Branimir MARETIĆ*, Borna ABRAMOVIĆ
University of Zagreb, Faculty of Transport and Traffic Sciences,
Department of Railway Transport
Vukelićeva 4, 10000 Zagreb, Croatia
**Corresponding author*. E-mail: branimir.maretic@gmail.com

THE SPATIAL REORGANIZATION OF AN INTEGRATION TRANSPORT POINT: A CASE STUDY OF THE CITY OF ŠIBENIK

Summary. This paper formulates a specific methodology based on a mathematical model that selects the optimal terminal configuration of individual transport modes within the point of integration of passenger transport. The methodology is applicable for the purpose of analyzing the current situation and proposing improvements to the point of integration of passenger transport. The application of the methodology is presented at the point of integration of different transport modes in the city of Šibenik. As the main parameter in the mathematical model, the time distance required for a certain type of passenger to walk between each individual terminal within the integration point was chosen. Technical and technological criteria that influence the choice of the optimal configuration were evaluated and included in mathematical calculations. By selecting the optimal terminal configuration within the integration point, the preconditions for better integration of transport modes as well as for greater passenger satisfaction will be achieved.

1. INTRODUCTION

Šibenik is one of the oldest Croatian Adriatic cities and the cultural, educational, administrative, and economic center of the Šibenik-Knin County [5]. This means that residents of the entire county gravitate toward Šibenik – from islands in the south and to the hinterland of Knin in the north. For mobility to be functional in and beyond Šibenik, an optimal transport network is required. The existing transport network of the city and the county comprises road, railway, and sea transport. These three fundamental networks merge in Šibenik. There are several methods of transport available on the transport network – cars, buses, taxis, bicycles, rail and boat transport, and walking. As Šibenik is a popular tourist destination, the number of passengers varies. For instance, more passengers arrive in the summer than in the winter [15]. Furthermore, as some passengers continue their journey toward an island or the county's hinterland, transport modes must be integrated. The integration has so far remained largely disregarded; hence, the organization of transport terminals remains the same as it was several decades ago. A terminal is a place at the end of a journey used for the transfer, reception, and dispatch of passengers [3], whereas an integration point or a hub is an element of the urban communication network that ensures interaction between various transport modes and between urban and suburban areas in which the transport service is provided [8]. This study aims to determine the possibility of increasing mobility within an integration point of the transport modes in Šibenik to optimize the time distance for passengers moving between terminals of various transport modes.

2. ON INTEGRATED PASSENGER TRANSPORT

Integrated passenger transport is defined as the system of providing "door-to-door" passenger transport [6]. It is a system of local public transport that includes various transport modes in a single transport network in an area [1]. Integrated passenger transport is an organizational process that connects the elements of transport planning and the elements of creating transport service, irrespective of the transport mode, the service provided, and the institutions, all with the aim of increasing economic and social benefits [11].

Such a system utilizes the benefits of transport modes within the system. The joint organization of the modes largely outweighs the drawbacks of a single transport mode [9]. This type of transport system raises the issue of branched transport.

Organizing integrated transport offers benefits such as reduced travel time due to greater departure frequency, reduced walking time and reduced driving time, and reduced fare and the potential need for using smaller transportation vehicles [13]. It also yields numerous other benefits such as a unified transport ticket, timetable integration, and subsidies for some passenger groups, all while increasing the number of passengers, and thereby, profit. Evidently, such a system requires engaging a huge number of participants, as well as taking into consideration the elements of integration. The foundation of the system are passengers, which is why public transport must consider various passenger profiles. Not all passengers can use the system under the same conditions. For instance, persons with disability and reduced mobility can only use the on-demand transport service from the point of exiting the main route in the integration to their own place of residence [12].

Integrated passenger transport entails several kinds of integration [2]: 1) Physical integration, 2) Network integration, 3) Information integration, 4) Fare integration, and 5) Institutional integration.

Physical integration encompasses the physical construction of the system. Good physical integration ensures easier exchange of passengers between transport modes, greater comfort and passenger safety, as well as accompanying services. Network integration includes the integration of transport network between modes of transport. When passengers depart a network – for instance a railway network – they continue their journey on the road, etc. Fare integration ensures a unified transport ticket. Passengers pay for a single transport fare valid on all transport modes. Institutional integration means aligning and harmonizing legislation and ordinances so that the integration can have maximum impact.

The most important principle of integrated passenger transport is the harmonized network integration because this enables passengers to receive a fast transport service and, in any direction, [16]. Particular attention must also be paid to the integration features, such as accessibility and connection to the urban transportation system [10]. In the literature review of tariffs in integrated passenger transport, it is clear that the most significant feature of urban transport accessibility and connectivity is car and bicycle safety [14].

