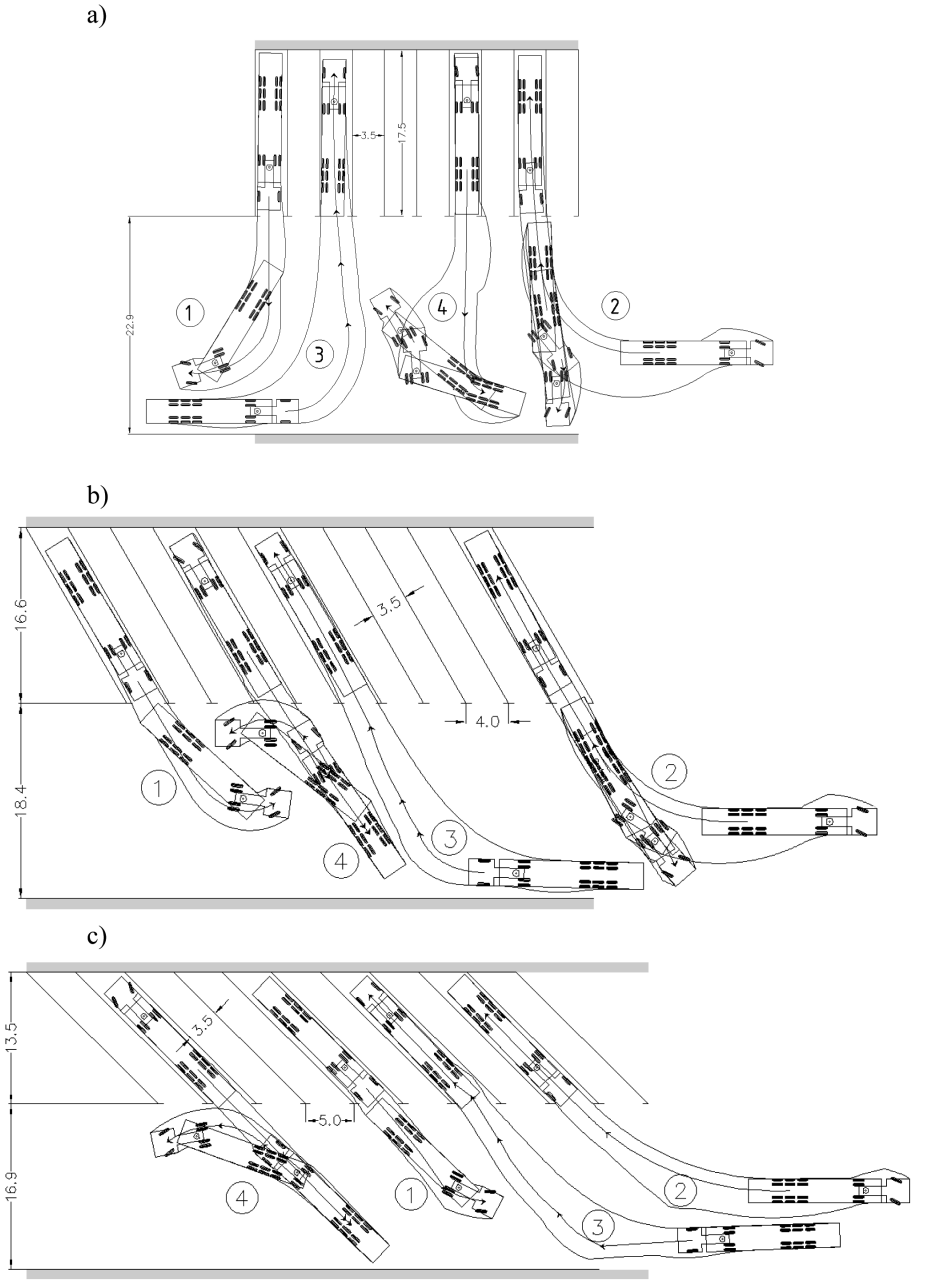

Fig. 1. Maneuvering schemes for a train (16.5 m) in a parking. (a) the location of the parking space at an angle of 90°; (b) the location of the parking space at an angle of 45°; (c) the location of the parking space at an angle of 60°. 1 - way forward; 2 - backing; 3 - forward ride; 4 - reversing

It was found that for reversing a large maneuvering lane is needed than in other variants. This maneuver is a common parking method for road train drivers [27]. With this in mind, the width of the maneuvering strip was determined.

