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Improving the Efficiency of Urban Public Transport by Optimizing the Bus Schedule in the City of Lida

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Abstract
The paper presents the optimization problem of public transport schedule in the city of Lida in response to the improvement in passenger service quality. Using scheduling technique of route vehicles on duplicating stretches allows to determine the optimal vehicle traffic intervals for each route, considering duplicating stretches; coordinate the movement of route vehicles on duplicating stretches; reduce waiting time for route vehicles for those passengers who can be transported using several route options; increase uniformity of vehicle occupancy.
Improving the bus schedule on duplicating stretches in the city of Lida was conducted to illustrate the effectiveness of the proposed technique. Experimental research has shown the applicability of the developed technique in practice.

Keywords: Urban Public Transport, Scheduling Technique, Duplicating Stretches, Traffic Interval

1. Introduction

Urban public transport is the main way to move passengers in cities. The main role of urban public transport is to ensure sustainable urban development. Compared with individual vehicles, urban public transport significantly increases the safety of passenger transportation and provides significant savings in natural and financial resources.
One of the main characteristics that shows the level of public transport services is the regularity of bus traffic, depending on a well-designed schedule.
The bus schedule should be developed considering the need to ensure:

- Meeting the needs of the population for transportation on each route;
- Use of bus capacity according to established standards.
- Minimum time spent by a passenger on trips;
- Regulation of bus traffic throughout the routes;
- Creating the necessary amenities along the way;
- Compliance with the regime and working conditions of drivers and conductors, in accordance with labor legislation;
- Efficient use of buses.

The schedule is the main regulatory document in the organization of the work of buses. It regulates the mode of movement and downtime, the mode of work of drivers and the time of operation of the route, the number of rolling stocks on the line and the intervals of movement.
The schedule of public transport should ensure the safety of passenger transportation, ease of travel, minimum travel time, high regularity of movement, increased productivity of drivers and the ability to fulfill the plan in terms of volumes, economic and financial indicators.
To solve these problems the scheduling technique of route vehicles on duplicating stretches was created [5-9]. The problem of the improvement in passenger service quality and efficiency of urban public transport is to align the schedules of different routes on duplicating stretches, thereby contributing to more regular traffic interval and vehicle occupancy.

2. Scheduling technique of route vehicles on duplicating stretches

Scheduling technique of route vehicles on duplicating stretches [5-9] includes some steps:

- Analysis of public transport network and determining a lot of duplicating stretches,
- Calculation the optimal time intervals among arrivals of route vehicles and alignment these intervals among consecutive route vehicles on duplicating stretches,
- Analysis of the quality of adjusted schedule with route vehicles of different kinds included,
- Determining the optimization efficiency for duplicating stretches.

To substantiate and test the scheduling technique of route vehicles on duplicating stretches [5-9], it is proposed to use it to optimize the bus schedule in the city of Lida, Republic of Belarus.

3. Optimization of the bus schedule in the city of Lida

The city of Lida is located in the western part of the Republic of Belarus in the Grodno region. Lida is an industrial city in the Grodno region, the administrative center of the Lida district. The population of the city of Lida is about 104 thousand people.

Currently, in the city of Lida, passengers are transported on 18 bus routes. Fig 1 shows the route network of buses in the city of Lida.

