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Optimization of the tourist route by solving the problem of a salesman

Vladimir Shinkarenko¹, Sergii Nezdoyminov¹, Svetlana Galasyuk¹, Larysa Shynkarenko²

¹*Odessa National Economic University, Odessa, Ukraine, 2072945@gmail.com*

²*International Humanitarian University, Odessa, Ukraine, shinkar@te.net.ua*

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Abstract. The article is devoted to the problem of constructing the optimal transport route of a bus excursion tour of a tour operator according to the minimal length criterion. Transportation expenses are an important part of a bus tour cost, and their minimization is a required condition for route development and planning. To solve this problem, the authors

used the tour route calculating method as a kind of transport task, namely the task of the salesman. To solve this problem, one of the varieties of the transport problem, namely the salesman traveling problem, is applied. The essence of the traveling salesman problem is to find the shortest route between cities, if the distances between them are known. The beginning of the route and its end coincide, that is, the route is cyclic. The most popular in Ukraine sightseeing tours of tour operators to the Transcarpathian region are taken for the optimization. A mathematical model of the traveling salesman problem is made to construct an optimal transport route. The solution was found using the Microsoft Excel's Solver add-in application program package. To solve the problem by this method, it was reduced to a special form and additional variables were introduced. The analysis helped the tour operator to check the existing sightseeing bus routes by the minimal length criterion. The results allowed making assumptions about the need to change some popular routes of Ukrainian tour operators in order to reduce transport costs. The method of bus tours evaluation of tour operators according to the minimal length criterion allows to check the tourist transportation optimality while planning the route and developing their own tourist product. The introduction of modern digital technologies and software to optimize the territorial organization of tourist routes is proposed, which will help tour operators of Ukraine in the design of bus tourist trips to nature and recreational locations in tourist regions. The development of an optimal model for the transportation of tourists on the highways and the reduction of their costs for consumption of transport services will contribute to the development of tourist trips in Ukraine. The necessity of using methods of geolocation of tourist resources for the construction of routes for visiting natural and cultural-historical monuments and tourist centers has been determined. The application of the proposed method will allow tour operators to reduce transport costs and, as a consequence, the total cost of the tourist product.

Keywords: tourist route, Transcarpathian region, tour operator, traveling salesman problem, optimization, solution search

Оптимізація туристичного маршруту за допомогою вирішення завдання комівояжера

В. Шинкаренко¹, С. Нездоймінов¹, С. Галасюк¹, Л. Шинкаренко²

¹*Одеський національний економічний університет, Одеса, Україна, 2072945@gmail.com*

²*Міжнародний гуманітарний університет, Одеса, Україна, shinkar@te.net.ua*

Анотація. Стаття присвячена проблемі побудови оптимального транспортного маршруту автобусного екскурсійного туру туроператора за критерієм мінімальної довжини. Транспортні витрати є важливою складовою вартості автобусного туру, їх мінімізація є необхідною умовою при розробці та плануванні маршруту. Для вирішення зазначеної проблеми авторами застосовано метод розрахунку руху маршруту туру як різновиду транспортної задачі, а саме завдання комівояжера. Сутність задачі комівояжера полягає у знаходженні мінімального маршруту між містами, якщо відомі відстані між ними. Початок маршруту та його закінчення співпадають, тобто аналізований маршрут циклічний. Для оптимізації маршруту взято найпопулярніші в Україні екскурсійні тури туроператорів у Закарпатський регіон. Для проектування оптимального транспортного маршруту побудовано математичну модель задачі комівояжера. Розв'язок задачі знаходився за допомогою прикладного пакету «Пошук рішення» електронних таблиць MS EXCEL. Для вирішення задачі зазначеним методом її було зведено до спеціального вигляду і введено додаткові змінні. Проведений аналіз надає змогу туристичному оператору перевірити наявні туристичні автобусні маршрути за критерієм мінімальної довжини. Отримані результати дозволили зробити припущення щодо необхідності зміни напрямків руху деяких популярних маршрутів українських туроператорів з метою зменшення транспортних витрат. Розроблена методика оцінки автобусних турів туроператорів за критерієм мінімальної довжини шляху, дозволяє перевірити оптимальність