The design vehicle made a maneuver at the location of a parking space at an angle of 90°, 60° and 45° (see Fig. 1). After each maneuver, the parking length, maneuvering lane, and parking width were determined.

Studies have shown that for one passenger car, taking into account maneuvering, 28.7 m^2 of parking space is needed. For a road train length of 16.5 m, this value is 143.1 m^2 of area.

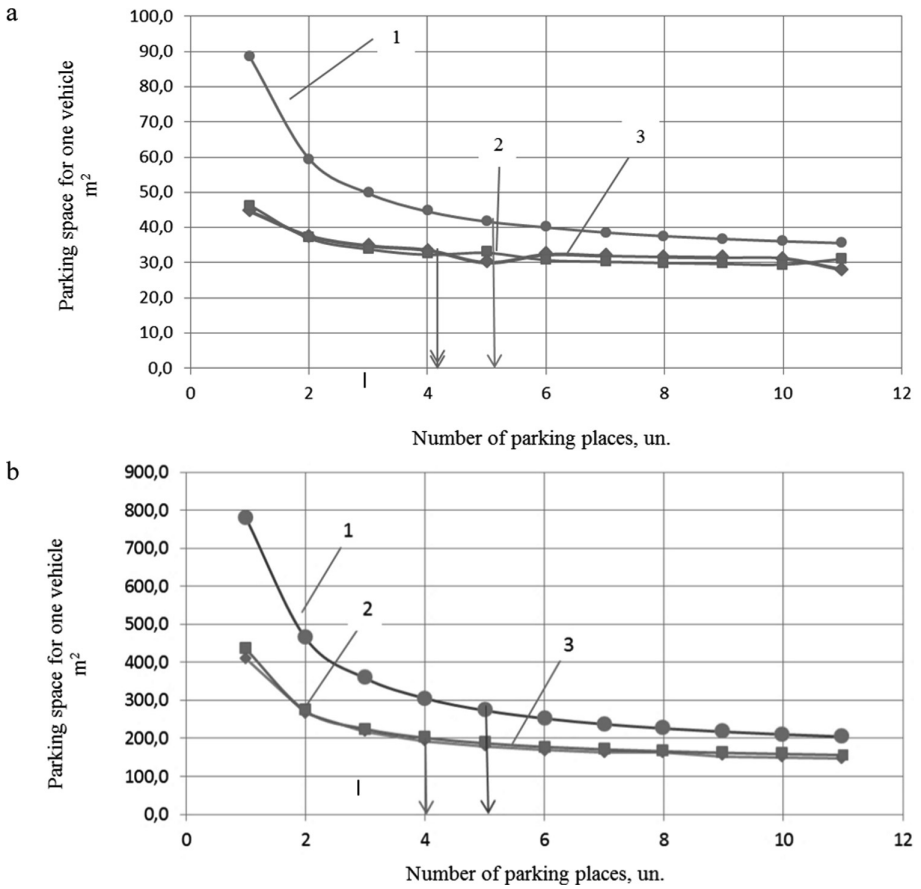

Fig. 2. The dependence of the area of parking space on the number of parking spaces for passenger cars (a) and for a train 16.5 m long (b) when set at the corners: 1 - 90°; 2 - 60°; 3 - 45°

From Fig. 2 it follows that with more than five parking spaces, the area of parking space for one vehicle does not increase (depending on the angle). When the parking space is located at an angle of 90°, and if there are less than 5 parking spaces in the

parking, the parking space is reduced by one car. At the location of parking spaces at angles of 60° and 45°, the indicator is 4 parking spaces. Similar values are obtained for cars and for trucks. Proceeding from this, it can be concluded that, when parking places at an angle of 90°, designing less than five parking spaces is ineffective for any type of car, and if placed at angles of 60° or 45°, up to four parking spaces are considered ineffective.

