THE EFFECT OF THE TRAFFIC COMPOSITION ON THE URBAN TRAFFIC CAPACITY. PASSENGER CAR EQUIVALENT COEFFICIENTS

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Abstract

Predicting the traffic capacity and its elements requires bringing the traffic flow represented by various vehicles to uniformity expressed in the equivalent number of passenger cars, through the use of the passenger car equivalent coefficients (PCE). The currently used in Russian Federation passenger car equivalent coefficients are taken on the basis of studies of the capacity of the Russian Federation, carried out in the 70s - 80s of the last century on rural roads, where most of the vehicles were heavy vehicles. Currently, the traffic flow is mostly represented by passenger cars. The riding qualities of cars, especially trucks, have changed significantly. This situation is especially common to Moscow. In this regard, the question of clarifying the traffic flow composition and revising the passenger car equivalent coefficients becomes relevant. The article presents the methodology and results of studies carried out on the route sections between road crossings to determine the passenger car equivalent coefficients and the traffic composition in Moscow.

Keywords: passenger car equivalent coefficient, capacity, traffic composition

1 Introduction

Predicting the level of traffic load to plan the development of a network and design individual objects requires modern techniques, one of the important components of which is the reduction factor of cars of various categories to a passenger car. It can vary depending on the behavior of drivers, which in turn depends on improvements in vehicle design, including active safety systems. In this regard, regular studies of traffic flows are needed to track changes in parameters that affect traffic capacity. Designing highways and city streets requires determining the capacity of traffic lanes on highways and various types of road crossings.
As the traffic flow consists of many types of cars, it is necessary to bring it to the equivalent traffic of cars to determine traffic capacity. Today, the Russian traffic flow mainly consists of cars, trucks with a carrying capacity of 2 to 14 tons, minibuses, buses of small, medium and large capacity, articulated buses and road trains with a carrying capacity of 12 to 30 tons. The reduction of a mixed flow of vehicles to a homogeneous one consisting of an equivalent number of cars is carried out using the reduction factors. Thus, the reduction factors are a fundamental component in determining the throughput of highways and roads. The research aim is to determine traffic composition and passenger car equivalent coefficients on the urban roads sections in modern conditions in Russian Federation.

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Section 2 presents literature review of PCE studies in Russian Federation and other countries. Section 3 contains information about the current research methods and data collecting. Section 4 presents the researches results and data analyses. In section 5 future recommendations are discussed.

2 Literature review

Most of the domestic studies devoted to the determination of the reduction factors were carried out in the 70s of the last century [1]. For this purpose, various methodological approaches can be used [1].

Method 1. The method is based on the analysis of distances and time intervals between successive cars of different types, in comparison with the movement of cars.
This method compares the dynamic dimensions of the vehicle under consideration and a passenger car. The value of the reduction factor PCE_{ij} is determined by the ratios:

$$PCE_{ij} = \frac{d_{ij}}{d_{ii}} \quad (1)$$

or

$$PCE_{ij} = \frac{\Delta t_{ij}}{\Delta t_{ii}} \quad (2)$$

Where
d_{ij} – distance between the considered vehicles, m;
d_{iI} – distance between passenger cars, m;
Δt_{ij} – time interval between the considered vehicles, sec;
Δt_{ii} – time interval between passenger cars, sec.

Method 2. The method is based on the analysis of the “speed-intensity” relationship for various car flows in comparison with a similar relationship for a passenger car flow.
This method compares the average speed of the mixed vehicle flow and the speed of the passenger car flow, and analyzes the traffic intensities at the same flow speed. The reduction factors PCE_{ij} are determined by the ratio:

$$N_{ii} = (1 - p)N^{ij} + PCE_{ij} pN^{ij} \quad (3)$$

Where
N_{ii} – traffic intensity of a passenger car flow, vehicle/hour;
N^{ij} – traffic intensity of a mixed vehicle flow, vehicle/hour;
p – number of slowly moving cars.

Method 3. The method is based on the analysis of traffic capacity with different traffic flow composition.
It compares capacities of a road lane with homogeneous flows, consisting of the considered vehicles for the case of movement along a horizontal rectilinear section with the passenger car traffic capacity.

Method 4. The method is based on the analysis of the traffic density of mixed vehicle flows.
The values of the factors PCE_{ij} were determined from the ratio of the traffic densities of the considered vehicles and the traffic flow with the corresponding capacity. Density is determined by the maximum density of a standing traffic flow:

$$q=0.5q_{max} \tag{4}$$

where
g – density of the traffic flow with corresponding capacity;
q_{max} – density of the considered vehicles.