перевезення туристів при плануванні маршруту та розробки власного туристичного продукту. Запропоновано впровадження сучасних цифрових технологій та програмних продуктів щодо оптимізації територіальної організації туристичних маршрутів, що допоможе туроператорам України в проектуванні автобусних туристичних подорожей до природно-рекреаційних локацій в туристичних регіонах. Проведені дослідження будуть сприяти розробці оптимальної моделі транспортування туристів на автошляхах. Визначено необхідність використання методів геолокації туристичних ресурсів для побудови маршрутів щодо відвідування природних та культурно-історичних пам'яток, туристичних центрів. Практичне застосування запропонованого методу дозволить операторам зменшити транспортні витрати та, як наслідок, загальну вартість туристичного продукту.

Ключові слова: туристичний маршрут, Закарпатський регіон, туроператор, завдання комівояжера, оптимізація, пошук рішення

Introduction. The increase in competitiveness between enterprises rendering tourist services is of great importance for the economic growth of the regions in the context of international integration of the tourism market. Competing with each other, tour operators are looking for new ways to meet the needs of tourists, while trying to use optimally available natural and material resources. In 2018, the number of tourists in Ukraine has increased more than one and a half times compared to 2016. In 2018, tour operators and travel agencies provided services to more than 4 million 557 thousand people. The Travel and Tourism Competitiveness Index of Ukraine has raise by 10 positions, ranking 78th place (Ukraine has improved its position in rating among the most attractive countries for tourists in 2019).

Transport services are an integral part of the tourism industry. The quality and comfort when traveling significantly affect the overall impression of a tourist from vacation. The idea of scientific consideration of the tourism impact belongs to the Swiss scientist W. Hunziker (1972), who believes that tourism is a set of relationships and phenomena that result from the movement of people and their stay outside their place of residence, when staying is not a permanent place of residence and is not linked to earning a profit. Further development of the research field of transport tourist traffic is acquired in the works of Claude Kaspar (2018). The English scientist John R. Walker believes that the history of tourism development as a whole is divided into two parts: the first - to the appearance and use of transport mass modes; the second - after their appearance, which in turn consists of separate stages according to the emergence of new types of vehicles, namely: the railways age, the cars age, the jet aircraft age and the cruise age on seagoing ships (Walker 2009). The researchers analysed the experience of the development of geotourism destinations, which has become the new global phenomenon in recent years (Kaygili, Sinanoglu, Aksoy, & Sasmaz, 2018).

Ukrainian scientists draw attention to the infrastructural support for the development of the potential of the sphere of recreational services and

tourist trips (Kiptenko et al., 2017; Nezdoyminov, Milashovska, 2019), the creation of geo-information systems of tourist destination for the infrastructure of highways and tourist locations (Matviychuk, Lepky, Kostenko, 2016). Researchers made analysis of the transport network for tourism development in the western region of Ukraine (Grytsevych, Podvirna, Senkiv, 2019). Studies of the passenger traffic in 2018 in Ukraine shows that road passenger transportations reduced by 5.6% to 1 906.9 million passengers compared to 2017, passenger turnover decreased by 2.5% to 34.611 billion passenger-km due to deterioration of the fleet of carrier vehicles and increase of transportation tariffs. Passenger transport services were used by 4486.7 million passengers, or 96.5% from 2017 (Statistical yearbook: Transport and Communication of Ukraine – 2018, 2019).

There are a number of objective and subjective contradictions in the transport services market: between the quantitative load of transport flows and tourist destinations; between the concentration of passenger flows and the time interval; between the cost of transport services and the pricing policy of tourist operators; between the existing road transport infrastructure and the tourist transportation speed. This work is devoted to one of the methods of eliminating these contradictions.

Rail and road transport dominates in short-distance passenger traffic. There is a great demand among Ukrainian tourists for bus tours, which allow to view tourist sites, cultural monuments and terrain directly along the route and excursions. A tour operator charts a tourist route according to the following criteria: minimizing the time spent on moving between the main points of the route and ensuring maximum information of the trip. The scheme of this routing is called “the traveling salesman task”.

