# Simulation of Optimal Routes Passenger Transport

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*Abstract*: **The purpose of the study is to create an economic and mathematical model for improving the performance of urban passenger transport and to make effective management decisions for planning and redevelopment of city routes. The research takes into account the current plans for the development of the city of Ternopil and the trends of urban passenger transportation.**

*Keywords:* **passenger transport, route, passenger transportation, optimal route, network, graph.**

## I. Introduction

The main task of urban passenger transport is the provision of passenger transportation services. This topic is relevant as there is a need to create new routes and increase the competitiveness of existing urban passenger traffic through the provision of quality transport services. It is possible to improve their quality by improving technological and organizational transportation provision.

The theme of the study becomes particularly relevant, given the current plans for the development of the city of Ternopil and the trends of urban passenger transport. The optimal organization of urban passenger transport to date is not sufficiently explored. That is why we set ourselves the task of improving the organization of urban passenger transport, improving the quality of transport services for the city's residents, reducing transport tensions on the roads, improving the ecological situation and ensuring the economic efficiency of transport enterprises.

The following scientists worked on improving the efficiency of urban passenger transport: Afanasyev LL, Braylovsky MO, Butko T.V., Vorkut AI, Gavrilov EV, Geronimus B.L., Granovsky B. I., Dmitrichenko MF, Dolya V.K., Zablotsky G.A., O.S. Ignatenko, V. V. Kobozev, A. Kotsyuk, P. Levkovets, P. Lopatin, L. P. Magnanti, T.L. Mun, V. V. Polischuk, A. Petrashevsky, Samoilov DS, Safronov Ye.A., Khabutdinov RA, MS Fiscsells, Hasselstroem D., Mandl C., Nebelung H., Sonntag H. et al.

The city of Ternopil does not belong to large cities (more than 250 thousand people), nor to secondary (up to 250 thousand people), it is on the border between large and medium. For such a city, the time spent traveling from the place of residence to the place of work or training is 30-35 minutes, and for those who live in remote districts - 60-70 minutes. For this period in Ternopil 40% of passengers transport electric transport and 60% - bus. The total length of the contact network is more than 60 km, and the total length of trolleybus routes is approximately 150 km. The length of short trolleybus routes is 10-14 km, the average 15-19 km, and long 20-23 km. The total length of bus routes is approximately 500 km. The average length of the bus route is 16.5 km.

We found that in the city of Ternopil, the longest bus route is the route number 18. In one direction, it travels about 15 km and it takes about 55 minutes. The longest trolleybus route is the route number 8. In one direction, it travels about 11 km and it takes about 52 minutes. In Ternopil, city passenger transportation provides 55 trolleybuses of large and especially large passenger capacity, as well as 210 buses of low passenger capacity, which are designed for 42 passengers.

The Trolley Park of Ternopil city contains 32 trolleybuses with a total passenger capacity of 100 passengers (TP14) and 23 trolleybuses with a passenger capacity of 150 passengers (TP15). However, in most of them the term of normative exploitation has expired and needs to be replaced. In order to fully update the trolleybus park, you need a lot of money, because new trolleybuses are very expensive (the new short Lviv or Lutsk trolleybus costs about 2 million UAH, and the big one - not less than 4 million UAH).

The bus fleet of the city consists of three types of buses: IVAN, Bogdan and Etalon. Most of these buses also need an update[2-5].

In Ternopil, motor transport complements electric transport due to duplication of routes. In peak hours, buses take up a significant number of passengers, and in the period when the number of passengers is small - contribute to reducing the number of trolleybuses on the line to save energy.

## II. The Method of Obtaining of the Optimal Route

The terms of each routing task include a description of the network of communications, which determine the set of possible ways of following one or more moving objects. Typically, the structural parameters of the network remain unchanged from the beginning and until the end of the process of solving the problem.

The task of finding the optimal route in urban transport networks can only be solved by a complete overview of all possible options [7]. It is worth noting that the number of possible variants of route schemes is equal to $2n \cdot (n-1)$, where $n$ – the number of public transport stops. With increasing $n$ this value is rapidly increasing, and already at $n$=10 it is approximately 1,24×1027 variants.

