Study of the ways to increase the urban street and road network capacity

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Abstract. During the existing situation assessment on the urban road network and intersections design, it is necessary to establish the traffic capacity value of streets and its elements. When forecasting the capacity value it is necessary to turn traffic flow presented by different vehicles to uniformity expressed in the equivalent number of passenger cars by using passenger car equivalent coefficients (PCE). PCE currently used in the Russian Federation are formed on the capacity studies of the street-road network, carried out in the 70s - 80s of the last century on rural roads, where the traffic flow was mostly presented by heavy vehicles. Nowadays the major percentage of traffic flow is presented by passenger cars. At the same time, the dynamic performances of trucks and buses have changed significantly. In this regard, the question of clarifying the traffic flow composition and revising the passenger car equivalent coefficients becomes urgent. High level of streets congestion and intersections with a small heavy vehicle percentage in the traffic flow is most often observed in large cities. The studies were carried out on the the multi-lane highway in Moscow in the sections free from the intersections and junctions influence. The purpose of the study was to clarify the traffic flow composition and determine the passenger car equivalent coefficients in modern traffic conditions.

1. Introduction
The traffic load forecast in planning the development of a network and designing individual objects requires modern methods, the important components of which is the various vehicle types reduction factor to a passenger car. The passenger car equivalent coefficients can vary depending on the drivers behavior, which in turn is influenced by the improvements in vehicle design, including active safety systems.

In this regard, the regular studies of traffic flows are required to track the dynamics of changes in parameters that affect traffic capacity.

During the highways and urban streets design, it becomes necessary to determine the capacity of traffic lanes on highways and various types of intersections.

Due to the fact that the traffic flow consists of many vehicle types, in order to determine the capacity, it is necessary to turn it into the equivalent traffic flow of passenger cars.

Nowadays in Russia, the traffic flow mostly consists of passenger cars, 2-14 tonnage trucks, minibuses, buses of small, medium and large capacity, articulated buses and 12-30 tonnage heavy trucks/
The mixed traffic flow reduction to a homogeneous traffic flow consisting of an equivalent number of passenger cars is carried out using the passenger car equivalent coefficients. Thus, the passenger car equivalent coefficients are a fundamental component in the highways and urban roads capacity determination.

2. The passenger car equivalent coefficients estimation methods

Most of the studies in Russia devoted to the passenger car equivalent coefficients estimation were carried out in the 70s of the last century by using several methodological approaches [3].

Method 1. It is based on the analysis of distances and headways between different vehicle types moving one after another in comparison with the movement of passenger cars.

This method compares the dynamic dimensions of the studied vehicle and a passenger car. The value of the passenger car equivalent coefficient \( PCE_{ij} \) is determined by the following ratios:

\[
PCE_{ij} = \frac{d_{ij}}{d_{ii}}
\]

or

\[
PCE_{ij} = \frac{\Delta t_{ij}}{\Delta t_{ii}}
\]

where

- \( d_{ij} \) – distance between the studied vehicles, m;
- \( d_{ii} \) – distance between passenger cars, m;
- \( \Delta t_{ij} \) – headway between the studied vehicles, s;
- \( \Delta t_{ii} \) – headway between passenger cars, s.

Method 2. It is based on the “speed-traffic flow” analysis relationship for mixed traffic flows in comparison with a similar relationship for an equivalent traffic flow consisting of passenger cars.

Using this method, the average speed values of the mixed traffic flow and the equivalent passenger car flow were compared and the traffic at one flow speed were also analyzed. The passenger car equivalent coefficients \( PCE_{ij} \) are determined according to the following position:

\[
N_{ii} = (1 - p)N^{ij} + PCE_{ij}pN^{ij},
\]

where

- \( N_{ii} \) – traffic flow, consisting only of passenger cars, veh/hour;
- \( N^{ij} \) – mixed traffic flow, veh/hour;
- \( p \) – percentage of slow moving cars.

Method 3. It is based on the capacity analysis for different traffic flow comparisons.

The traffic lane capacities are compared in homogeneous flows consisting of the considered vehicle types for the case of movement along a horizontal straightway with the traffic lane capacity of the homogeneous flow of passenger cars.

Method 4. It is based on the traffic flow density analysis for different traffic flow comparisons. The passenger car equivalent coefficients \( PCE_{ij} \) were determined from the traffic flow density ratio between the considered vehicle type flow and the passenger car flow in condition of the corresponding capacity. The density value is determined by the maximum density observed with a standing traffic flow:

\[
q = 0.5q_{max},
\]

where

- \( q \) – traffic flow density of passenger cars corresponding to traffic capacity;
- \( q_{max} \) – traffic flow density of the studied vehicle type.

Method 5. It is based on the traffic flow determination at which the maximum number of overtaking is observed.

