International Journal of Engineering Inventions
e-ISSN: 2278-7461, p-ISSN: 2319-6491
Volume 12, Issue 1 [January. 2023] PP: 141-144

Optimization of Urban Passenger Transport Schedule on Duplicating Stretches in the City of Rechitsa

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ABSTRACT: *This paper presents the optimization problem of public transport schedule in the city of Rechitsa 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, taking into account 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, which reduces the number of passengers in the cabin and reduces the risk of COVID-19 transmission.*

Improving the bus schedule on duplicating stretches in the city of Rechitsa was conducted to illustrate the effectiveness of the proposed technique. Experimental research has shown the applicability of the developed technique in practice.

KEYWORDS*: urban passenger transport, scheduling technique, duplicating stretches, traffic interval.*

Date of Submission: 01-01-2023 Date of acceptance: 08-01-2023

I. INTRODUCTION

The main role of urban passenger transport is to ensure the sustainable development of cities. In particular, compared with individual vehicles, urban public transport significantly increases the safety of transportation and provides considerable savings of natural and financial resources [1].

It makes the task of improving the schedule of passenger transport actual. A lot of articles are devoted to the scheduling methodology of passenger transport [2 – 4].

When scheduling, the impact of compatible travel stretches of route vehicles is more often ignored, which is significant weakness for urban passenger transport services. If there are several routes servicing the same stretch, it is necessary to coordinate traffic schedules of different routes on compatible or duplicating stretches of their traffic [5, 6].

Servicing of duplicating stretches causes some problems: transport queues at the transport stops, irregular intervals of traffic vehicle, increasing passengers' waiting time which leads to discomfort while travelling, uneven occupancy of vehicles and, as a consequence, overflow of some of them, which leads to an increased risk of infection with COVID-19.

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. It would appear to be possible to achieve abovementioned coherence in vehicle schedule of different routes through the primary coordination of traveling time through "basic" transport stops with further calculation of the traveling time through the other transport stops of the route.

II. SCHEDULING TECHNIQUE OF ROUTE VEHICLES ON DUPLICATING STRETCHES

Scheduling technique of route vehicles on duplicating stretches [5 – 9] includes the following steps.

Step 1. Analysis of public transport network and identifying duplicating stretches.
Step2. Selection of a duplicate section to optimize the schedule and determine its characteristics
Step 3. Alignment of time intervals among consecutive route vehicles on duplicating stretches.
Step 4. Analysis of the quality of adjusted schedule for duplicating stretches.
Step 5. Analysis of the quality of adjusted schedule with route vehicles of different kinds included.
Step 6. Evaluating the effectiveness of schedule optimization.

III. APPLICATION

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 Rechitsa (Gomel region, Republic of Belarus).

Currently, in the city of Rechitsa, passengers are transported on eleven bus routes. When studying the public transport scheme, four duplicating stretches were identified, on which the movement of buses of two or more routes is provided.

The first stretch D_1 "Frunze Street – Dzerzhinsky Street" is common for routes number 7, 7 b, 1 rr, 5, 8 for seven transport stops. This joint stretch of the road is one of the most important in the city of Rechitsa, as it passes through the busiest traffic streets of the city (Sovetskaya Str., Khlus Str.). A large number of passengers are waiting at public transport stops here.

The second duplicating stretch D_2 "Pharmacy – Dzerzhinsky Street" is common to routes 7, 7 b, 5 for twelve stops. This joint stretch is one of the longest in the city of Rechitsa, runs along the main street of the city – Sovetskaya Street. On this site there are such places of attraction of people as: house of culture, department store, art school, etc.

The third duplicating stretch D_3 "Dzerzhinsky Street – Frunze Street" is included in the second duplicating stretch. It is common for routes 7, 7 b,1 lr, 5, 8 for six bus stops. This duplicating stretch runs through the busiest streets of the city – Khlus Street, Sovetskaya Street.

The fourth duplicating stretch D_4 "Dzerzhinsky Street – Proletarskaya Street" is common to routes 7 b and 6 for seven bus stops. This routes run along the Svetlogorsk highway – one of the busiest transport sections in the city.

As a result of the traffic schedule optimization along four duplicating stretches, the traffic intervals of buses were aligned, total deviation value of intervals among consecutive buses from the optimal value has decreased.

The quality of schedule optimization for set of duplicating stretches is determined by the following parameters.

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

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

$| I_{Dr}^* - I_i |$ – 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 efficiency of optimizing public transport schedules on duplicating stretches is calculated:

$$F_r^* = D_r^0(I) - D_r^*(I) \quad (2)$$

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.

Performance evaluation of the adjusted schedule by four duplicating stretches is presented in Table 1.

Table(1). Optimization result of the schedule by four duplicating stretches.

DS	Before optimization		After optimization		$F_r^*(I)$, minute
	$D_r^0(I)$, minute	T_W^0, minute	$D_r^*(I)$, minute	T_W^*, minute	
D_1	506,99	12496	139,026	11244	367,964
D_2	396,56	12114	151,56	9764	245
D_3	82	32268	53	31560	29
D_4	394,42	12614	200,41	11418	194,01
Sum	1379,97	69492	543,996	63986	835,974

Based on the results of the optimization, the following conclusions can be drawn. The waiting time for passengers of route vehicles decreased for the first duplicating stretch D_1 "Frunze Street – Dzerzhinsky Street" by 10%, for D_2 "Pharmacy – Dzerzhinsky Street" – 20%, for D_3 "Dzerzhinsky Street – Frunze Street" – 3%, for D_4 "Dzerzhinsky Street – Proletarskaya Street" – 10%.

