Substantiation of order of reconstruction of traffic intersections in Tyumen

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Abstract. For this article, we analyzed the source of traffic jams on main intersections of highways in Tumen, Russia, and made a selection of difficult transportation nodes, which were not included in the plan of city development. Our calculations contain figures of traffic jam time and economical losses, and using these data, the priorities for the construction of transport infrastructure objects were determined, starting with the most inconvenient ones in terms of traffic. In addition, we presented an algorithm for the calculation of a priority order of main intersections reorganization. To optimize the traffic, we designed a few projects of each transportation node rebuilding and compare them by their efficiency and price. There is an example of reconstruction of one specific intersection with Tyumen bypass highway by means of our solutions, grounding on this object.

1. Introduction
Expansion of the roadway of the central streets in Tyumen is impossible due to the extreme proximity of the building. The traffic cycles at the intersections and junctions are optimized as much as possible. Proceeding from the aforesaid, on the majority of transport hubs it is necessary to get onto construction of transport interchanges. These designs will greatly improve the correspondence between the districts of the city. To justify the optimal design solution for each transport hub, it is necessary to individually solve such problems as increasing safety on the hauls of traffic flows, writing in the terrain and general architectural layout of Tyumen.

2. Current situation
For today in the regional capital there is a considerable quantity of the hampered and constrained places in the form of narrow streets in the central part that reduces a level of safety and convenience for all participants of movement and is one of the main reasons of growth of quantity and extent of congestion. The regional capital is in the process of continuous development, which requires improving the state of the street-road network (UDS) to elaborate the situation in conjunction with the development of the city. Solving particular problems fundamentally will not change the situation, but will only move congestion from one point of the city to another. So, for example, after the creation of continuous traffic along the section of the Tyumen ring road (hereinafter - TKAD) with the opening of traffic junctions through the streets of Permyakova, Melnikayte, Moscovsky and Cheryshevsky tracts, a jam is formed at a regulated intersection with st. Avtoremontnaya. This says about the incomplete solution of the problem of increasing the capacity of a section of a road of considerable

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length. For the development of UDS is necessary to use integrated approaches, including the study of correspondence between districts of the city with the identification of complex transport hubs.

3. Prepositions for reorganization of the transport network

In the process of detailed analysis of the transport scheme in Tyumen, the busiest sections of the road network were identified, as follows: st. Respubliki, st. 50 let Oktyabrya, st. Profsoyuznaya, st. 50 let VLKSM, st. 30 let Pobedy, st. Shirotnaya, st. Druzhby, st. Melnikayte, st. Permyakova, TKAD, st. Fedyuninskogo, st. Montazhnihkov, st. Shcherbakova, st. 2nd Lugovaya.

In order to establish and determine the required road network parameters for the city roads and streets in consideration, the actual throughput of each section (haul) was determined [1]. Based on the calculation, it is established that the actual carrying capacity on the hauls of these streets varies from 1600 to 8100 buses / hour. (Table 1).

Table 1. Carrying capacity of main streets in Tyumen (table fragment).

| The name of the haul | Carrying capacity, vehicles / hour |
|----------------------|----------------------------------|
| st. Respubliki       | 2660                             |
| st. Profsoyuznaya – st. Melnikayte | 2660 |
| st. Melnikayte – st. Permyakova | 4560 |
| st. Permyakova – st. Montazhnihkov | 4560 |
| st. Montazhnihkov – st. Chekistov | 2660 |
| st. 50 let Oktyabrya  |                                  |
| st. Profsoyuznaya – st. Maksima Gorkogo | 3780 |
| st. Maksima Gorkogo – st. Melnikayte | 3780 |
| st. Melnikayte – st. Permyakova | 3780 |
| st. Permyakova – st. Gilevskaya Roshcha | 3780 |

The bandwidth value depends on the number of lanes, the width of the lanes and the roadway, the width of the curb, the presence of side disturbances, the number of vehicles in the stream, the distance of visibility, the radius of the curve in the plan, the speed limit on the road section, the presence of lanes for public transport, traffic lights regulation at the intersections, as well as the level of loading.