The traveling salesman task is a partial case of the General transport task formulated for the first time by G. Monge (1781). The mathematical model of the problem was formulated by F. Hitchcock (1941), for the first time an algorithm for solving the problem was given in the works of G. Dantzig (1951). Despite the known general methods of solving transport

problems, their practical application requires the development of new methods for finding the initial and optimal solutions. Thus, the work of Padmabati and Monalish (2017) provides a method of approximation and approximate calculation of the optimal solution in problems of sufficiently large size with a fuzzy income function. Modern scientists have proposed an algorithm for creating a travel route using a traveling salesman problem (TSP) and k-means clustering method to develop a web application that will help travellers to plan their route (Rani, Kholidah, Huda, 2018). The development of travel routes based on visitor profiles, distances and travel costs is explored in the paper (da Silva, Morabito, Pureza, 2018), solved the problems of optimizing the route of the “day tour” (Mao, 2019). The authors consider the problems of forming a single cloud architecture to manage a variety of multimedia content of tourist destinations routes (Pierdicca, Paolanti, Frontoni, 2019), to build routes for visiting the monuments, the researchers propose to use the methods of graph theory with the use of modern information technologies (Mikhailov, 2019). A study of classical heuristics methods for solving transportation problems was carried out in the work of Polish scientists (Szwarc, Boryczka, Twaróg and Szoltysek, 2019).

It is worth noting that in the scientific literature there is no single approach and a common algorithm for the process of constructing the itinerary of the tourist tour and evaluation of its optimality. The urgency of solving these issues defined the choice of the topic of our study, determined its purpose and objectives.

The aim of the article. The purpose of the article is to develop technological and management decisions to optimize the geographical route of tourist’s transportation by the method of “traveling salesman” as one of the tools for solving problems of tourist transportation by motor transport. On the basis of this research, to determine the optimal algorithm of transportation of tourists on the regional highways of Ukraine, which will help to reduce the expenses of the trip organizer for transport services, to build schemes of routes to natural and cultural-historical monuments, tourist centres.

Material and methods of research. To determine the route of bus travel between territorial tourist locations and to form an optimal transport route, a mathematical model of the traveling salesman problem was constructed. The solution was found using the Microsoft Excel’s Solver add-in application program package. To solve the problem by this method, it was reduced to a special form and additional variables

were introduced. The methods of estimation of bus tours of tour operators according to the criterion of the minimum length of the path are used, which allows to check the optimality of transportation of tourists when planning a route and developing a tour operator own tourist product.

Results and analysis. In general, the traveling salesman problem can be formulated as follows. A salesman must visit n cities. The distances between these cities are known. It is necessary to build a route with a minimal total length of travelling. The mathematical model of the problem has the following form:

$$f(x) = \sum_{i=1}^n \sum_{j=1}^n c_{ij} \cdot x_{ij} \rightarrow \min$$

$$\sum_{j=1}^n x_{sj} = 1, (s = \overline{1, n}), \quad \sum_{i=1}^n x_{si} = 1, (s = \overline{1, n}),$$

$$x_{ij} \in \{0;1\}, (i = \overline{1, n}; j = \overline{1, n}), \quad (1)$$

where $c_{ij}, (i = \overline{1, n}; j = \overline{1, n})$ – the distances matrix elements between cities,

$x_{ij} \in \{0;1\}, (i = \overline{1, n}; j = \overline{1, n})$ – the distances matrix elements of the route.

Scientists have developed quite effective methods of solving this problem. The most common method is a complete and random selection of routes. More advanced versions of these methods are the algorithms of Dijkstra (1959), Little et al. (1963), elastic mesh and others. The development of computer technology and software has allowed to obtain the so-called metaheuristic optimization methods, the most famous of which are Hopfield neural networks (Hopfield, 1982) and the ant colonies algorithm, proposed by the Belgian researcher Marco Dorigo (1997), the Lin-Kernighan-Helsgaun algorithm (Helsgaun, 2014). Modern researchers consider a heuristic approach to the development of individual tourist routes for heterogeneous tourist groups (Zheng, Liao, 2019) and propose heuristic algorithms in the process of solving the transport problem using the Modified Distribution Method (MODI).