It is clear that the complete overview of such an amount of options takes a lot of time and requires very powerful computing [6]. That is why we came up to solve this problem from the expert point of view, that is, built the routes in order to cover as much territory as possible and at the same time minimize overlap with one transport route of another.

It is known that the base model for constructing an optimal transport network in the routing problem is a weighted graph $H = (V, U)$ with a set of vertices $V$ and a plurality of edges $U$. The vertex i∈V, $|V| = n$, corresponds to city stops. The vertices i and j form in the graph $H = (V, U)$ the edge {i, j} if they are represented by stops, directly connected segments of the road (trails), adjacent street crossings on a city map, etc[6].

Imagine an existing trolleybus route No. 9 (see Fig. 1) in the form of a graph. The vertices of this graph are the stops of the route, and the edges are the distance between the stops. Having analysed Figure 1, it can be argued that the current trolleybus route No. 9 has 29 stops, and its length is 21,795 km. Imagine an existing bus route No. 7 (see Fig. 2) in the form of a graph. The vertices of this graph are the stops of the route, and the edges are the distance between the stops. Having analysed Figure 2, it can be argued that the current trolleybus route No. 7 contains 25 stops, and its length is 6.95 km.

The calculation of the duration of the flight is carried out by the formula 1, which is presented below.

$$Tp = \frac{lm}{\beta \cdot Vt} + n_s \cdot t_s + t_{fs} \qquad (1)$$

where $lm$ – is the length of the route,
$\beta$ – runway coefficient (for Ternopil city $\beta = 0{,}9$),
$Vt$ – technical velocity (average for Ternopil $Vt$ = 25 km/h),
$n_s$ – number of stops on the route,
$t_s$ – idle time at a stop (for the city of Ternopil $t_s = 0{,}02\ h$),
$t_{fs}$ – idle time at the final stop (for the city of Ternopil $t_{fs} = 0{,}11\ h$).

Calculate the duration of the voyage of the existing trolley route No. 9 by the formula 1:

$$Tp = \frac{21{,}795}{0{,}9 \cdot 25} + 29 \cdot 0{,}02 + 0{,}11 = 1{,}66\ h.$$

Calculate the duration of the voyage of the existing bus route number 7 by the formula 1:

$$Tp = \frac{6{,}95}{0{,}9 \cdot 25} + 29 \cdot 0{,}02 + 0{,}11 = 1\ h.$$

Thus, the duration of the voyage of the existing trolleybus route №9 is 1.66 hours, and the duration of the voyage of the existing bus route №7 is 1 hour.

The number of flights that is required for the smooth operation of urban passenger transport is calculated by the formula 2:

$$n_{\text{p}} = \frac{Tm}{Tp}, \qquad (2)$$

where $Tm$ – time on the route (for the city of Ternopil $Tm = 17\ hours$),
$Tp$ – the duration of the routes.

Calculate the optimal number of routes for the existing trolley route №9 for (2):

$$n_{\text{p}} = \frac{17}{1{,}66} = 10\ routs$$

Calculate the optimal number of routes for the existing bus route number 7 for (2):

$$n_{\text{p}} = \frac{17}{1} = 17\ routs$$

Thus, the required number of routs for the existing trolleybus route number 9 is 10, and the required number of routs for the existing bus route number 7 is 17.