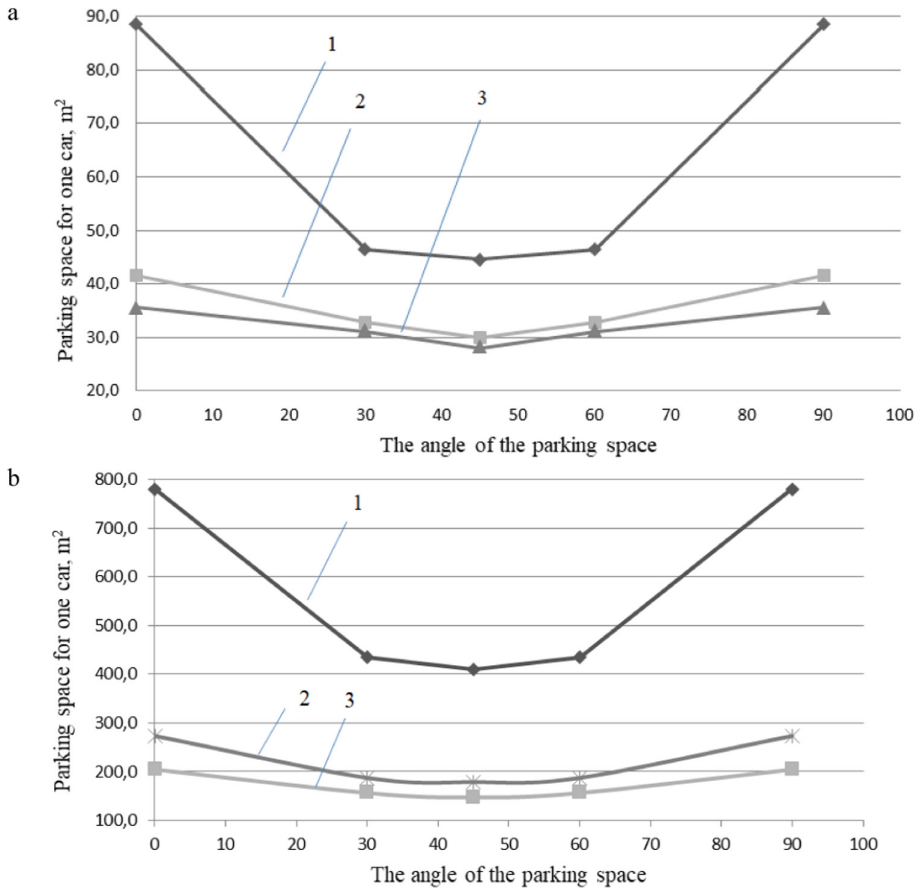

Fig. 3. Dependence of the required parking space at different angles of the installation for passenger cars (a) and for a train 16.5 m long (b): 1 - one vehicle; 2 - 5 vehicles; 3 - 11 vehicles

From Fig. 3 follows that at the location of parking spaces at an angle of 45°, less space is required than at an angle of 60° or 90°. These values do not affect the number of parking spaces; moreover, these values are the most effective indicator when maneuvering cars on a parking lot [28].

The results of theoretical and experimental studies by the author of the influence of the turning radius on the width of the dynamic dimension are shown in Fig. 4.