<u>Method 5.</u> The method determines the traffic flow with the maximum number of overtaking. It compares the traffic flow with the greatest number of overtaking of trucks by passenger cars. The average number of overtaking e with different traffic composition is determined by the formula:

$$e=q_i(V_i-V_j)q_j \tag{5}$$

where
q_i – density of freely moving cars;
V_i – speed of freely moving cars;
q_j – density of slowly moving cars;
V_j – speed of slowly moving cars.

The traffic composition and the passenger car equivalent coefficients obtained by methods 1-5 in 1970-s in Russian Federation are presented in Table 1.

Table 1 The traffic composition and the passenger car equivalent coefficients obtained by methods 1-5 in 1970-s in Russian Federation

Vehicles	**PCE_{ij} obtained by each method**					
	1	**2**	**3**	**4**	**5**	
Passenger cars	1.00	1.00	1.00	1.00	1.00	1.00
Motorcycles	0.75	0.70	0.68	0.40	0.72	0.65
Light trucks	1.20	1.60	1.70	1.40	1.68	1.52
Medium trucks	1.36	1.83	1.95	1.68	1.92	1.75
Heavy trucks	1.75	2.60	3.10	1.75	2.80	2.40

The passenger car equivalent coefficients depend on a large number of factors, the main of which are speed, traffic composition, and road conditions. Given the difficulty of obtaining reliable design relationships to find the passenger car equivalent coefficients, they should be used only to calculate the traffic capacity [1].
Today, the regulatory documents of the Russian Federation use the passenger car equivalent coefficients obtained on the basis of the ratio of the dynamic dimensions of vehicles excluding the differentially different traffic conditions (road sections of streets, various types of road crossings, etc.) [2].
The term “ passenger car equivalent coefficients (PCE)” was first introduced abroad in 1965 in the American Highway Capacity Manual. Since that moment, a number of foreign authors [4-8] have carried out a large number of studies to determine the passenger car equivalent coefficients for various elements of the road network.
One of the many foreign approaches to the determination of the passenger car equivalent coefficients on the street and road sections is a method based on comparing the headways of different vehicle types [8, 9].
The following intervals are determined when a car is moving behind another car, and when various vehicle types are following a passenger car (Figure 1).

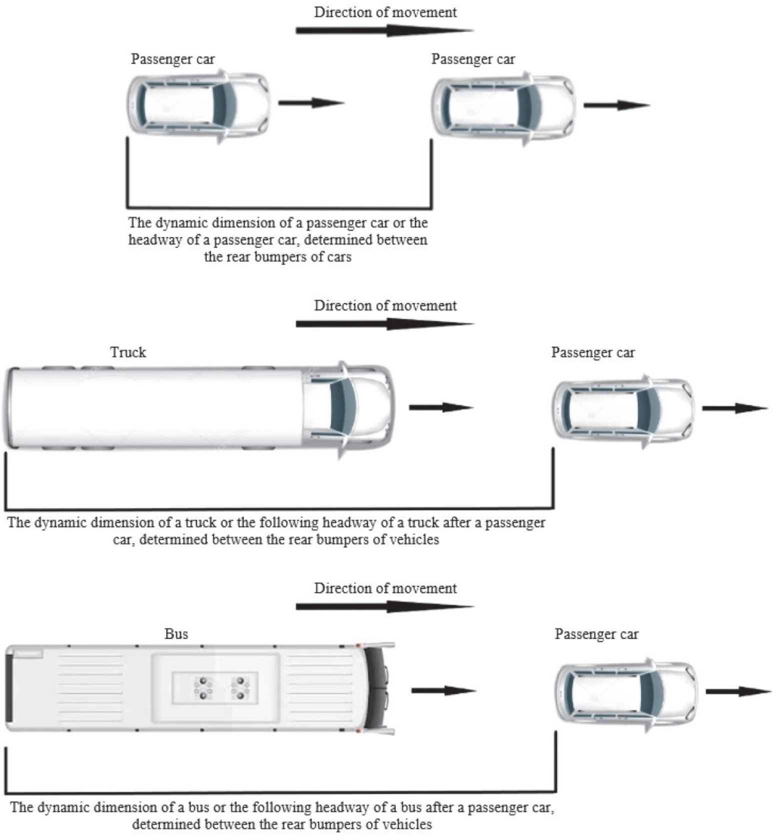

Figure 1 The following headways of different vehicle types

In this connection, the passenger car equivalent coefficients PCE_{ij} are determined by the formula:

$$PCE_{ij} = \frac{\Delta H_{ij}}{\Delta H_{ii}} \tag{6}$$

where
ΔH_{ij} – the following headway of the selected vehicle type behind a passenger car;
ΔH_{ii} – the following headway between passenger cars.