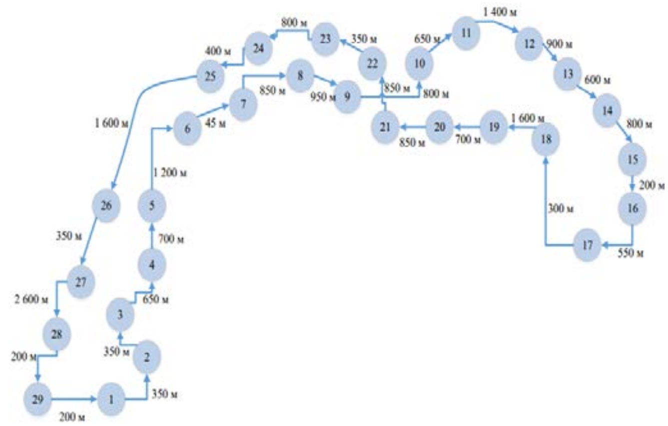

Fig. 1 Active trolleybus route №9

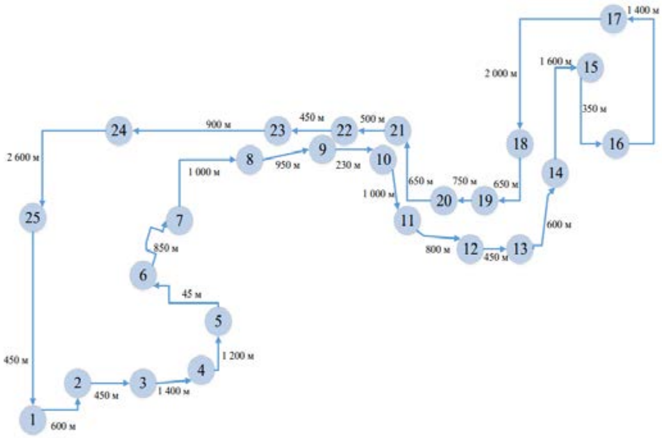

Fig. 2 Active bus route №7

The need to build new optimal routes in the city of Ternopil is due to the fact that a new micro district is being built, which will provide the city with a large passenger traffic (approximately 43 284 people/month). This is due to the fact that in the "Warsaw neighbourhood" will be built: a large sports complex and swimming pool, shopping and entertainment centre, a new bus station, multi-level parking, houses, school and kindergarten.

It should be emphasized that for the laying of routes in the area, it is necessary first to lay 750 m road and 1850 m contact network. It will bring the city's expenses in the amount of 6008000 UAH. However, these costs will quickly pay off.

Imagine a new trolleybus route №9A (see Figure 3) in the form of a graph. Having analyzed Figure 3, it can be argued that the new trolleybus route №9A contains 29 stops, and its length is 20,755 km.

Imagine a new bus number 7 (see Figure 4) in the form of a graph. After analyzing Figure 4, it can be argued that the new bus № 7 has 27 stops, and its length is 20,435 km.

Calculate the duration of the route of the new trolley route №9A for (1):

$$Tp = \frac{20{,}755}{0{,}9 \cdot 25} + 29 \cdot 0{,}02 + 0{,}11 = 1{,}62h\,.$$

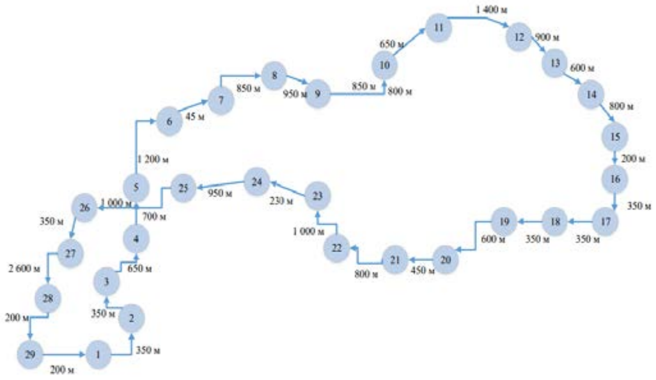

Fig. 3 New optimized trolleybus route №9A

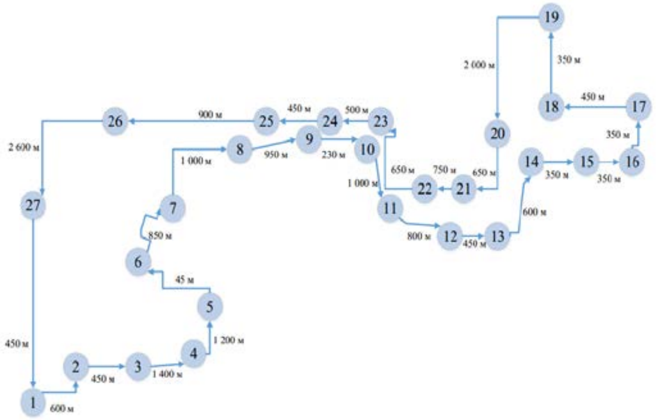

Fig. 4 New optimized bus route №7

Calculate the duration of the routes of the new bus route number 7 for (1):

$$Tp = \frac{20{,}435}{0{,}9 \cdot 25} + 29 \cdot 0{,}02 + 0{,}11 = 1{,}6\ h.$$

Thus, the duration of the route of the new trolley route №9A is 1.66 hours, and the duration of the flight of the new bus route №7 is 1 hour.