The traffic flows at which the greatest number of overtaking of trucks by passenger cars is observed are compared. The average number of overtaking \( e \) with different traffic flow composition is determined by the following formula:
\[ e = q_i (V_i - V_f) q_f. \]  

(5)

where \( q_i \) – traffic flow density of free moving passenger cars; \( V_i \) – flow speed of free moving passenger cars; \( q_f \) – traffic flow density of slow moving cars; \( V_f \) – flow speed of slow moving cars.

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

### Table 1. Traffic flow composition and the passenger car equivalent coefficients obtained by the methods 1-5

| Vehicle types   | \( PCE_{ij} \) values obtained by the method | Average \( PCE_{ij} \) values |
|-----------------|---------------------------------------------|-------------------------------|
|                 | 1   | 2   | 3   | 4   | 5   | 1   | 2   |
| Passenger cars  | 1.00| 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|

Nowadaysthе passenger car equivalent coefficients used in Russian Federation design manuals, are obtained on the basis of the vehicles dynamic dimensions ratio without taking into account different traffic conditions (street segments, various types of intersections, etc.) [2]. The exception is roundabouts, for the calculations of which are used passenger car equivalent coefficients, based on the gap ratio between different vehicle types when driving directly at roundabouts. In addition, over the past 20 years, a passenger car equivalent coefficients establish method has been introduced, taking into account the starting delay at signalized intersections [1].

In foreign countries the term “passenger car equivalent coefficient” was first introduced in USA road design guideline HCM 1965 (Highway capacity manual). Since that moment, foreign authors [7, 8, 13, 16, 17] have carried out a large number of studies carried out in passenger car equivalent coefficient establish for various elements of the road network.

One of many foreign approaches of the passenger car equivalent coefficients determination on the highways is a method based on the headway comparison between different vehicle types [4, 16]. In addition, this method can be applied in the passenger car equivalent coefficients determination in Russia, as it has been indicated above (method 1).

The headways are determined when a passenger car drivers move behind a passenger car drivers, and when drivers of different vehicle types follow a passenger car driver (Fig. 1).
Figure 1. Headways of different vehicle types in traffic flow

In this regard, the passenger car equivalent coefficients $PCE_{ij}$ are determined by the ratio:

$$PCE_{ij} = \frac{\Delta H_{ij}}{\Delta H_{ii}},$$

where $\Delta H_{ij}$ – lagging headway of the selected vehicle type following the passenger car,
$\Delta H_{ii}$ – passenger cars lagging headway.

Over the past 10-15 years, the PCE redefinition problem has been studied in India. A number of authors [9, 10, 11, 12] carried out the PCE determination researches on urban 2-lane highways, urban street segments and various types of intersections.

The fundamental task in the PCE determination is the traffic flow composition separation into vehicle types.

In Russian Federation design manuals, depending on the affiliation of a street or road to urban or rural conditions, different flow compositions and PCE are used. For urban streets are used 13 vehicle types and 14 are accepted for rural roads. In the studies devoted to the PCE determination, a number of authors [2, 3] use a simplified traffic flow composition, including 3-4 vehicle types (passenger cars, light trucks, buses, heavy trucks). The simplified traffic flow composition is also used in foreign studies [4, 7-13, 16, 17].

The American FHWA 2013 guidelines adopted a very detailed traffic flow division (13 classes, including 34 subclasses) depending on the vehicle type and its dimensions. However, Highway Capacity Manual 2010 and 2016 [14, 15] presents the average PCE values: 1.00 for passenger cars and 2.00 for all other vehicle types.

The comparison of the PCE estimation studies by foreign authors and PCE used in the Russian Federation is given in Table 2.
Table 2. Comparison of research results by foreign authors and reduction factors used in the Russian Federation

| Vehicle type | PCE according to various manuals and authors researchs | At urban and rural highways | At signalized intersections | At roundabouts (ODM 218.2.071-2016) |
|--------------|-------------------------------------------------------|----------------------------|-----------------------------|-----------------------------------|
|              |                                                       | At urban and rural highways | At signalized intersections | At roundabouts (ODM 218.2.071-2016) |
|              |                                                       | SP                          | ODM 218.2.020-2012          | SP 396.12580.2018                  |
|              |                                                       | ODM 218.2.020-2012          | SP 396.12580.2018          | ODM 218.2.020-2012                  |
|              |                                                       | ODM 218.2.020-2012          | SP 396.12580.2018          | ODM 218.2.020-2012                  |