It is established that the existing main streets of citywide importance have insufficient width and number of lanes within the established traffic intensity of vehicles [2].

This is one of the reasons for the formation of traffic congestion of considerable length. In the course of the analysis, the actual list of objects for the reorganization of the transport infrastructure for the near future is established (Table 2).

After the establishment of transport infrastructure facilities, which require reorganization, a calculation is made to assess the order of reconstruction and construction of traffic interchanges. The calculation sequence is presented below.

4. Determination of the order of reorganization

The definition of the priority of the reorganization of transport infrastructure facilities is based on the assessment of time and economic losses.

The calculation technique was adopted on the basis of the thesis work by Andronov RV. "Simulation of queues at the regulated intersections of a street-road network of a large city in conditions of a dense traffic flow" [3].

The algorithm for calculating the priority of the reorganization of transport infrastructure facilities includes the following stages:

- the first - the calculation of the loss of time from the stop before the crossing;
- the second - the calculation of economic losses for passenger and public passenger transport in the mode of traffic congestion.
Table 2. Objects of reconstruction.

| Number of the object | Name of the object (current characteristic)                                                                 | Decision on reorganization                                                                 |
|----------------------|-------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------|
| 1                    | Decision on reorganization st. Timofeya Karmatskogo (a local street with primer coating)                    | Increase in capitality of the covering with the device of transport interchanges          |
|                      | st. Gazovikov – st. 2-ya Lugovaya (no existing intersection)                                                | Continuation of st. Gasovikov with its connection with the street. 2-ya Lugovaya with the construction of a road junction at the intersection of streets |
| 2                    | st. Belinskogo – st. Internatsionalnaya (no existing intersection)                                           | Continuation of st. Belinskogo to the street Internatsionalnaya with the construction of a transport tunnel under the Trans-Siberian Railway |
|                      | st. Barnaulskaya - TKAD (intersection in one level with traffic light regulation)                           | Construction of a traffic junction at the intersection                                     |
| 4                    | St. Avtoremontnaya – TKAD (intersection in one level with traffic light regulation)                          | Construction of a traffic junction at the intersection                                     |
| 5                    | St. Proyezd Voroninskiye gorki – TKAD (intersection in one level with traffic light regulation)            | Construction of a traffic junction at the intersection                                     |
| 6                    | st. Chekistov - st. Tallinskaya (non-existent intersection)                                                 | Continuation of st. Chekistov to the st. Tallinskaya with the construction of a transport tunnel |
| 7                    | st. Vorovskogo - st. Gilevskaya roshcha (non-existent intersection)                                        | Continuation of st. Vorovsko-go to the street. Gilevskaya roshcha with the construction of transport tunnel under a branch railway line |
| 8                    | st. Gilevskaya roshcha – st. Dambovskaya (non-existent intersection)                                        | Continuation of st. Gilevskaya roshcha to the st. Dambovskaya with the construction of a traffic junction |

Below are the basic formulas for determining the indicators of time loss and economic losses of transport.

According to the calculated data, measures are planned to increase the capacity and reduce the number of congestion using the construction of new traffic junctions and pedestrian tunnels.

Losses from transport delays at a separate adjustable intersection are calculated as total from a single stop and from traffic in a jam.

Given the existence of a jam at the intersection of the loss of time \( P_j \) are determined by the formula:

\[
P_j = \sum_{i=1}^{a} \frac{D \cdot N \cdot t_d}{3600 \cdot K_{max}} \cdot T_j
\]

where \( D \) is the number of days with the existence of congestion on the MAC (300 days are taken, minus weekends and holidays); \( N \) – traffic intensity in the direction of the intersection at "rush hour", vehicles/h; \( t_d \) – delay time, movement of the car in the jam, sec, determined by the formula 2; \( T_j \) – the average time of the existence of the jam, depending on the length of the jam and the belonging of the main street to the characteristic area (center, peripheral zone or other mains) [3]; \( K_{max} \) – a coefficient taking into account the ratio of the maximum observed length of the jam to its average length [3].