The ant colony optimization algorithm is based on the following assumptions: the number of graph vertices is equal to the number of ants; each ant begins its path from its graph vertices (its city); to the beginning of the movement the pheromone the intensity is the same; the choice of the first vertex is determined by the distance minimization rule, and each subsequent one by the rule

$$P_{ij,k}(t) = \frac{[\tau_{ij}(t)]^\alpha \cdot [1/c_{ij}]^\beta}{\sum_{j \in J_{i,k}} [\tau_{ij}(t)]^\alpha \cdot [1/c_{ij}]^\beta}, j \in J_{i,k}; P_{ij,k}(t) = 0, j \notin J_{i,k}, \tag{2}$$

where $\tau_{ij}, (i = \overline{1, n}; j = \overline{1, n})$ – the number of pheromones on the path (i, j) at time t , that is, the attractiveness of the path (i, j) for an ant; α, β – parameters that specify the trail of the pheromone;

$J_{i,k}, (i = \overline{1, n}; k = \overline{1, n})$ – the cities visited by an ant k , which is in the city i .

The ant colony optimization algorithm is probabilistic and can be programmed in most application packages. The vehicle route construction is carried out step by step by selecting the next point until all cities are traversed. The ant selects the next city from the list of available cities, after which the target function is updated, and changes occur in the list of cities available for visiting. Then the available city is selected again. The ant returns to the original city in case of passing all the cities. The route total length is calculated as the target function value of the complete route that the ant has travelled. The use of ant algorithms is highly effective in the case of a large number of cities to visit.

The algorithm for solving the traveling salesman problem using Microsoft Excel’s Solver add-in application program package is also an effective tool. For this purpose, the problem (1) is reduced to the form

$$f(x) = \sum_{i=1}^n \sum_{j=1}^n c_{ij} \cdot x_{ij} \rightarrow \min$$

$$\sum_{i=1}^n x_{sj} = 1, (j = \overline{1, n}), \quad \sum_{j=1}^n x_{sj} = 1, (i = \overline{1, n}), \tag{3}$$

$$u_i - u_j + (n - 1)x_{ij} \leq n - 2,$$

$$x_{ij} \in \{0; 1\}, (i = \overline{1, n}; j = \overline{1, n}),$$

Additional variables u_i, u_j are needed to avoid the so-called cyclic routes, that is, the traveling salesman arrives in each city only once and there are no return routes.

One of the most popular tours “Warm Weekend: Transcarpathian region and Thermal Waters” was chosen to check the optimality of the tourist transportation route. The tour program is available on the official website of one of the largest Ukrainian tour operators “Accord Tour” (<https://www.accordtour.com/tours/1118340/>). The route covers favorite places of rest, cultural monuments and ancient fortresses of

the Ukrainian Carpathians and Transcarpathian region and is composed as follows: Lviv – Mukachevo – Koson – Synevyr Lake – Shypit Waterfall – Borzhava – Uzhhorod – Karpaty (palace of Counts Schoenborn) – Lviv. The tourist sights and locations of the tour route are shown in Fig. 1.

Along the route, tourists are offered a visit to the thermal pools. The construction of a unique thermal natural resort in the Berehiv region began in 1988. Later, the first “Twin Baths” were built there, which were a copy of the Eger Thermal Baths (Hungary). Over time, the complex “Kosyno” began to receive actively tourists from different cities of Ukraine and Europe. The bus tour route also includes Synevyr Lake, which is fairly considered the most valuable natural treasure of the National Park having the same name and one of the visiting cards of the Ukrainian Carpathians. It is located at an altitude of 989 m above sea level. The scheme of the bus route of the “Accord-tour” tour operator is shown in the figure 2.

A task to substantiate a route scheme optimization for a tourist trip can be solved on the basis of the geo information systems. The table which indicates the distance between the points of tourist movement is created to determine the route total length, using the Google map of the specified area. According to table 1, the total length of the tourist route is 987 km.

We will check the route optimality with the help of the Microsoft Excel’s Solver add-in application program package. Figure 3 shows a MS EXCEL worksheet with the problem solution.

