Ways of coordinating schedules in regional passenger traffic

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Abstract. In the modern conditions of the Russian Federation in the traffic management field one of the priorities is the development and improvement of the route transport functioning quality. One of the main passengers’ requirements is the minimum travel time expenditures. Satisfying such a requirement without the mutual coordination of transport processes on routes and the use of roadside station by vehicles and passengers is problematic due to their interdependence. The problem of such coordination is inherited both in the cities, and in regional settlements. In this study, a methodology has been developed for coordinating bus schedules on regional routes that have common route sections or roadside station. This methodology was implemented in the Sargatsky district of the Omsk region. According to the obtained results, the average passenger waiting time in the case of a switch was reduced by 37%.

1. Introduction
Passenger carriage by public transport has a significant impact on the mobility of the population and the country’s socio-economic development. The organization and technology of such carriages on regular routes are complex processes and are determined by a large number of different factors.

One of the main passengers’ requirements is the minimum travel time expenditures [1–4]. From the passenger’s point of view, the traffic quality is understood as the travel time expenditures. It also depends on the consistency of the buses’ movement on different routes.

Therefore, scientific research aimed at improving the bus passenger carriage organization by the criterion of routes and stopping points the time characteristics’ consistency regarding the passenger throughput characteristics, is relevant, especially when transporting between large and small settlements.

Any kind of carriages has its own characteristics. Thus, in the city the distance between stopping points and the traffic interval are extremely short [5]. Regional transportation differs from urban transport: passengers travel mostly within a city and much less often within a region or district. Another feature of regional transport is that the buses departure and arrival time is dictated by the needs of the local residents in the movements.

Also among the regional transportation features there are: a longer standstill time at the final and intermediate stopping points, there is no buses traffic interval on the route, the complexity of the drivers’ work and rest organization. Unsteady and unstable passenger traffic associated with low population density and remoteness of settlements from each other. These factors necessitate the variety of routes organization. Some routes connect small settlements with the district center, the other – with the regional. Besides, the vast majority of the latter transits through the district center. In such conditions,
in order to reduce passengers’ travel time expenditures, it is necessary to coordinate the movement of buses on different routes in time.

2. Analysis of methods and techniques for coordinating buses movement on joint areas
The existing methods of organizing buses movement on routes can be divided into the following groups:

1. Methods of buses distribution on routes [6,7].
2. Methods of organizing rolling stock group movement on routes [8,9].
3. Methods of buses movement coordinating by changing the routes and their amount. These methods are described in the works of V.M. Kurganov [10,11], I.N. Pugachev [12,13] and other scientists [14].
4. Methods of buses work coordinating on the line by adjusting schedules [15,16].
5. Approaches taking into account the influence of various additional factors.

For example, in M.E. Koryagin’s work [17] the effect of fare on passenger waiting time was investigated. The author found that the majority of passengers do not pay attention to this factor when the fare is the same for all types of transport and they choose the first transport that arrives at roadside station.

The first group of methods for the buses distribution on routes does not consider: passenger service quality indicators, the random factors influence, the passenger throughput characteristics, and the regularity of traffic on the route in general and on joint sections in particular.

The second group of methods does not take into account the effect of the traffic in the joint areas on the passenger service quality at the joint areas’ roadside points.

The third group of methods is associated with the routes reduction [12], the new routes addition [10], or the modification of existing ones [12, 14].

The fourth group of methods regards changing the intervals of buses movements from end stops in order to coordinate their movement on joint sections of different routes. Methods [15,16] were designed for urban traffic, taking into account the large number of buses on the line.

Improved traffic regularity reduces the number of buses and average passenger’s waiting time, and ensures the efficient use of vehicle’s capacity. Recurring problems, such as traffic jams, can be solved by planning. One-time problems such as vehicle breakdowns and traffic accidents add an extra level of complexity to managing the system in real time. For service planning, it is important that unreliable service does not directly affect the passengers’ waiting time [14].

Bowman and Turnquist [18] found that waiting times at bus stops are much more sensitive to the schedule than the frequency of maintenance. An increase in waiting time leads to an increase in transportation costs, which ultimately affect the choice of solution mode. Transit services reliability is an important measure of service and directly affects both passenger demand and service level.

In the study [19], several coordinated scheduling models for airlines were developed. To form the models, the network flow method was used. Models were formulated as problems with a multitude of flows in product networks that can be solved using a mathematical programming solver.