The time of motion of the car in the jam is determined by:

\[
t_d = \frac{L_c \cdot 3.6}{V_c} + 0.24 \cdot V_a
\]
where $L_j$ – the average maximum observed congestion length in "peak hour", m; $V_a$ – the average speed of traffic before the entrance to the intersection, is assumed to be 40-60 km / h; $V_j$ – the average speed of the car in the jam, km / h, determined by the formula:

$$V_j = \frac{N \cdot I_a}{1000 \cdot n}$$  \hfill (3)

where $I_a$ – the average distance occupied by one car in the jam, m; $n$ – the number of lanes on the approach to the intersection.

In calculating economic losses, the main problem is an adequate economic assessment of the lost time with forced delays in jams by cars and passengers (car-hour, pass-hour).

For the traffic flow, the cost of lost time will be expressed in the cost of the car-hour of operation of the car, taking into account depreciation charges.

The cost of a passenger-hour can be expressed through the gross regional product (GRP) of a city or region, or the average earned payment for a city. Data on urban GRP is not available, because Tyumen is not a separate subject of the federation. Using the GRP data for the Tyumen region in the calculations is not correct, because part of the GRP of the region is created in the autonomous districts (Khanty-Mansiysk and Yamalo-Nenets Autonomous District) in the process of mining and practically is not connected with the city's economic activities. Thus, the most correct use will be in determining the cost of a passenger-hour average earned pay for Tyumen in 2017, equal to 39,542 rubles per month [4]. In this case, the cost of passenger-hour will be calculated according to the formula:

$$E_{p-h} = \frac{W_a}{D \cdot T}$$  \hfill (4)

where $W_a$ – the average wage in the city, rubles; $D$– number of working days in the month equal to 21; $T$ – the length of the working day equal to 9 hours.

In the calculations, based on the data of transport enterprises in Tyumen, the following initial data as of 2017 were taken: the cost of using car-hour of motor transport - 1,148 rubles for cars, 1934 rubles for freight and 1753 for bus [5]; average occupancy of vehicles - 1.5 passengers for cars and 28.8 for buses [6].

Transport losses in the congestion regime are determined by the formula:

$$S^j = P^j \cdot C_m$$  \hfill (5)

where $C_m$ – the weighted average cost of machine hours, rubles, is determined by the formula:

$$C_m = \sum D_i \cdot C_i$$  \hfill (6)

where $D_i$– the proportion of each mode of transport in the total flow; $C_i$ – the cost of a car-hour of a corresponding type of transport, rubles. [5,6].

The loss of passengers from being on the road with a single stop is determined by the formula:

$$S^i_{pas} = \frac{\sum D_i \cdot C_{pas} \cdot \left( T_k + 2 \cdot T_g \right) \cdot T_{Db} \cdot \left( N^c \cdot n^c + N^b \cdot n^b \right)}{T_k \cdot 3600 \cdot K_{km}}$$  \hfill (7)

where $N^c$ and $N^b$ – the intensity of cars and buses at "rush hour", vehicles/hour; $n^c$ and $n^b$ – respectively, the average number of passengers in a car and a bus.

The value of lost time is translated into monetary expression through the average hourly wage rate, rubles / hour.

The loss of passengers from being on the road in a jam is determined by the formula:
To calculate the mathematical model, the Microsoft Excel software complex was used. The results of the calculations are shown in Figure 1.

\[
S_{\text{pas}}^j = \sum_{i=1}^{d} \frac{D \cdot C_{\text{pas}} \cdot t_{d} \cdot \left( N^{e} \cdot n^{e} + N^{b} \cdot n^{b} \right)}{3600 \cdot K_{\text{pas}}} \cdot T_{j}
\]  

Equation (8)

Figure 1. Determination of the order of reorganization of the transport infrastructure of Tyumen.

The rational sequence of the construction of transport infrastructure facilities is determined in a strict sequence of economic losses of vehicles and passenger traffic, taking into account the traffic intensity at these transport hubs (Table 3).