3. RESEARCH METHODOLOGY

The methodology can be explained in two ways: 1) general and 2) specific. The general methodology does not specify special (local) details of the innovative solutions. The analysis of the existing state encompasses defining the scope, collecting data, and a theoretical overview of the functioning of the system in the scope area. Optimization is a mathematical discipline that is used to determine the best quantitative solution [7]. Based on the quantitative result, the best proposal for the innovative solution will be determined.

The optimization methodology, which follows three steps, was described in another part (2). The first part of the analysis is the time distance between the railway and bus terminals and the port. The data for this part are collected by taking measures in the field. The collected data will then be used to create matrices, which will determine the minimum and maximum time distance between the terminals and the port.

In the second optimization step, the time–distance data will be analyzed in the spatial context (horizontal and vertical). The data on the spatial features of each station and port will also be gathered and used to analyze the impact of space on time distance. The end of the second step will also help to determine which station or port deviates from others in some aspects or another. This is what determines the process of the third step, which is a consideration of the technical or technological adjustment possibility. Optimization with and without spatial relocation will also be considered. While creating the solution proposal, the obtained and lost features will also be analyzed. Finally, a comparative analysis will be used to evaluate the proposed solutions.

A mathematical optimization model is constructed. Let $N \in N$ be the number of points in the optimization model and let each point denote a transport terminal. Each point can be found on various positions. Let point 1 be assigned with k_1 possible positions and point 2 with k_2 possible positions, that is, point N with k_n possible positions. This means that the system of points is available in various configurations. First, we will examine how many different combinations there are, that is, how many configurations of point systems are possible. This is obtained using the fundamental counting principle (Eq. 1), in which the total number of system configurations Ω is expressed as:

$$\Omega = k_1 k_2 \ldots k_N = \prod_{i=1}^{N} k_i \qquad (1)$$

After the counting, the optimal configuration is determined. The optimization model will be carried out based on the time distance of walking between terminals. Therefore, the aim is to obtain the optimal point configuration so that the total walking time between the points is as little as possible. $t_{i_l i_k}^{lk}$ stands for the time distance, in which the higher indices denote the points between the time distance measured, while the lower indices i_l i i_k denote the potential position in which these points are found (e.g., t_{34}^{12} denotes the time distance between points 1 and 2, where point 1 is in its 3rd possible position, while point 2 is in its 4th possible position). The sum of the total walking time between all points of a given configuration (Eq. 2), in which point 1 is in position p_1, point 2 in p_2, … and point N in p_N, is:

$$L_{p_1 p_2 \ldots p_N}(p_1, p_2, \ldots, p_N) = \frac{1}{2} \sum_{l=1}^{N} \sum_{k=1, k \neq l}^{N} t_{p_l p_k}^{lk} w(p_1, p_2, \ldots, p_N) \qquad (2)$$

where p_1 is one of the k_1 configurations available to point 1 and p_2 is one of the k_2 positions accessible to the second point, that is, p_N which is one of the k_N configurations accessible to the Nth point. To describe additional value services, that is, the additional transport offer, we use $w(p_1, p_2, \ldots, p_N)$ as an additional element that takes into account the "weight" of some integrated passenger terminals. This means that this element can be used to express the preference of one configuration over another due to external criteria. If $w(p_1, p_2, \ldots, p_N)$ is in the sum as a multiplication, the lower $w(p_1, p_2, \ldots, p_N)$ denotes a higher preference of the configuration, but it also denotes $w(p_1, p_2, \ldots, p_N) \in (0,1]$. The analysis will also examine which $p_1, p_2, \ldots, p_N$ results in the minimum L in all possible system configurations (Eq. 3):