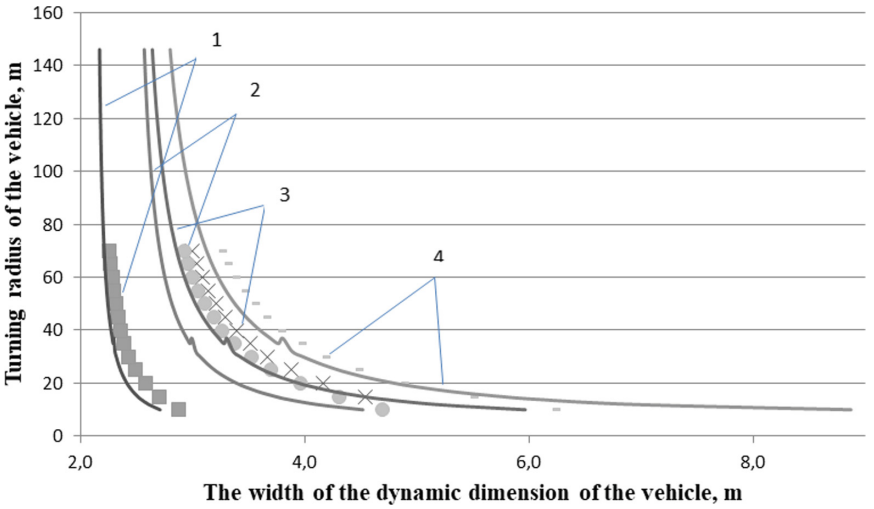

Fig. 4. The results of the influence of the turning radius of the vehicle on the dynamic size of vehicle (the lines show the results of theoretical studies, dots show the results of experimental studies). 1 - passenger car; 2 - bus; 3 - truck; 4 - road train length of 16.5 m

As can be seen from the results (Fig. 3), with a decrease in the turning radius of the vehicle, the dynamic dimension increases. This is clearly expressed in road trains, as in these types of vehicle the length of the base is longer than that of passenger cars or buses. And this is also due to the fact that the rear wheels do not follow the exact same path as the front wheels when the vehicle moves along a horizontal curve. In the study of the movement of vehicles found that the value between theoretical and experimental data are insignificant. When the turning radius of the car is 45 m, according to theoretical calculations, the width of the dynamic dimension of a passenger car is 2.25 m.

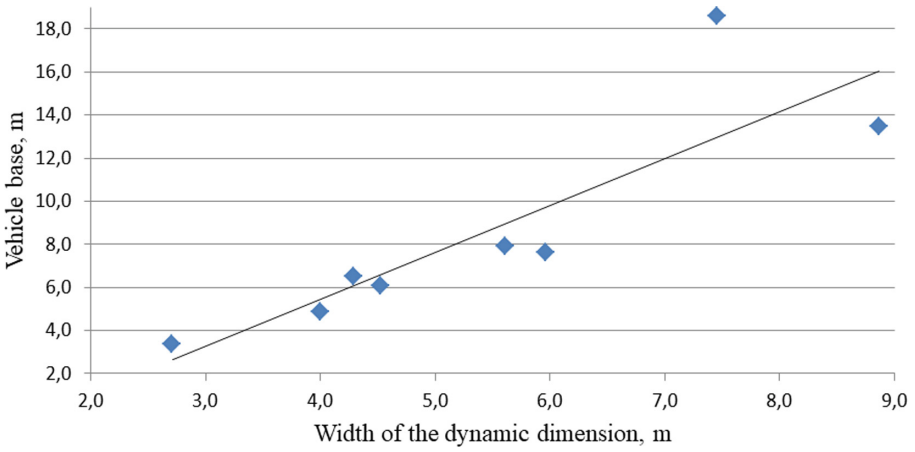

Fig. 5. Dependence of the dynamic dimension of the vehicle on its base

And the experimental data show 2.34 m. The greatest difference is noted for buses with a base of 6.1 m. If the theoretical dynamic dimension was 2.86 m, the experimental data show its values equal to 3.19 m with a turning radius of 45 m. The change in the dynamic dimension is typical for all types of vehicles, but its greatest changes are noted for road trains. With a turning radius of 45 m, according to theoretical calculations, the dynamic size of the train is 3.48 m, and according to the result of the survey it shows 3.64 m.

As follows from Fig. 5, the dynamic dimension of cars depends on the length of the base of cars. With the increase in the length of the base of the vehicle width of the dynamic dimension increases. The equations defining this dependence correspond to a straight line with the equation $y = 2,1774x - 3,2676$. The correlation coefficient is R = 0.74.