The efficiency of the optimized schedule for the first duplicating stretch D_1 is 73%, for D_2 – 62%, D_3 – 36%, D_4 – 50%.

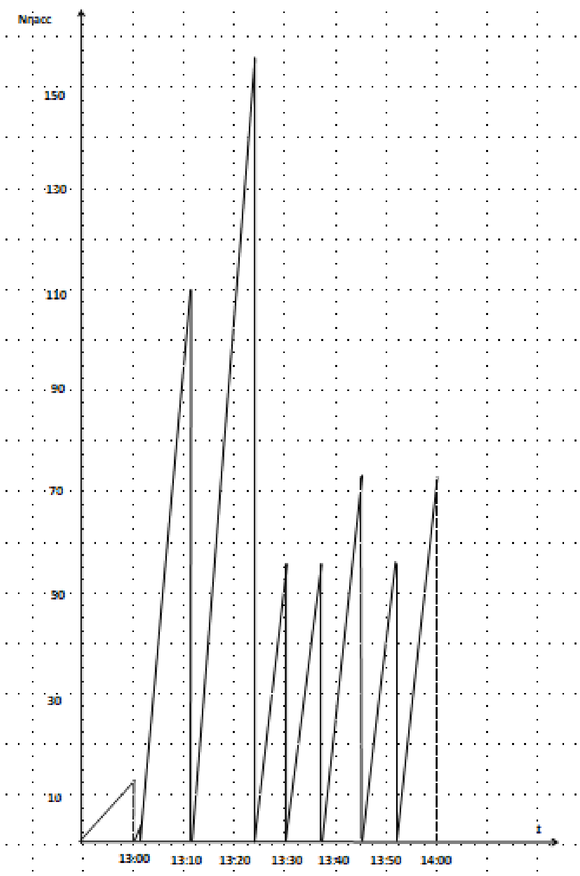
The efficiency of schedule optimization is achieved by reducing the waiting time for public transport passengers. The waiting time for passengers of vehicles at the transport stop is defined as

$$T_{Wi} = I_i \, \lambda_i \, , \tag{3}$$

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

Figure 1 shows an example of diagrams of passengers waiting for route vehicles at the transport stop in the period from 13.00 to 14.00 for the first duplicating stretch D_1 before (Figure 1, *a*) and after optimization (Figure 1, *b*).

a)



b)

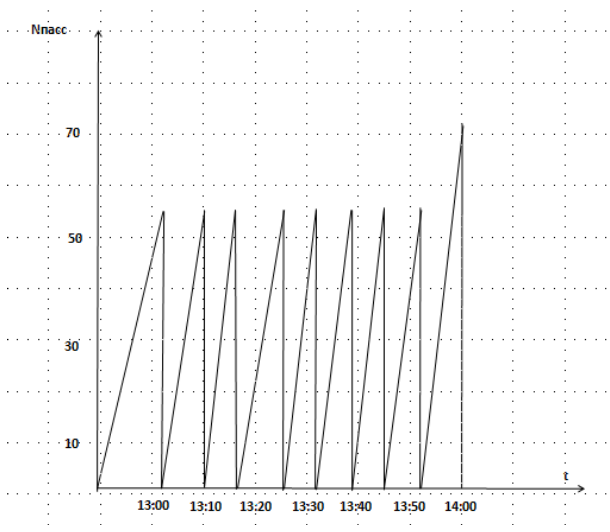


Fig. 1 Diagrams of passengers waiting for route vehicles at the transport stop

Environmental losses from forced downtime of route vehicles in front of the transport stop are calculated:

$$E_i^S = \sum_{j=1}^{n} q_{ij}^S \, S \, K, \tag{4}$$

where q_{ij}^S is specific emissions of the *i*-th substance when stopping (braking, acceleration) of *j*-th route vehicle (grams per transport stop),

S – the specific number of traffic stops (stops per vehicle), *K* – the emission correction factor depending on the speed of route vehicle.

Emission values for following pollutants are calculated for each transport stop: carbon monoxide (CO), nitrogen oxide (NO), volatile organic substances (VOC), solid particles (PM) and fuel.

$$E_{CO}^{s} = 3{,}6 \cdot 1 \cdot 0{,}64 = 2{,}304, \text{grams}$$

$$E_{NOx}^{s} = 3{,}9 \cdot 1 \cdot 0{,}64 = 2{,}5, \text{grams}$$

$$E_{VOC}^{s} = 1{,}5 \cdot 1 \cdot 0{,}64 = 0{,}96 \text{ grams}$$

$$E_{PM}^{s} = 0{,}3 \cdot 1 \cdot 0{,}64 = 0{,}192, \text{grams}$$

$$E_{fuel}^{s} = 80 \cdot 1 \cdot 0{,}64 = 51{,}2, \text{grams}$$

As a result of calculations, it was found that 51.2 grams of fuel and 6 grams of pollutants are released into the air at each bus stop. Accordingly, when 23 extra bus stops are detected before the schedule is optimized, 1178 grams of fuel and 138 grams of pollutants are released into the air.

As a result of the traffic schedule optimization on the duplicating stretches

– the traffic intervals of vehicles for each route separately and for duplicating stretches were aligned,

– passengers' waiting time for route vehicle arrival, average queuing time and queue length for route vehicles, load factor of transport stop by vehicles were reduced.

IV. 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 Rechitsa 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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