So, some methods of organizing the buses work on routes consider the route as a separate existing system, which work is not affected by other routes. Other methods, taking into account the influence of this factor, instead of considering the problems of the passenger service quality, primarily examines the problems of traffic management. That is, they are designed to solve problems associated with the overloaded street-road system and are designed mainly to decrease rolling stock units number on the roadside points of joint areas. The majority of methods were developed and applicable only under the city conditions. At the same time, the issues of coordinating the buses movement on routes connecting large and small settlements remain without due cognizance.

3. Problem description
The main regional carriages features that form the issue are: lack of transport for long periods of time (no hauls), simultaneous departure of several buses on different routes with large joint sections,
duplication of long-distance routes with short routes, long time expenditure on transferring from one route to another, short interval between arrival and departure of two different buses.

All these features lead to the fact that part of the buses are half empty, passengers refuse to travel because of the inability to transfer from one bus to another, or because of the long waiting time for the next haul. Thus, it is necessary to develop a method to coordinate the arrival and departure of buses at the stopping points.

The reasons for adjusting the timetables from the passenger’s point of view can be:
1. Long wait when transferring from one route to another.
2. The small interval between arrival and departure.

For example, a passenger needs to get from point A to point B. There is no direct route connecting these points, or there is a route, but there is no bus schedule at the time required for the passenger. Then the passenger can get to point B with a transfer in point C (Figure 1) by completing a trip on the section of the route passing through section 1, then 2.

![Figure 1](image1.png)

**Figure 1.** Scheme of buses traffic plan through a stopover.

Sections 1 and 2 can connect intermediate or final routes’ points. Points A, B, C for some routes may be initial (final), for others (transit) – intermediate.

If the passenger misses the transfer to another bus, he will have to wait for the next one, which may come through a long period of time. In order to reduce the waiting time at the interchange point, it is necessary to coordinate the route schedules.

4. **Route matching technique**

A technique, coordinating the buses movement during the passengers carriage between large and small settlements, has been developed (Figure 2.)

Using this technique, it is possible to coordinate bus schedules. Consider its application on the example of the Sargatskii district of the Omsk region.

| Choice of settlement and routes for approval |
|---------------------------------------------|
| Creating a consolidated schedule for the selected settlement |
| Scheduling buses on selected routes |
| Waiting time determination for passengers boarding |
| Determining the method of finalization and approval |
| Route schedules correction according to the chosen method |
| Corrected scheduling estimation |

**Figure 2.** Scheme of methods for coordinating bus schedules.

1) Choice of settlement and routes for approval
To select routes for approval, it is necessary to analyze existing routes. To do this they were displayed on the map.

Figure 3 shows that traffic scheme forms a “tree”. This is due to the large number of duplicate routes, having a common point – the village Sargat. In total, from 22 to 26 routes passes through this point daily.
Figure 3. Bus traffic patterns of the Sargat district without transit routes.

The greatest branching occurs from the Sargat settlement, therefore the coordination is carried out at the Sargat stop. Consolidated schedule of Sargat district routes is in Table 1.

2) Creating a consolidated schedule for the selected settlement

Information about the routes is entered in the table: working days, departure time of from the starting point (SP) and arrival at the final point (FP), stay in the intermediate point.

Table 1. The consolidated schedule of Sargat district routes.

| Rout                      | Working days | Forward direction | Backward direction |
|----------------------------|--------------|-------------------|-------------------|
| 1 Sargatskoe - Tambovka   | wed.         | SP: 15:20, Sargat: 17:00 | SP: 17:10, FP: 18:50 |
| 5 Sargatskoye - Ploskoye | fri.         | SP: 15:30, Sargat: 16:50 | SP: 17:00, FP: 18:20 |
| 102 Sargatskoye - Nizheiryshskoe | tue., thu.  | SP: 12:20, Sargat: 12:55 | SP: 13:00, FP: 14:14 |
| 103 Sargatskoe - Kazarly | tue.         | SP: 15:00, Sargat: 16:10 | SP: 16:20, FP: 17:30 |
| 104 Sargatskoe - Mikhaylovka | sat.       | SP: 12:30, Sargat: 13:40 | SP: 13:50, FP: 15:00 |
| 1068 Omsk - Bolshereche  | All          | SP: 9:10, Sargat: 11:05 | SP: 16:50, FP: 18:25 |
| 1090 Omsk - Chapaevsko - Kabury  | All         | SP: 13:20, Sargat: 15:20 | SP: 18:50, FP: 6:40 |
| 1099 Omsk - Ploskoye     | All          | SP: 9:30, Sargat: 11:50 | SP: 13:45, FP: 15:30 |
| 1106 Omsk - Tara         | All          | SP: 10:30, Sargat: 12:20 | SP: 16:00, FP: 23:20 |
| 1116 Omsk - Znamenskoye | All          | SP: 8:30, Sargat: 10:10 | SP: 14:50, FP: 15:30 |
3) Scheduling buses on selected routes

Scheduling in a graphical form allows observing the problem zones in the schedules (Figures 4-6). Problem zones are temporary areas that correspond to long waiting times for passengers at the transfer point, waiting for the next haul to the destination. In Figure 4a, these zones are signed “waiting”. There is also a zero wait when transferring from a bus following route 1106 to a bus following route 102.