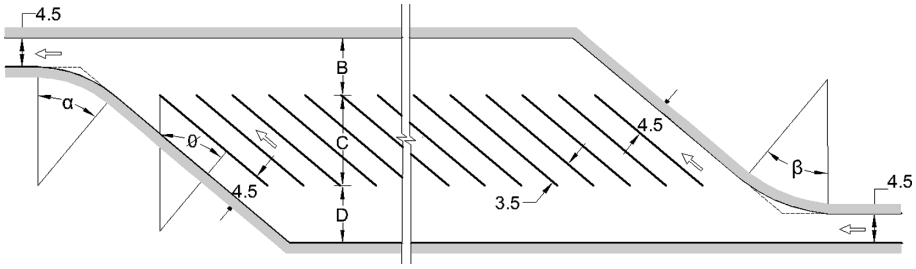

Fig. 6. Elements of breakdown of parking space for trucks. α – β – parking angle; Ø – vehicle installation angle; B – D – maneuvering strip; C – parking module length

Table 1. Sizes of parking spaces at different corners of the parking of trucks

Installation angle, degree		Sizes of parking spaces, m (see Fig. 9)			
Ø	α	β	B	C	D
A 16					
30	30	30	7,5	12,0	7,5
35	35	35	8,5	13,0	8,5
40	40	40	8,7	13,5	8,7
45	45	45	9,5	15,5	9,5
A 20					
30	30	30	8,0	13,0	8,0
35	35	35	9,0	15,5	9,0
40	40	40	9,2	16,5	9,2
45	45	45	10,0	17,7	10,0

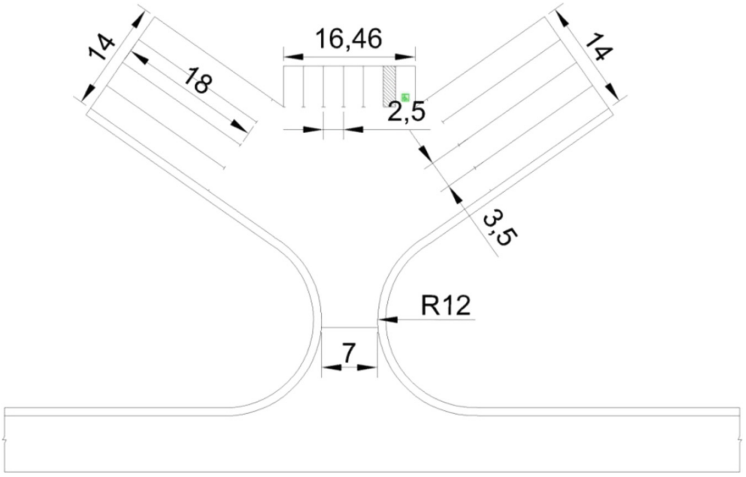

Fig. 7. Dimensions of dead-end parking spaces

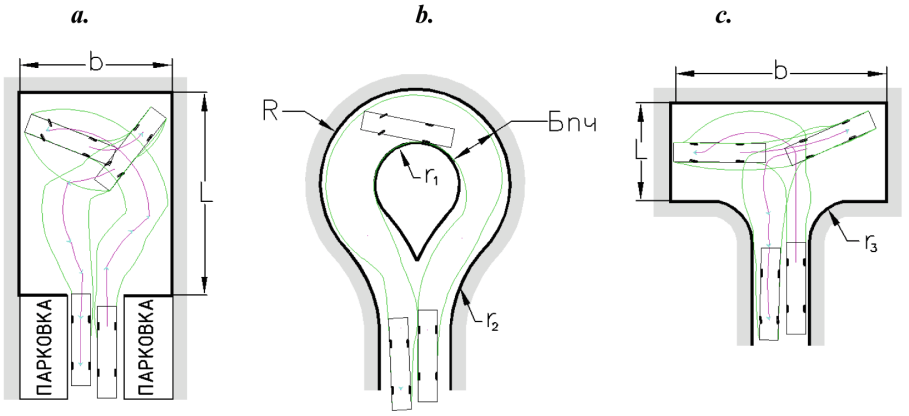

Fig. 8. Schemes of turning platforms on the territory of the road service facilities of the dead-end (a) circular (b) and T-shaped (c) type