Passenger car |
Motor cycles  |
Minibus       |

| - from 2 t up to 6 | 13 | 1,1 | 1,5 |
| - from 6 up to 8 t | 1,4 | 1,8 | 2,0 |
| - from 8 up to 14 t | 1,8 | 2,4 | 3,0 |
| - over 14 t         | 2,0 | 2,5 | 3,5 |

| - from 2 t up to 6 | 1,34 | 1,58 |
| - from 6 up to 8 t | 1,5 | 1,37 |
| - from 8 up to 14 t | 1,6 | 1,75 |
| - over 14 t         | 1,7 | 1,6 |

| - from 2 t up to 6 | 1,06 | 1,24 |
| - from 6 up to 8 t | 4,5 | 1,65 |
| - from 8 up to 14 t | 2,8 | 2,3 |
| - over 30 t         | - | 2,2 |

| - small  | 1,4 |
| - medium | 2,5 |
| - full   | 3,0 |

| articulated buses | 4,6 | 4,0 |
| Trolley buses     | - | 3,0 |

It is interesting to note that in mentioned studies, various traffic flow compositions and PCE determination methods were used. At the same time, foreign [5, 13] and Russian authors are similar in decision that there are a lot of factors which influence on the PCE values and it is necessary to estimate PCE for each element of the road network (street segments and highways, signalized intersections, unsignalized intersections, roundabouts) taking into account the special traffic conditions (conflict points, movement directions, traffic signals, delays, drivers behaviour).

3. Data collection and analysis

The subject of research was presented by urban highways with continuous traffic, where is no influence of ramps and inflowing traffic flows on the main traffic flow.
This situation can be regularly observed on Moscow Ring Highway. With a high traffic density in the two right lanes, there is a flow includes heavy vehicles. Medium-tonnage vehicles move in the 2nd and 3rd lanes. Light commercial vehicles move in the 3rd and 4th lanes. The 4th and 5th lanes are occupied mainly by passenger cars.

With a high traffic density, the speed on the left lanes on the overtaking between ramps is approximately equal to the speed on the right lanes. This allows comparing the space occupied by different vehicles on the road under similar driving conditions.

During the preparation for the research, two ways of the PCE establish were studied.

The first method involved counting the number of cars that passed through the road cross-section with different traffic composition, determining the percentage of trucks and calculating the PCE values based on the ratio of the physical number of cars and the composition of the traffic flow.

The second method involved field studies by video recording the traffic stream movement of different composition in adjacent traffic lanes in a selected area. When traffic flows in adjacent lanes were at approximately the same speed, the headways between different vehicle types were fixed.

Video recording is performed by the drone located at an altitude of 50-100 m above the selected area, which allows the observation of all lanes at the same time.

The recording result is a 15 minutes video, which is a subject of further processing to obtain a database.

The data includes traffic flow, number of vehicles divided by the selected traffic composition, lagging headways between different vehicle types.

The selected drone height allows determining the vehicle type in motion. When processing video materials, a road cross-section is selected, driving through which the lagging headways are established.

One of the research objectives was to define the actual traffic flow composition in Moscow. For this purpose, the traffic flow composition was adopted in accordance with the current design manuals. The obtained data analysis is based on the theory of lagging headways ratio (methods 1, 6), presented above.

During the study, it was found that some vehicle types percentage in traffic flow is rather low for reliable PCE determination in the given conditions, which confirmed the necessary to divide traffic flow in simplified composition during researches.

The results are shown in table 3 and in graphs 2 and 3.

| № | Vehicle types                                      | Vehicle types percentage in traffic flow, % | Average lagging headway values, s | PCE values |
|---|----------------------------------------------------|--------------------------------------------|----------------------------------|------------|
| 1 | Passenger car                                      | 83,85                                      | 2,55                             | 1          |
| 2 | Minibus                                            | 1,01                                       | 3,52                             | 1,38       |
| 3 | Trucks with carrying capacity up to 2 tons         | 2,97                                       | 3,47                             | 1,36       |
| 4 | Small bus                                          | 1,71                                       | 3,16                             | 1,24       |
| 5 | Trucks with carrying capacity from 2 to 6 tons     | 7,49                                       | 2,58                             | 1,02       |
| 6 | Large bus                                          | < 1,00                                     | -                                | -          |
| 7 | Trucks with carrying capacity more than 6 tons     | 1,5                                        | 3,48                             | 1,37       |
| 8 | Articulate bus                                     | < 1,00                                     | -                                | -          |
| 9 | Heavy truck                                        | 1,07                                       | -                                | -          |

Table 3. Results
Figure 2. The Moscow Ring Highway traffic flow composition

Figure 3. The Moscow Ring Highway lagging headways and PCE values

The comparison of the obtained research results with the PCE values of the Russian Federation design manuals are shown in the graph 4:
4. Results and discussion
The PCE values are more dependent on the speed, traffic flow composition and road conditions. The influence of a large number of additional factors in the PCE determination results in difficulties in obtaining reliable calculated dependencies.

In the course of research, many authors accept a simplified system for the traffic flow composition: cars, trucks and buses.

The results of traffic flow the studies of the on the Moscow Ring Highway showed that the PCE values obtained in the 70s, the PCE values used at the actual design manuals and the PCE values obtained through the field observations are various.

Taking into that in urban conditions the traffic flows nature on highways and various intersection types is very different, the PCE values should be established for each situation separately.

Within the framework of the above mentioned study, the PCE values were obtained for the highway segments with continuous traffic.

Due to the fact that a huge number of factors affect the PCE values, this issue should be studied in more detail in future researches.

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