$$L = min \{L_{p_1 p_2 \ldots p_N}(p_1, p_2, \ldots, p_N)\}_\Omega \qquad (3)$$

4. THE ANALYSIS OF TRANSPORT MODES INTEGRATION IN ŠIBENIK

The City of Šibenik is connected to the Croatian and European transport systems by road, air, rail, and sea, which has ensured that it is a significant transport position. The connection between the city and its hinterland is ensured by road, rail, and the A1 motorway, which connects Šibenik to the rest of the country and Europe in a more efficient way. The infrastructure and the transport network, as well as the vicinity to two airports, ensure an excellent connection and accessibility to the city. All said, transport modes have terminals for the reception and dispatch of passengers. The bus terminal is located next to the coast of the city. Not far from the terminal, to the south-east, there is the Vrulje pier, which acts as a port for the reception and dispatch of passengers in sea transport. Above the pier, at 50 meters above sea level, is the railway terminal. See Fig. 1.
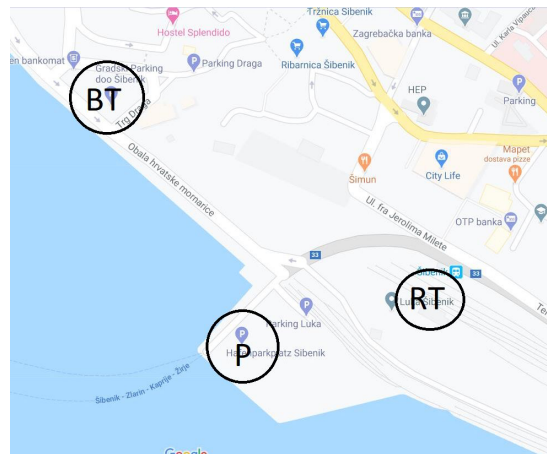
Fig. 1. Terminals on the integration point in Šibenik

The point of integration is designed to allow passengers to walk uninterruptedly between changes of individual transport modes. To properly analyze the existing state, all the types of passengers being analyzed must be known. According to a study [4], three types of passengers were determined:
1. Passengers travelling alone (daily commutes).
2. Passengers with luggage (tourist journeys).
3. Families (parents with children).

The analysis of the journey all of types of passengers between each of the terminals will be performed. The journey times will be measured for each group based on the sample of 10 journeys. Based on the journeys, the average values of the obtained times will be outlined and conclusions will be drawn on the proposals of improvement of the integration point of an area. The time distance between the points will be shown using the time–distance analysis matrix. In the matrix record of the time distances, RT stands for the railway terminal, BT stands for the bus terminal, and P stands for the port.

The analysis of the time distance (Table 1) between elements has established that not one of the time distances from or to the BT is satisfactory. The time distance between the RT and P is also unsatisfactory. The reason is a relatively short air distance between the terminals and the long walking distance, the need for walking around, and having to go through the entire block of streets to reach the destination.

Table 1

The walking time distance matrix according to the current state [mm:ss]

	Passengers			Passengers with luggage			Families		
	RT	**BT**	**P**	**RT**	**BT**	**P**	**RT**	**BT**	**P**
RT	/	7:50	11:40	/	9:15	13:15	/	12:30	16:25
BT	7:50	/	4:00	9:15	/	4:45	12:30	/	5:15
P	11:40	4:00	/	13:15	4:45	/	16:25	5:15	/

Source: Authors

The time–distance analysis in the spatial context reveals that the bus terminal is the reception–dispatch point that should be brought closer to the railway terminal and the port. The bus terminal is cut from the railway terminal by multiple infrastructural obstacles and from the port by micro-infrastructural unevenness. As Šibenik attracts increasingly more passengers each year, the bus terminal capacities are being exceeded and have become unsuitable for all types of passengers. The port and the railway terminal are closer to one another and infrastructurally limited; thus, bringing the

port closer would have a positive impact on the overall integration. Passengers should have the possibility of transferring between transport modes with as few time losses as possible.

5. PROPOSAL FOR INCREASING MOBILITY WITHIN AN INTEGRATION POINT OF TRANSPORT MODES IN ŠIBENIK

Since the analysis has shown that the time distance is unsatisfactory, optimization needs to be carried out. It will entail two technical solutions of carrying out intermodal passenger terminals. It is impossible to implement more than two solutions due to spatial restriction. If the bus terminal is relocated farther in space from the port and the railway terminal, the time distance will increase. This, in turn, allows only two solutions – on the level of the port or on the level of the railway terminal.

The first variant entails relocating the bus terminal to a location next to the port as shown in Fig. 2. The railway terminal would be located at a higher sea level. The port would have an independent passenger maritime terminal that would be a ticket vendor and distributor of accompanying services. The bus terminal would be at a lower sea level and would also have the same kind of facilities. The railway terminal on the upper level would be connected to the lower level via a staircase or escalator placed right next to the bus terminal. The passenger terminal would be located at the same place it is today. The lower level would have a taxi rank, rent-a-car and cycling facilities, and park & ride and kiss & ride systems.