Calculate the optimal number of routes for the new trolley route №9A for (2):

$$n_{\text{p}} = \frac{17}{1{,}62} = 11\ routs$$

Calculate the optimal number of $routs$ for the new bus route №7 for (2):

$$n_{\text{p}} = \frac{17}{1{,}6} = 11\ routs$$

Thus, the required number of $routs$ for the new trolley route № 9A and the new bus route №7 is 11.

Determine the planned volume of passenger transportation per day:

$$Q_{daily} = \frac{Q_{\text{p}}}{D_c}, \tag{3}$$

where $Q_{\text{p}}$ – is the volume of passengers transported per year;

$D_c$ – calendar number of days in a year.

Planned volume of passenger traffic per day with new optimal routes:

$$Q_{daily} = \frac{43\ 284 \cdot 12}{365} = 1\ 423\ pass.$$

Determine the daily passenger traffic by the formula:

$$\text{P}_{daily} = Q_{daily} \cdot l_{med}, \tag{4}$$

where $l_{med}$ – is the average distance over which the passenger overcomes (for the city of Ternopil $l_{med} = 2\ km$).

$$\text{P}_{daily} = 1\ 423 \cdot 2 = 2\ 846\ pass.km$$

The coefficient of variability of passengers is determined by the formula:

$$\eta_v = \frac{lm}{l_{med}} \tag{5}$$

Determine the coefficient of passenger variation for the new trolley route No. 9A:

$$\eta_v = \frac{20{,}755}{2} = 10{,}38$$

Determine the coefficient of variation of passengers for the new bus number 7:

$$\eta_v = \frac{20{,}435}{2} = 10{,}22$$

Determine the maximum daily productivity of vehicles:

$$W_Q^{max} = q \cdot Y_{max} \cdot n_p \cdot \eta_v,$$

where q is the nominal capacity of the vehicle (the "Etalon" bus is 42; the trolleybus "14Tr" is 100; the trolleybus "15Tr" is 172);

$Y_{max}$ - coefficient of passenger capacity utilization (for the city of Ternopil $Y_{max}$= 0,5).

Since, in Ternopil there are two types of trolleybuses with different passenger capacity, we will determine the maximum daily productivity for each of them with the help of (6).

For trolleybus "14Tr" of the new trolley route №9A:

$$W_Q^{max} = 100 \cdot 0{,}5 \cdot 11 \cdot 10{,}38 = 5\ 709\ pass.$$

For trolleybus "15Tr" of the new trolley route №9A:

$$W_Q^{max} = 172 \cdot 0{,}5 \cdot 11 \cdot 10{,}38 = 9\ 820\ pass.$$

For the bus "Etalon" of the new bus route number 7:

$$W_Q^{max} = 42 \cdot 0{,}5 \cdot 11 \cdot 10{,}22 = 2\ 361\ pass.$$

Determine the required number of vehicles:

$$\text{A}_{\text{pc}} = \frac{Q_{daily}}{W_Q^{max}} \tag{7}$$

For trolleybus "14Tr" of the new trolley route №9A:

$$\text{A}_{\text{pc}} = \frac{1\ 423}{5\ 709} \approx 1\ \text{trolleybus}$$

For trolleybus "15Tr" of the new trolley route №9A:

$$\text{A}_{\text{pc}} = \frac{1\ 423}{9\ 820} \approx 1\ \text{trolleybus}$$

For the bus "Etalon" of the new bus route number 7:

$$\text{A}_{\text{pc}} = \frac{1\ 423}{2\ 361} \approx 1\ \text{bus}$$

So, for optimal operation of the transport in the "Warsaw district" it is expedient to launch 1 bus "Etalon", 1 trolley bus "14Tr" and 1 trolley "15Tr".