4) Waiting time determination for passengers boarding

Waiting is defined as the difference between the nearest time of arrival and departure and vice versa. Among the values obtained for each route, the average value of the waiting time is calculated (formula 1).

\[ t_{wait} = \frac{\sum ( t_{depart} - t_{arriv} )}{2} \]  \hspace{1cm} (1)

where \( t_{depart} \) – departure time of the bus from the roadside-interchange station point; \( t_{arriv} \) – arrival time of the bus from the roadside-interchange station point.

Let us calculate the average value of the passenger’s waiting time at the transferring point from Omsk to Nizhneirtyshskoye. There is no direct route. Therefore, a transfer is required at Sargat point. The departure time of the bus following the route No. 102 from the Sargatskoye transfer point to Nizhneirtyshskoye is 12:20. The nearest route from Omsk is No. 1099, the next route passes through the Sargatskoye transfer point has an arrival time in Sargatskoye – 11:50. The gap in departure and arrival times between routes No.102 and No.1099 is 30 minutes. When moving from Nizhneirtyshskoye to Omsk, the waiting time for a passenger at the Sargatskoye transit point is 1 hour 26 minutes. The average passenger waiting time is 58 minutes.

5) Determining the method of finalization and approval

The methods include: changing the standstill time, the departure time shift from the starting point. In this example, both methods of agreement are applied.

6) Route schedules correction according to the chosen method

In Figures 4-6, the standstill time change is made for routes No.102 and No.104, the departure time shift – for routes 102 and 103.

After the adjustment, the average passenger waiting time at the Sargatskoye transit point on route 102 on Thursday constitute 33 minutes.

7) Corrected scheduling estimation

The assessment is based on a comparison of the average passenger waiting time before and after the changes.

The decrease in the average waiting time on route 102 on Thursday constitutes 25 minutes, which is 43% less than the existing option.

5. Results

The developed methodology application on the example of routes Sargatsky district of the Omsk region showed the following results. Bus schedules before and after changes are shown in Figures 4-6.

In Figures 4-6, the abscissa line (0) corresponds to the Sargatskoye transfer point, -100 – to the final point Omsk.

The average waiting time before and after the changes is presented in Table 2.

| Route | 1 | 5 | 102 | 102 | 103 | 103 | 104 | Average waiting time |
|-------|---|---|-----|-----|-----|-----|-----|----------------------|
| Before the changes | 0:30 | 0:12 | 0:58 | 0:58 | 0:42 | 0:25 | 0:42 | 0:38 |
| After the changes | 0:20 | 0:12 | 0:33 | 0:33 | 0:22 | 0:25 | 0:27 | 0:24 |

As a result of the developed methodology application, it was possible to reduce the average passenger waiting time at a stopping point by 37%.
Figure 4. Traffic schedules on Tuesday before (a) and after (b).

Figure 5. Traffic schedules on Wednesday before (a) and after (b).

Figure 6. Traffic schedules on Thursday before (a) and after (b).
6. Discussion

Figure 4 illustrates the situation when the bus on route 1106 to the Sargatskoye stopover and the bus on route 102 from Sargatskoye to Nizhneirtyshskoye (12:20) arrives and departures at the same time. In this case, passengers do not have time to transfer. Thus, they are forced to use an earlier haul while traveling from Omsk to Sargatsky. For those passengers traveling from Nizhneirtyshskoye to Omsk with a transfer at Sargatskoye, they are forced to wait for the nearest bus to Omeks 1 hour and 26 minutes after arriving at Sargatskoye. The developed method provides a graphical representation of the schedule (Figure 4-6), which allows to identify such situations and adjust the route schedule so that the waiting time for passengers at the transfer point is acceptable.

7. Conclusions

The developed method application allows organizing an acceptable distribution of buses arrival and departure during the day according to the criterion of the minimum passengers’ time expenditures at the interchange point. The developed method allows solving the problem of inconsistency in the buses movement. Experimental verification showed that the use of this technique reduces the waiting time for passengers at transfer points by 40%, which also reduces the route travel time.

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