Features of macromodeling of small towns with a monostructured economy

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Abstract. The article discusses the features of a development macromodels of small towns with a monostructural economy. For a more accurate setting of the model, which will correspond to reality, the additional parameter “check in for a colleague at work” was taken into account when development a general origin-destination matrix(matrix OD). The model with this method was tested on the 2019 models and has a high convergence according to GEH statistics.

1. Introduction
Macromodeling is currently one of the most important means of describing the transport systems of cities. The article discusses the features of development macromodels of small cities with a monostructural economy. By a small town with a monostructural economy, we mean a town with a population of less than 50,000 inhabitants, with a single town-forming enterprise or a group of enterprises in one sector of the economy. It is Implied that a most percentage of the working-age population works in this enterprise. It will also be implied that this institution is located at some distance from residential areas, i.e. or outside the town or within the town, but on the outskirts. The most interesting (characteristic) for this study will be the option of the location of the enterprise at a significant (more than 20 km) distance from the residential area of the town.

When modeling the transport systems of such cities, significant discrepancies arise with the existing theory. Consideration of the causes of their occurrence and the ways correcting the methods of modeling for these objects are the purpose of this research.

The research is based on models developed by the authors in 2019 for 4 cities in the Russian Federation: the town Polyarnye Zori and Kovdor and the towns of Borodino and Zelenogorsk in the.

Town Zelenogorsk, strictly speaking, is somewhat beyond the scope of this research. Its population is slightly higher - 61,915 inhabitants according to 2019 data, but, as will be shown, it has the same modeling features, therefore, it is also given in this work.

2. Materials and methods
The main research method is the method of macromodeling, in which transport demand and transport supply are considered, and the transport subarea is taken as the main element of modeling. At the initial stage of modeling, the initial data concerning the transport network and characteristics of subareas are collected, as well as the necessary measurements of the characteristics of traffic flows are made, which are necessary in the future for the calibration and validation of the model.
A large number of scientific works are devoted to transport modeling. An important role in further reasoning is played by displacement models depending on the purpose of travel [1-22]. Typically, all trips made by the respondents are subdivided into “home-work”, “home-other”, “work-home”, “work-other point” and “other point-other point”. The fundamentals of this approach are outlined in [2] and [3].

Models that consider longer chains of the type "home-work-home", "home-shop-home", etc. are called activity-based models. One of the first models of activity is the SAMS model developed by Kitamura et al. [14, 15].

In [4] and [5], the travel of employees (workers) during the day is considered, in [22] - the coordinated movement of family members, including the sharing of personal transport. This work is also devoted to the sharing of personal vehicles.

3. Theory / Calculation

The key factors for applying the approach described below are as follows:

- small linear size of the town;
- a monostructural town economy: the presence of a town-forming enterprise, which employs most of the able-bodied population;
- the remoteness of the enterprise from the town center should significantly exceed the linear dimensions of the town.

The most typical for the approach described below is the model of the town of Polyarnye Zori, therefore, on its example, the main theoretical provisions will be formulated. Its main features are as follows:

- the population is 16.5 thousand people, i.e. it belongs to small type cities
- the monostructural economy of the town: the main (town-forming) enterprise providing the vast majority of jobs (more than 2000);
- town-forming enterprise is significantly removed from residential areas of Polyarnye Zori (formally, it is one of the town's districts) - at a distance of about 13 km from the town center;
- The town has compact dimensions: the length of the route between its most distant parts is 2 - 2.5 km.
- grocery stores start working at 9:00.

Let's consider the features of development a model of the morning "rush hour". According to measured traffic flows, the highest traffic intensity falls on the time period from 6:30 am to 8:00 am. This is primarily due to the fact that the shift at the town-forming enterprise starts at 8:00. Due to the fact that shops start working at 9:00 am, there are no "home-to-shop" trips during the morning rush hour. The overwhelming majority of correspondence is made up of trips "home - work" and, much less, "work - home" (workers returning from the night shift). It is not difficult to determine the amount of traffic flow from the town to the gas station and vice versa, since a single road leaves the town in this direction (Figure 1). The colors correspond to the service levels, which represent the ratio of the average vehicle speed on the segment of street and road network to the free movement speed.