The results obtained with the help of the “Solution Search” show that the route planned by the tourist operator is not optimal in terms of the shortest distance. The minimal route length was found: Lviv - Shypit Waterfall - Synevyr Lake - Borzhava - Koson - Uzhhorod - Mukachevo - Karpaty (palace of Counts Schoenborn) - Lviv. A plan of this 771 km route is shown in the figure 4. It should be noted that transportation on the found route will significantly reduce the transportation costs for the organization of the tour and provide tourists with accommodation facilities in the village Koson. The obtained optimal route is 216 km shorter than the original one. It should be noted that transportation by the found route will significantly reduce transport costs for the tour organization. For example, according to technical specifications, the gasoline consumption for the Neoplan Euroliner at 60 km / h per 100 km is 26 liters. The average cost of purchasing gasoline for 216 km is 1460 UAH in prices as of 01.02.2020. According to the official site of the tour operator “Accord-tour”, it is planned to conduct 22 routes on this route in 2020. According to



Fig. 1. Tourist sights and locations of Transcarpathian region Resource: <http://ruraltourism.com.ua/index3.php?a=viewoblast&id=21>

our calculations, the annual cost of the tour operator at the expense of fuel savings on route optimization can be reduced by 32124 UAH.

An example of the route optimization of the popular bus tour “Warm Weekend: Transcarpathian region and Thermal Waters” of the Accord Tour showed

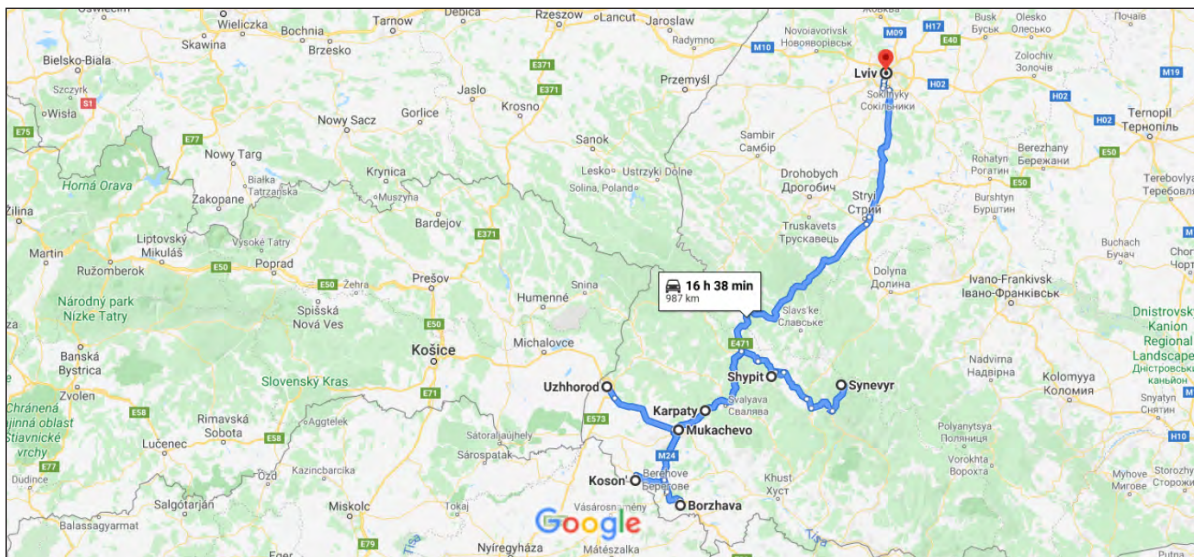


Fig. 2. The bus route plan of the tour “Warm Weekend: Transcarpathian region and Thermal Waters” Resource: prepared by the authors according to the scheme of the tour operator “Accord-tour” and using the image Google Maps (<https://www.google.com/maps>)

Table 1. The distance between cities of the tourist route

Cities / points	Lviv	Mukachevo	Koson	Synevyr Lake	Shypit Waterfall	Borzhava	Uzhhorod	Karpaty (palace of Counts Schoenborn)
Lviv		229	264	252	198	270	267	213
Mukachevo	229		43	136	82	44	41	17
Koson	264	38		177	123	33	63	58
Synevyr Lake	252	136	177		60	141	175	121
Shypit Waterfall	198	82	123	60		124	121	67
Borzhava	270	44	33	141	124		80	59
Uzhhorod	267	41	63	175	121	80		56
Karpaty (palace of Counts Schoenborn)	213	17	58	121	67	59	56	

Resource: prepared by the authors using the Google Maps (<https://www.google.com.ua/maps>)

that operators do not always construct the shortest route. We have tested several more tours of domestic tourism on the minimum distance criterion. Drawing up the salesman’s problem and its solutions helped to conclude that:

- the total minimal distance criterion is achieved for most circular routes;
- radial routes, i.e. routes with a base departure point for daily excursions, do not meet the criterion of minimizing transport costs;

points in the further development. For example, it is possible to optimize the route of tourists within the city of Mukachevo, etc.