Over the past 10-15 years, redefining of the passenger car equivalent coefficients has been very actively studied in India. A number of authors [14, 15, 16, 17] carried out research to determine the passenger car equivalent coefficients on 2-lane urban roads, road sections and various types of road crossings.
The fundamental task in determining the passenger car equivalent coefficients is the traffic composition by vehicle types.
The regulatory documents of Russia use different traffic compositions and passenger car equivalent coefficients for urban streets and rural roads. For urban streets, 13 types of cars are accepted, for rural roads - 14. In studies devoted to the determination of the passenger car equivalent coefficients, a number of authors [1, 2, 3] use a simplified traffic composition, including 3-4 types of cars (cars, trucks, buses, and road trains). A simplified stream composition is also used in foreign studies [1-10].

The 2013 American FHWA guidelines adopted a very detailed traffic composition (13 classes, including 34 subclasses) based on the type of vehicle, its dimensions, and carrying capacity. However, the 2010 and 2016 HCM guidelines [12, 13] use the average PCE: 1.00 for passenger cars and 2.00 for all other vehicle types.
Comparison of the results of foreign authors and the passenger car equivalent coefficients used in the Russian Federation is shown in Table 2.
The above studies used various traffic composition and methods for determining the passenger car equivalent coefficients. At the same time, both foreign and domestic authors agree on the influence of a large number of factors on the passenger car equivalent coefficients and the need to introduce special coefficients for each element of the road network (sections of streets and roads, signalized intersections, unsignalized intersections, roundabounds), considering their traffic conditions (conflict points, direction of movement, traffic control regime, delays) [1, 2, 3, 5, 7].

Table 2 Comparison of the results of foreign authors and the passenger car equivalent coefficients used in the Russian Federation

Vehicle type	PCE on the road sections according to various regulatory documents and authors					
	SP 34.13330.2012	**ODM 218.2.020-2012**	**SP 396.1325800.2018**	**Mehar, Arpan & Chandra**	**Indian Roads Congress (IRC SP 41)**	**Ahmed Anwaar&Boxel**
Cars		1.0	1.0	1.0	1.0	1.0
Motorcycles	1.0	0.5	0.5	0.19-0.26	0.5	-
Minibuses		-	1.5	-	1.5	-
Trucks, carrying capacity:						
- max. 2 t	1.3	1.1	1.5			
- 2-6 t	1.4	1.8	2.0			
- 6-8 t	1.6	2.1	2.5	1.34-1.58	1.5	1.37
- 8-14 t	1.8	2.4	3.0			
- over 14 t	2.0	2.5	3.5			
Heavy trucks, carrying capacity:						
- max. 12 t	1.8	2.2				
- 12-20 t	2.2	2.4	4.0	1.06-1.24	4.5	1.65
- 20-30 t	2.7	-				
- over 30 t	3.2	3.3				
Buses, carrying capacity						
- low	1.4					
- medium	2.5		2.5			
- high	3.0	2.6		-	3.0	-
Articulated buses	4.6		4.0			
Trolleybus		-	3.0			

3 Data collection

As the subject of research, we selected sections of urban motorways with continuous traffic, where the influence of ramps and main traffic inflows is absent.
This situation is common to the Moscow ring road. With a high traffic density in the two right-hand lanes, there is a flow that includes heavy vehicles, medium-tonnage vehicles moving along the 2nd and 3rd lanes, and light commercial vehicles in the 3rd and 4th lanes. The 4th and 5th lanes are occupied mainly by passenger cars.
The study was carried out on the section of the Moscow ring road: 31 km – between M-4 “Don” and Varshavskoe highway and 71 km between Putilkovskoe highway and Novokurkinskoe highway.
Before the study, the following PCE assessment method was considered. The method involved field studies by video recording of the intervals between different vehicles moving with the same speed.
Video recording is carried out using an unmanned quadcopter at an altitude of 50-100 m above the selected area to simultaneously cover all traffic lanes. The selected shooting height allows determining the type of a moving vehicle.
The database includes traffic flow, the number of cars with the selected traffic composition, the headways between cars, determined between the rear bumpers of cars.