3 Conclusions

Based on the above data, we can draw the following conclusions:

1. Less than 5 parking places at an angle of 90° is economically inefficient for any type of vehicle.
2. When located at angles of 60° or 45°, up to 4 parking places are considered to be economically inefficient.
3. On the dynamic size of the car affects the length of the base of the car. With an increase in the distance of the base length, the width of the dynamic dimension increases.

4. When determining the size of parking spaces should be taken into account the dynamic size of vehicle.

The following types of design vehicles were recommended as most frequently encountered on the roads: passenger car (P); city bus (CB); bus (B); articulated bus (AB); truck (T); road train consisting of truck tractor and semi-trailer (A16); road train consisting of a truck and a trailer (A20).

Considering the foreign experience of organizing parking spaces for large-sized vehicles, which provides for entry and exit to a parking without reversing, as a result of research, it is recommended to take the dimensions of parking spaces in accordance with the values in Table 1 and Fig. 6.

For servicing two-way traffic at road service facilities, the authors recommend dead-end parking spaces for semi-trailer (A16) (see Fig. 7).

If necessary, the organization of the reversal of vehicles, provide turning areas (Fig. 8), the dimensions of which are presented in Table 2.

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References

1. Mikusova, M., Gnap, J.: Experiences with the implementation of measures and tools for road safety. CIT 2016: XII congreso de ingenieria del transporte, Valencia, Spain, pp. 1632–1638 (2016)
2. Horalek, J., Sobeslav, V.: Analysis of software routing solution based on mini PC platform for IoT. In: Nguyen, N.T., Pimenidis, E., Khan, Z., Trawiński, B. (eds.) ICCCI 2018. LNCS (LNAI), vol. 11055, pp. 455–466. Springer, Cham (2018). https://doi.org/10.1007/978-3-319-98443-8_42
3. Mikusova, M., Torok, A., Brida, P.: Technological and economical context of renewable and non-renewable energy in electric mobility in Slovakia and Hungary. In: ICCCI 2018 - 10th International Conference on Computational Collective Intelligence - Special Session on Intelligent Sustainable Smart Cities, pp. 429–436 (2018)
4. Jamroz, K., Budzynski, K., Kustra, W., et al.: Tools for road infrastructure safety management - Polish experiences. In: 17th Meeting of the EURO-Working-Group on Transportation, Transportation Research Procedia, vol. 3, pp. 730–739 (2014). https://doi.org/10.1016/j.trpro.2014.10.052
5. Jankowska, D., Mikusova, M., Wacowska-Slęzak, J.: Mobility issues in selected regions of poland and slovakia – outcomes of international project SOL (Save Our Lives) survey. Periodica Polytech. Transp. Eng. **43**(2), 67–72 (2015). https://doi.org/10.3311/pptr.7580
6. Mikusova, M.: Joint efforts needed to prevent traffic accidents, injuries and fatalities. Saf. Secur. Eng. V, 503–514 (2013). https://doi.org/10.2495/safe130451
7. Mikušová, M.: Value of networking in transport policy related to the road safety. In: Mikulski, J. (ed.) TST 2011. CCIS, vol. 239, pp. 70–77. Springer, Heidelberg (2011). https://doi.org/10.1007/978-3-642-24660-9_8