Table 3. The priority of construction of objects.

| Number of the object | Name of the object | Decision on reorganization                |
|---------------------|--------------------|-------------------------------------------|
| 1                   | St. Avtoremontnaya – TKAD | Multilevel transport interchange          |
| 2                   | St. Barnaulskaya – TKAD   | Transport junction                        |
| 3                   | St. Belinskogo – st. Internatsionalnaya | Transport tunnel                          |
| 4                   | st. Chekistov – st. Tallinskaya | Transport tunnel                          |
| 5                   | st. Timofeya Charkova    | City street                               |
| 6                   | st. Proyezd Voroninskiye gorki – TKAD | Transport tunnel                          |
| 7                   | st. Gilevskaya roshcha – st. Domostroiteley | City street                               |
| 8                   | st. Shcherbakova – st. 2-ya Lugovaya | Multilevel transport interchange          |
| 9                   | st. Energetikov – st. Gilevskaya roshcha | Transport tunnel                          |

The analysis of the calculation made it possible to establish the order of construction of transport infrastructure facilities in Tyumen taking into account the following factors:

- development of a network of streets and provision of continuous transport link between areas with the elimination of difficult sections at transport hubs;
- solution of problems to reduce traffic congestion on the street-road network in Tyumen;
- rise of traffic safety;
• introduction of new technologies for the construction of engineering facilities in the form of transport tunnels, which will be innovative for Tyumen and the region;
• obtaining economic effects from the implementation of projects.

For each object, several variants of the reorganization decision were proposed and, on the basis of comparison, optimal designs of transport intersections were chosen.

For the selected solutions, the traffic management schemes were developed in detail, providing for increasing the capacity and reducing congestion.

Below is a description of the reorganization of road traffic on one of the objects.

5. Reorganization of movement on the object st. Avtoremontnaya – TKAD

Under existing conditions, the intersection includes traffic light regulation, which, to a large extent, reduces the capacity of the transport junction. Also, this object is characterized as the most economically expensive because of the emerging traffic congestion.

After the creation of continuous traffic along the extended section of the TKAD with the opening of traffic intersections through the streets of Permyakova, Melnikayte, Moscovskiy and Chervyshhevskiy tracts, a large number of vehicles use this route every day, creating a traffic jam before the crossing with st. Avtoremontnaya of considerable length. This increases economic losses and necessitates the reconstruction of the transport hub to eliminate congestion and increase the crossing capacity.

Four variants of the traffic intersection were developed. The first option is a diamond-shaped transport interchange, the second option is a traffic intersection joined to allied outer hinges, the third option is a traffic intersection with right-side congresses, the fourth option is a transport junction with a circular traffic related.

A comparative analysis of four variants of transport junctions showed the effectiveness of the application of the third option. In this variant, a secondary direction is organized according to the second level, all right-handed congresses are present, and left-wing congresses are assigned to the nearest junctions, namely, TKAD-st. Yamskaya and TKAD-st. Internatsionalnaya, the rerun will be in the first case 1,600 meters, in the second - 1200 meters (Figure 2).

Parameters of the selected option are shown in Table 4.

Table 4. Parameters of the selected option.

| Parameters                              | Transport junction |
|-----------------------------------------|--------------------|
| Area of land occupied, m²               | 4 875              |
| Number of conflicting points            | 8                  |
| Number of levels                        | 2                  |
| Maximum rotation angle, left / right, degrees | 90/90             |
| Presence of left-hand driveways         | 0                  |
| Ability to turn                         | –                  |
| Throughput after implementation, vehicles/h.| 7500              |
| Presence of traffic light regulation    | –                  |

This option was chosen due to the summation of the positive parameters that are needed at this intersection, as well as the aesthetic characteristics of the inscription in the overall architecture of the terrain.

The calculation of economic effects was based on such indicators as growth of throughput capacity, reduction of the crossing time of the transport hub, and economic losses from congestion.

After the construction of this version of the interchange, the throughput of the transport hub will increase by 62.34%, and the crossing time will decrease by 79.48%.

Economic losses from congestion for passenger turnover and traffic of cars after the introduction of reconstruction will decrease by 51.33% [3].


6. Conclusion
On the basis of the analysis of the existing situation of congestion of city streets and roads in Tyumen and determination of the order of construction of transport infrastructure objects, it can be concluded that detailed study is required for each transport hub in Tyumen using the applied and advanced engineering structures of our city.

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