The modern development of the tourist industry and the organization of itinerary tours require the search and use of various types of software technologies working with graphical information, geoinformation systems and provide extended spatial GIS analysis. For example, the ArcGIS Online World Routing Service module also programs and solves the prob-

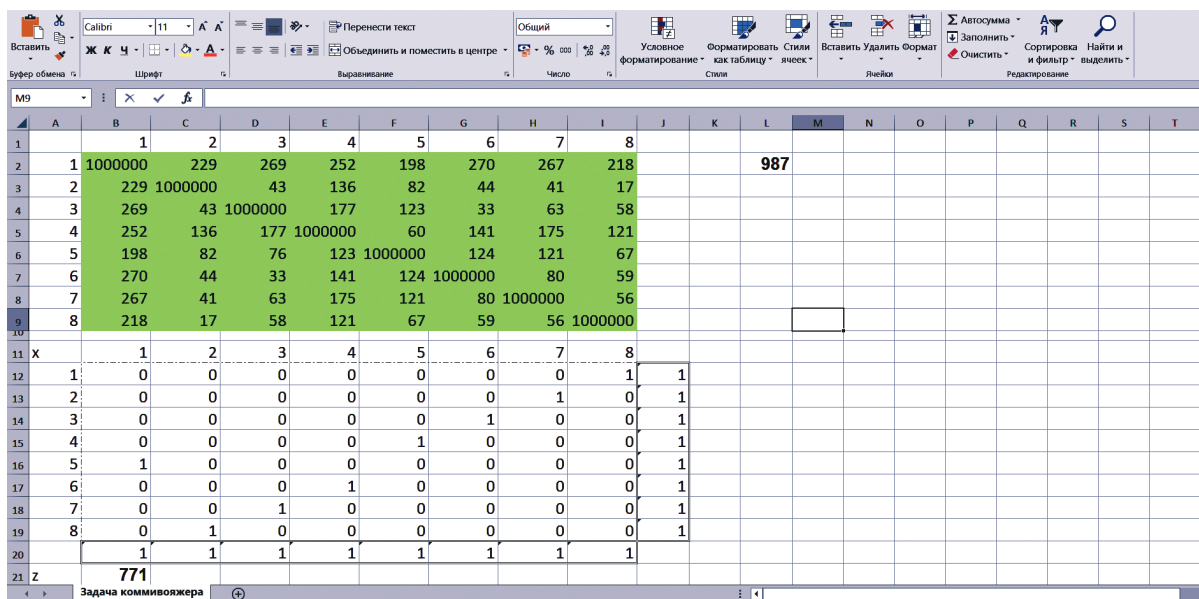


Fig. 3. Solving the traveling salesman problem with the help of the “Solution Search” package

Resource: prepared by the authors using the “Solution Search” package

- some of the combined routes are also not optimal in the sense of achieving the shortest overall route length.

There are other potential areas where the considered route can be optimized. Thus, in the optimization of tourist routes, it is advisable to analyze the movement of tourists within the studied geographical visit

lem of building the shortest route. Minimizing the total transport costs of the tour operator for the tourist transportation is an important component of the tourist route planning. However, there are a number of restrictions related to the tour intensity, the cost and quality of accommodation, the comfort of travel. The tourist transportation logistics requires a comprehen-