We will calculate what revenue will get vehicles per day for this multiply the maximum performance of the vehicle by the fare in it:

For trolleybus "14Tr" of the new trolley route №9A:

$$\text{Revenue} = 5\ 709 \cdot 3 = UAH\ 17\ 127\,.$$

For trolleybus "15Tr" of the new trolley route №9A:

$$\text{Revenue} = 9\ 820 \cdot 3 = UAH\ \ 29\ 460$$

For the bus "Etalon" of the new bus route number 7:

$$\text{Revenue} = 2\ 361 \cdot 4 = UAH\ 9\ 444$$

The total revenue that vehicles will receive per day is UAH

56030. However, taking into account the privileged travel, it will amount to UAH 47626.

Develop a visualization of the transport system and interactive surveillance, which will allow you to see the traffic of vehicles on the route in real time from stop to stop.

This interactive model will, unlike the existing ones, automatically take into account the location of the vehicle on the route, and will also provide instant detection of deviations from normal traffic.

The interactive transport network, constructed taking into account the adjusted routes for the new "Warsaw" district in the city of Ternopil, is presented in Figures 5 and 6.

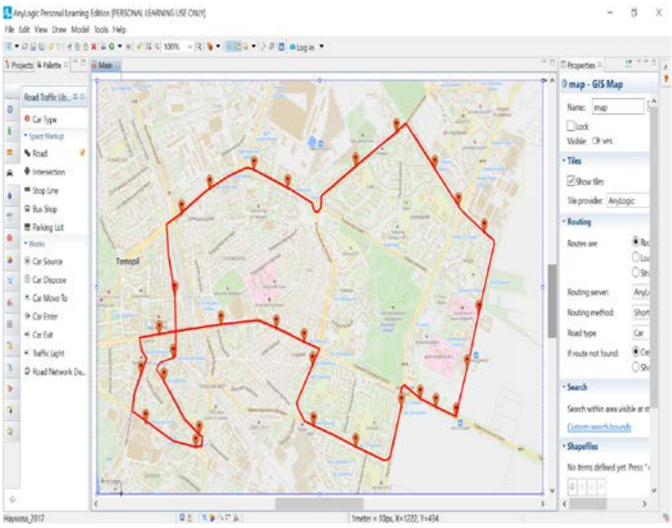

Fig. 5 Interactive transport network of optimized trolleybus route №9

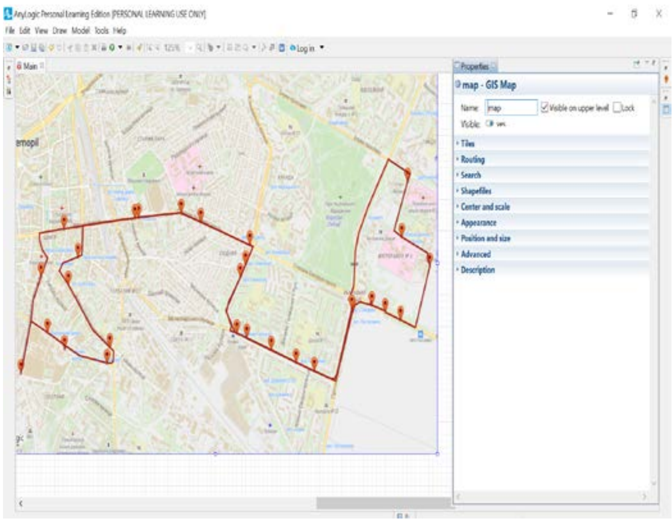

Fig. 6. Interactive transport network of optimized bus route №7

The constructed model of the interactive transport network can be used as a tool for developing new and improving existing urban passenger transport routes. It allows you to predict the number of vehicles on the route, the length of routes, the intervals between vehicles. It also allows you to take into account speed mode and change of traffic rules (for example, the appearance of new road signs on routes).

## III. Conclusion

As a result of the research carried out, the visualization of the transport system and interactive surveillance, which allows you to see the movement of vehicles on the route in real time from stop to stop.

This interactive model will, unlike the existing ones, automatically take into account the location of the vehicle on the route, and will also provide instant detection of deviations from normal traffic.

An interactive transport network, built on tailored routes for a new micro district in the city of Ternopil.

The constructed model of an interactive transport network can be used as a tool for developing new and improving existing urban passenger transport routes. It allows you to predict the number of vehicles on the route, the length of routes, the intervals between vehicles. It also allows you to take into account speed mode and change of traffic rules (for example, the appearance of new road signs on routes).

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