4 Results

One of the objectives of the study is to determine the current traffic composition in Moscow. For this purpose, the traffic composition was adopted in accordance with the current regulatory documents. The research results are shown in Table 3 and in the diagram (Figure 2).
The analysis of the data obtained is based on the comparison theory of the lagging headways by equation (1) and equation (6) presented in section 2. The study found out that some vehicle types percentage is a very small value to reliably determine the drive ratios under given conditions.

Table 3 Traffic composition by research results in Moscow, Russia

No.	Vehicle type	%
1	Passenger car	83.85
2	Minibus	1.01
3	Truck with a carrying capacity of up to 2 tons	2.97
4	Small bus	1.71
5	Truck with a carrying capacity of 2-6 tons	7.49
6	Large bus	< 1.00
7	Truck with a carrying capacity of more than 6 tons	1.50
8	Articulated bus	< 1.00
9	Heavy truck	1.07

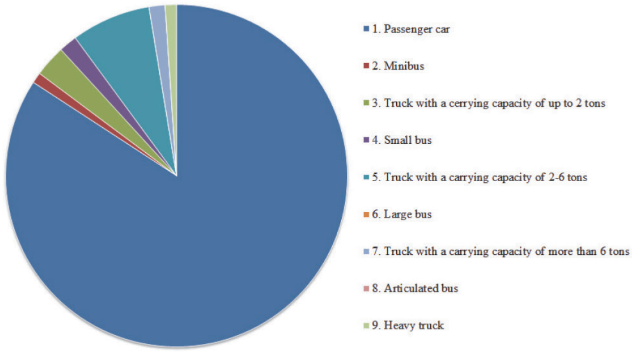

Figure 2 Moscow Ring Road traffic composition diagram

The results of PCE research on road sections in Moscow are presented in Table 4. The table presents determined average lagging headways between different vehicle types and calculated PCE. Comparison of the obtained research results with the passenger car equivalent coefficients specified in the current regulatory documents of Russian Federation* is shown on Figure 3.

Table 4 Lagging headway and PCE research results in Moscow, Russia

No.	Vehicle type	Average lagging headway, sec.	PCE
1	Passenger car	2.55	1.00
2	Minibus	3.52	1.38
3	Truck with a carrying capacity of up to 2 tons	3.47	1.36
4	Small bus	3.16	1.24
5	Truck with a carrying capacity of 2-6 tons	2.58	1.02
6	Large bus	-	-
7	Truck with a carrying capacity of more than 6 tons	3.48	1.37
8	Articulated bus	-	-
9	Heavy truck	-	-

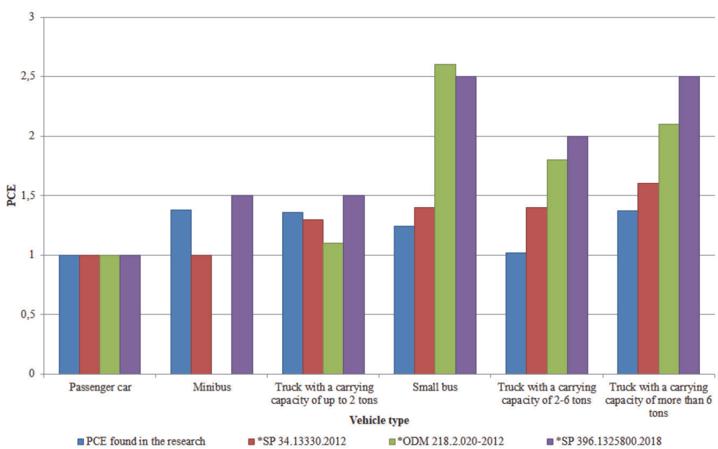

Figure 3 Comparison of the valid Russian and obtained PCE.

5 Conclusion

Many authors accept a simplified traffic composition in their research: cars, trucks, buses. The results of studies of the traffic flow on the sections of the city highway to Moscow (Moscow Ring Road) showed different passenger car equivalent coefficients obtained in the 70s, used at the moment and obtained in field studies. Given the very different nature of urban traffic on the road sections and various types of road crossings, the reduction factors should be considered for each situation separately. Within the framework of the above study, the passenger car equivalent coefficients were obtained for sections of continuous traffic on the city highway sections. Due to a huge number of factors affecting the passenger car equivalent coefficients, this issue should be considered in more detail in future studies.

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