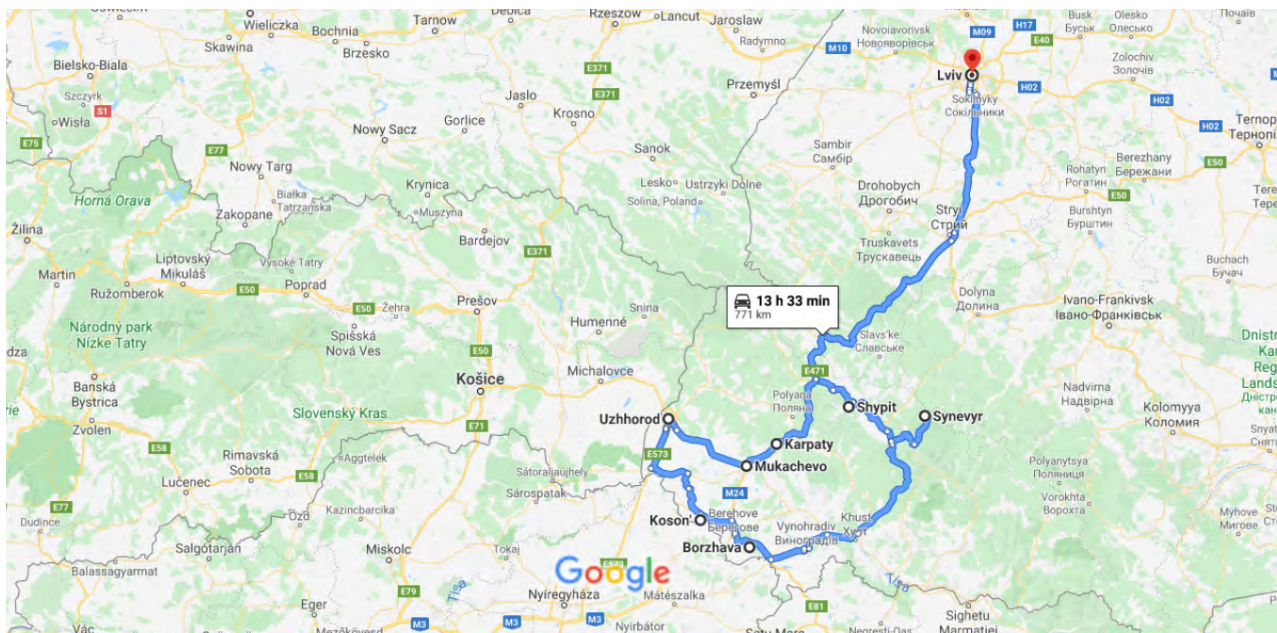


Fig. 4. An optimal scheme of the bus route of the tour “Warm weekend: Transcarpathian region and Thermal Waters”
 Resource: prepared by the authors using the Google Maps (<https://www.google.com.ua/maps>) and “Solution Search” package

sive solution to the problems arising from the tourist operator during the tour route planning. Competitive struggle in the tourist market makes strict conditions to the bus tourist routes organization. The winner in this fight is the operator that better uses modern geo-information systems, business planning technologies, marketing strategies, analysis of consumer demand and preferences, and so on. It should be noted that the organization of tourist trips on the internal highways of Ukraine, will promote the introduction of modern digital technologies to optimize the territorial organization of tourism and will assist the tour operators of Ukraine in the design of bus geotourism routes to the historical, cultural and nature-recreational sites.

Conclusions. The authors have proved that the design of bus routes by tourist operators according to the programs of visiting and acquaintance with cultural heritage, natural and recreational resources in the regions of Ukraine require the use of modern digital technology tools to optimize the traffic of tourists. The article considers the bus tours evaluation method by the minimal route length criterion. This criterion significantly affects the total cost of the tourist transportation and is important while planning a tour. It is proved that the circular routes meet the minimal length criterion, and radial, on the contrary, do not meet. To estimate the smallest distance between cities of tourist movement the linear programming theory, namely, the traveling salesman problem was applied. The solution was found using the Microsoft Excel’s Solver add-in package. The obtained results support and complement the algorithm of bus tour route estimation to improve the competitiveness of the tour operator’s product, as pro-

posed in studies on the development and evaluation of tourist routes (Friggstad et al., 2018).

The next stage of the logistic analysis of tourist bus routes is to check the optimality of the international tour routes in European cities. As the size of the problem will increase significantly, it is necessary to apply the ant spatial GIS analysis and algorithm described in the article for its solution.

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