8. Information and legal portal Garant. Electron. Dan. (2018). http://www.garant.ru/hotlaw/moscow/430367. Accessed 27 Jan 2018
9. Buranov, I.: Mayor shifted the burden of responsibility to the region. Newspaper "Kommersant", vol. 218 (5003) (2012)
10. Monitoring compliance with the norms, rules and standards when designation and construction of roadside facilities (service facilities). Methodical recommendations. SIC STSI of the Ministry of Internal Affairs of Russia, p. 28 (2004)
11. Rankin, V.U.: Automobile Transportations and the Organization of Traffic. Reference book. Per. from English, Rankin, V.U., Klafey, P., Halbert, S., et al. Transport, p. 592 (1981)
12. Baerwald, J.E.: Transportation and Traffic Engineering Handbook, 3rd edn., p. 717. Institute of Traffic Engineers, Washington (1965)
13. Mikusova, M.: Crash avoidance systems and collision safety devices for vehicle. DYNWIND2017, vol. 107, Article num. 00024. https://doi.org/10.1051/matecconf/201710700024
14. Design and equipment of highways to ensure traffic safety. Methodical recommendations. Transport (1983)
15. Regulations for the placement of multifunctional road zones of the service on the highways of the State company "Russian highways" (Approved by the order of the State company "Russian highways" 24 June 2013 No. 114). http://www.rhighways.ru/for_investor/road_service/multifunctionalroad_service_area/. Accessed 18 Dec 2018
16. Machado, L., Merino Dominguez, E., Mikusova, M.: Proposta de índice de mobilidade sustentável: metodologia e aplicabilidade. Cadernos Metrópole, 14(July–December) (2012). ISSN 1517-2422. http://www.redalyc.org/articulo.oa?id=402837818011. Accessed 18 Jan 2019
17. AutoTURN. Advanced vehicle simulations, Transoftsolution. http://store.softline.ru/transoft/transoft-autoturn. Accessed 18 Sept 2018
18. Help for guests. Guidelines. Elektron. Data (2013). http://www.gosthelp.ru. Accessed 18 Dec 2018
19. Mikusova, M., Zukowska, J., Torok, A.: Community road safety strategies in the context of sustainable mobility. Commun. Comput. Inf. Sci. **897**, 115–128 (2018)
20. Abdunazarov Nurmuhumatovich, J., Mikusova, M.: Application of GIS in automobile-road sector (Using the ArcGIS example). In: CMDTUR 2018 - Proceedings of 8th International Scientific Conference, pp. 324–327 (2018)
21. Callejas-Cuervo, M., Valero-Bustos, H.A., Alarcón-Aldana, A.C., Mikušova, M.: Measurement of service quality of a public transport system, through agent-based simulation software. In: Huk, M., Maleszka, M., Szczerbicki, E. (eds.) ACIIDS 2019. SCI, vol. 830, pp. 335–347. Springer, Cham (2020). https://doi.org/10.1007/978-3-030-14132-5_27
22. Zukowska, J., Mikusova, M., Michalski, L.: Integrated safety systems - the approach toward sustainable transport. In: Archives of Transport System Telematics, vol. 10, no. 2, pp. 44–48 (2017). ISSN 1899-8208
23. The Methodical recommendations on designing and equipping the highways for road safety, Minavtodor RSFSR, M.: Transport (1983)
24. Alsobky, A., Hrkút, P., Mikušová, M.: A smart application for university bus routes optimization. In: Kováčiková, T., Buzna, Ľ., Pourhashem, G., Lugano, G., Cornet, Y., Lugano, N. (eds.) INTSYS 2017. LNICST, vol. 222, pp. 12–20. Springer, Cham (2018). https://doi.org/10.1007/978-3-319-93710-6_2
25. Abdunazarov, J.N.: Justification the parameters of design vehicles for the design geometric elements of highways, PhD's thesis, Moscow, MADI, p. 143 (2015)

26. Mikusova, M.: Sustainable structure for the quality management scheme to support mobility of people with disabilities. Procedia Soc. Behav. Sci. **160**, 400–409 (2014). https://doi.org/10.1016/j.sbspro.2014.12.152
27. Mikusova, M.: Proposal of benchmarking methodology for the area of public passenger transport. Periodica Polytech. Transp. Eng. **47**(2), 166–170 (2019). https://doi.org/10.3311/PPtr.10271
28. Abnunazarov, J., Mikusova, M.: Testing trajectory of road trains with program complexes, The Archives of Automotive Engineering – Archiwum Motoryzacji, AMO-00003-2018-02