The respondents can get to the place of work either by personal or official transport; there is no public transport excluding for official transport and taxis. It is easy to determine the number of respondents using public transport by the occupancy of buses, which is recorded at the roundabout at the exit from the town (the "roundabout" icon in Fig. 1). At the same time, the flows inside the town should be directed exclusively towards the exit from the town, which is not observed. Further research showed that a significant portion of morning rush hour travel was “check-in for a work colleague”. Due to the small linear size of the town (2-2.5 km) and the significant remoteness of the place of work (13 km from the town center), when driving for a colleague at work, the lengthening of the path is no more than 10% of the route, i.e. subjectively perceived as insignificant. Again, due to the small linear dimensions of the town, these trips do not depend on the distance, i.e. the respondent is equally likely to visit any of the town's districts.
The share of these trips can be calculated based on two measurements:
- calculation of the average number of respondents per one passenger car;
- measurements of traffic flows at key intersections.

The calculation formula for calculating the correspondence matrix OD "check in for a work colleague" is:

\[
(a_{ij}) = \left(\frac{K_S \cdot W \cdot P_i \cdot P_j}{P^2}\right),
\]

\[1\]

where \(K_S\) is the coefficient of a joint trip, \(W\) is the number of employees of the town-forming enterprise, \(P_i\) is the number of residents of the \(i\)-th district, \(P_j\) is the number of residents of the \(j\)-th district, \(P\) is the number of residents of the town.

Verification of the model, supplemented with the matrix OD "check-in for a colleague at work", showed good correspondence of the model to real data: for the town of Polyarnye Zori, the value of GEH-statistics calculated by the formula:

\[
GEH = \sqrt{\frac{(V - C)^2}{V + C}}
\]

was not exceeded 3 units for the sections under consideration, with an acceptable value of 5 (dimensionless units), a good value of 4. The values of the GEH statistics are given in Table 1.

**Table 1. Assessment of the quality of calibration of the macromodel**

| Section of the road     | Intensity (fact), units / h | Intensity (model), units / h | The quantity GEH statistics |
|-------------------------|-----------------------------|-----------------------------|-----------------------------|
| To Kandalaksha          | 66                          | 64                          | 0.248                       |
| From Kandalaksha        | 43                          | 45                          | 0.302                       |
| St. Sivko d.16 (direction 1) | 48                          | 52                          | 0.566                       |
| St. Sivko d.16 (direction 2) | 80                          | 99                          | 2.008                       |
| To the Kola NPP         | 601                         | 635                         | 1.368                       |
| From the Kola NPP       | 48                          | 50                          | 0.286                       |
| Lomonosov 6 (direction 1) | 80                          | 89                          | 0.980                       |
| Lomonosov 6 (direction 2) | 147                         | 129                         | 1.532                       |
| Energetikov 33 (direction 1) | 38                          | 37                          | 0.163                       |
| Energetikov 33 (direction 2) | 170                         | 210                         | 2.902                       |
The evening rush hour model was built on the assumption that the correspondence "check-in for a colleague at work" will be performed in the opposite direction due to the fact that the change at the town-forming enterprise lasts an equal number of hours and exit through the checkpoint is carried out in time. The hypothesis of the reversibility of the matrix OD "check-in for a colleague at work" in the evening rush hour was confirmed for the town of Polyarnye Zori. In the general case, the evening matrix OD requires correction.

In addition to the town of Polyarnye Zori, this approach was used to develop models for the cities of Kovdor towns and Borodino and Zelenogorsk. Several roads lead from the town to the checkpoint, but only one of them has an asphalt-concrete surface, so more than 98% of the traffic falls on it. The Borodino evening rush hour model is shown in Figure 2. The colors correspond to the service levels.

Figure 2. Model of the evening rush hour in Borodino

4. Results
The paper considers an approach that makes it possible to most accurately develop a macromodel of a small town with a monostructural economy. The determining factors influencing the accuracy of model development are revealed. The calculation formula (1) is given - the formula for calculating the matrix OD of the type "check in for a colleague".

5. Discussion
For the town of Kovdor the town-forming enterprise remoteness from the town center is much less than in the town of Polyarnye Zori, therefore the coefficient of a joint trip (KS) is much lower than for the cities of Polyarnye Zori and Borodino.

In Zelenogorsk feature of modeling is that the entire territory of the town and suburb is formally the territory of the town. At the same time, the town of Zelenogorsk and the settlements of Oktyabrsky, Ovrazhny, 1000 courtyards, Orlovka, which formally are part of Zelenogorsk and the enterprise are located on the territory of a town. All public transport on the territory of a town, with the exception of several intermunicipal routes, is therefore urban. Despite the developed public and official transport, the share of joint trips "to work" is significant here due to the significant remoteness of the town-forming enterprise from the town center.
6. Conclusions
The approach developed for calculating the matrix OD "to work" (matrix OD "check-in with a colleague") was tested when creating models of 4 cities in 2019.
The high degree of correspondence of the models to the data of measurements of traffic flows proves the validity of the formulas obtained.

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