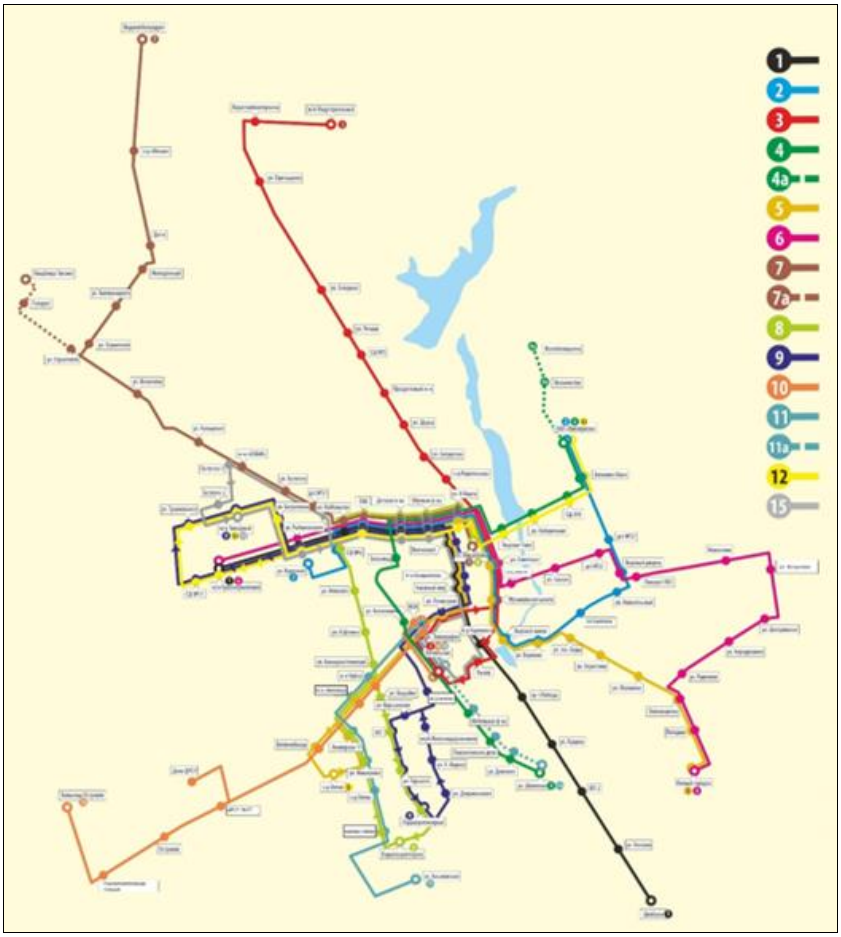

Fig 1: Lida city bus route network

Table 1: Parameters of duplicating stretches

Duplicating stretch	Bus routes	Transport stop amount
D_1 – «JSC «Lakokraska» – Children's Polyclinic»	№ 4, № 12	8
D_2 – «Zapadny Microdistrict – Shoe Factory»	№ 9, № 12, № 15	4
D_3 –« Beltex Optician – Vitalur Store»	№ 8, № 11	4
D_4 – «Bauman Street – 8th of March Street»	№ 2, № 5	4
D_5 – «Krasnoarmeysky microdistrict – Shoe factory»	№ 1, № 6	4

When studying this scheme, five duplicating stretches were identified, which provide for the movement of buses on two or more routes (See Table 1).

The first duplicating stretch D_1 «JSC Lakokraska – Children's Polyclinic» is common to the main bus routes № 4 and № 12 under consideration for eight stops. This joint stretch is one of the most important in the city of Lida, as it passes through the busiest traffic street on 8th of March Street in the city of Lida, within which a large number of waiting passengers are formed. This duplicating stretch starts moving from the Lakokraska plant, where passengers are formed during morning and evening rush hours.

The second duplicating stretch D_2 «Zapadny Microdistrict – Shoe Factory» is common to the bus routes № 9, № 12 and № 15 under consideration for four stops. This section also passes through the busiest traffic on 8th of March Street, as

well as through the objects of attraction of people, namely: The railway station, various shops, the military enlistment office, a shoe factory, schools, clinics.

The third duplicating stretch D_3 « Beltex Optician – Vitalur Store» is common to the bus routes № 8 and № 11 under consideration for four stops.

The fourth duplicating stretch D_4 «Bauman Street – 8th of March Street» is common to routes № 2 and № 5 for four stops. This duplicating stretch runs along Sovetskaya Street. On this duplicating stretch there are such places of attraction for people as: Children's music school, Leeds College, shops and cafeterias, etc.

The fifth duplicating stretch D_5 «Krasnoarmeysky microdistrict – Shoe factory» is common to routes № 1 and № 6 for four stops. This duplicating stretch passes through the busiest traffic on 8th of March Street.

To optimize the bus schedule on five duplicating stretches, it is necessary to:

- Calculate the optimal time intervals among arrivals of route vehicles,
- Align these intervals among consecutive route vehicles on duplicating stretches.

Objective function for the duplicating stretch $D_r(I)$ can be written down in the following format:

$$D_r(I) = \sum_{i=1}^{N_D} | I_{Dr}^* - I_i | + \sum_{i=1}^{N_{M1}} | I_{MD1}^* - I_i | + ... + \sum_{i=1}^{N_{Mk}} | I_{MDk}^* - I_i | \to \min$$

$| I_{Dr}^* - I_i |$ – deviation value of intervals between route vehicles from the optimal value for the duplicating stretch,

$| I_{MDk}^* - I_i |$ – deviation value of intervals between route vehicles from the optimal value for the routes on the duplicating stretch.

The waiting time for passengers of vehicles at the transport stop is defined as

$$T_{Wi} = I_i \lambda_i$$

Where λ_i is the intensity of arrival of passengers using vehicles of duplicating stretch.

An example of optimizing the schedule of bus routes № 4 and № 12 for the first duplicating stretch D_1 – «JSC «Lakokraska» – Children's Polyclinic» in the time period from 7.00 to 9.00 is presented in Tables 2, 3.

Table 2: Calculation of parameters for the first duplicating stretch with the existing bus schedule

Arrival time	№4	№12	$\| I_{D1}^* - I_i \|$	T_W	$\| I_4^* - I_i \|$	$\| I_{12}^* - I_i \|$
7:00	–	–	1	–	–	–
7:03	0	1	14	6	0	6
7:11	1	0	9	36	0	0
7:21	0	1	7	55	0	6
7:39	0	1	1	171	0	6
7:57	0	1	1	171	0	6
8:15	0	1	1	171	0	6
8:53	1	0	21	741	42	0
9:00	–	–	–	28	–	–
Sum	2	5	55	1379	42	30

Table 3: Calculation of parameters for the first duplicating stretch with an optimized schedule

Arrival time	№4	№12	$\| I_{D1}^* - I_i \|$	T_W	$\| I_4^* - I_i \|$	$\| I_{12}^* - I_i \|$
7:00	–	–	1	–	–	–
7:01	0	1	16	1	0	8
7:11	1	0	7	55	0	0
7:21	0	1	7	55	0	4
7:41	0	1	3	210	0	4
8:01	0	1	3	210	0	4
8:21	0	1	3	210	0	4
8:43	1	0	5	253	32	0
9:00	–	–	–	153	–	–
Sum	2	5	44	1147	32	24

As a result of optimizing the schedule for the first duplicating stretch D_1 – «JSC «Lakokraska» – Children's Polyclinic» in the time period from 7.00 to 9.00, the total deviation of the intervals between consecutive buses from the optimal value decreased from 55 to 44 minutes. The total waiting time for passengers of vehicles decreased by 17%.

The efficiency of optimizing public transport schedules on duplicating stretches is calculated:

$$FD_r^* = D_r^0(I) - D_r^*(I)$$

Where

$D_r^0(I)$ is deviation between consecutive route vehicles from optimal value before optimization,

$D_r^*(I)$ is deviation between consecutive route vehicles from optimal value after optimization.

The efficiency of schedule optimization is achieved by reducing the waiting time for public transport passengers.

The value ΔT_W determines the amount of reduction in the waiting time for passengers of vehicles on the routes of duplicating stretch D_r.

The value t_p determines the average waiting time by one passenger of the vehicle for the routes of duplicating stretch D_r.

Performance evaluation of the adjusted schedule by five duplicating stretches for rush hours is presented in Table 4.

Table 4: Optimization result of the schedule by five duplicating stretches for rush hours

DS	Before optimization		After optimization		$FD_r(I)$, minute	$FD_r(I)$, %	Δt_p, minute	ΔT_W, %
	$D_r^0(I)$, minute	t_p^0, minute	$D_r^*(I)$, minute	t_p^*, minute				
D_1	208	11,19	195	9,76	13	8	1,43	12
D_2	304	10,66	275	9,02	29	11	1,64	12
D_3	372	12,54	314	11,55	58	14	0,99	7
D_4	541	11,42	510	10,84	31	6	0,58	5
D_5	231	7,85	177	6,98	54	27	0,87	11
Result	1656	10,73	1471	9,63	185	11	1,10	9

4. Research results

Based on the results of the optimization, the following conclusions can be drawn: the waiting time for passengers of fixed–route vehicles has been reduced for five duplicating stretches: for the first by 12%, the second by 12%, the third by 7%, the fourth by 5%, the fifth by 11%. The difference in the total values of time interval deviations between consecutive route vehicles in all duplicating stretches was 185 minutes.

5. Conclusions

While optimizing the existent schedule, particular attention is paid to reduce transport delays; due to lack of forced idle time of route vehicles in front of transport stop (waiting for an opportunity to drive to it) and subsequent accelerations, there is also the effect of reducing economic (additional fuel consumption) and environmental (from emissions of air pollutants) losses.

Improving the bus schedule on duplicating stretches in the city of Lida was conducted to illustrate the effectiveness of the scheduling technique of route vehicles on duplicating stretches.

Experimental research has shown the applicability of the developed technique in practice.

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