Fig. 2. Variant 1of a transport solution of the integration point in Šibenik

Table 2

The walking time–distance matrix, variant 1 [mm:ss]

	Passengers			Passengers with luggage			Families		
	RT	**BT**	**P**	**RT**	**BT**	**P**	**RT**	**BT**	**P**
RT	/	3:45	5:00	/	4:50	6:05	/	5:15	6:55
BT	3:45	/	2:10	4:50	/	2:35	5:15	/	2:55
P	5:00	2:10	/	6:05	2:35	/	6:55	2:55	/

Source: Authors

Improvements in the second solution variant would be achieved by organizing two levels of an intermodal passenger terminal. The first, lower level would be the maritime passenger terminal. It would use boats, taxies, rent-a-car, public bike systems, and park & ride and kiss & ride systems for receiving and dispatching passengers. The second, upper level would comprise the integrated railway and bus terminal. This terminal would be situated exactly in the middle, right above the tunnel. The upper and lower levels would be connected with escalators and lifts within the terminal building. The upper-level reception and dispatch of passengers would offer services such as taxies, rent-a-car, public

bike systems, park & ride, and kiss & ride. The location is illustrated in Fig. 3. The second variant of the walking time–distance matrix (Table 3) yields better results than the current state and the variant 1 solution.
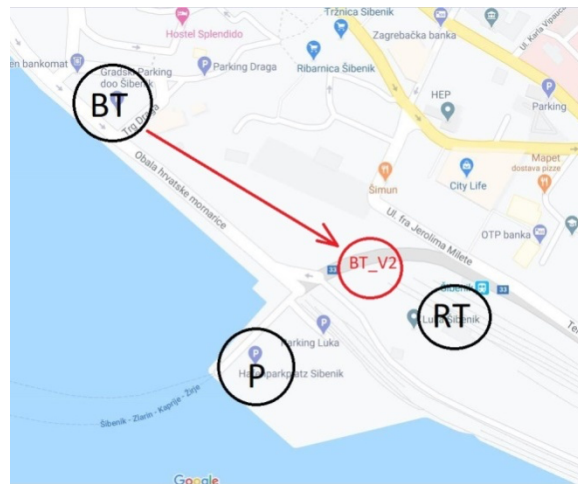

Fig. 3. Variant 2of a transport solution of the integration point in Šibenik

Table 3

The walking time–distance matrix, variant 2 [mm:ss]

	Passengers			Passengers with luggage			Family passengers		
	RT	BT	P	RT	BT	P	RT	BT	P
RT	/	0:55	3:25	/	1:10	3:40	/	1:15	4:00
BT	0:55	/	3:05	1:10	/	3:15	1:15	/	3:35
P	3:35	3:05	/	3:40	3:15	/	4:00	3:35	/

Source: Authors

As time distance cannot be the only criterion for bus terminal relocation, transport and technological factors will be observed, which will add weight to every variant. A comparison is outlined in Table 4. Variant 2 is based on comparable criteria, better than variant 1 and the current state. Therefore, the greatest weight is added to variant 2, which is expressed using the lowest coefficient w from here onward.

Table 4

Comparison between external criteria

Criteria	Current situation	Variant 1	Variant 2
Number of platforms	14	9	min. 14
Rent-a-car	1	1	2
Taxi	6	6	5 x 2
Public bike systems	1 conditionally	1	2
Quick bus stops	2–4	2	min 4
Car parks	1 (capacity)	350 parking spaces	3–4 (capacity)
Luggage storage facilities	0	0	1
Park&Ride	No	Yes	Yes
Kiss&Ride	No	No	Yes
Integrated with urban transport	No	No	Yes, the bus will be relocated to the top of the market

Source: Authors

For selecting the best of the proposed solutions, the model listed in Chapter 3 will be used. Since there are three different cases (passengers, passengers with luggage, and families), the weighted average journey time will be used, which is generally defined as $t = \frac{\sum_i \alpha_i t_i}{\sum_i \alpha_i}$ and in the case of normative coefficients, as $t = \sum_i \alpha_i t_i$. We estimate that the weighted times for passengers, passengers with luggage, and families will be, respectively: $\alpha_1 = 0.1, \alpha_2 = 0.15, \alpha_3 = 0.75$. Based on the model, an analysis was performed, where:

$$k_{AK} = 3; \; p_{AK} \in \{1,2,3\} \tag{4}$$
$$k_{\check{Z}K} = 1; \; p_{\check{Z}K} \in \{1\} \tag{5}$$
$$k_L = 1; \; p_L \in \{1\} \tag{6}$$

Where $\Omega = 3$ was obtained and the coefficient w is the lowest for $p_{AK} = 3$, which means the most preferred weighted position. Calculations of the weight of w are shown in Table 4. Some externally provided transport services criteria were analyzed, as well as additional qualitative services and the integration between terminals and the integration into public transport.

Having done that, the following estimation was made:

$$w(p_{\check{z}k} = 1, p_{ak} = 1, p_l = 1) = 1, \tag{7}$$
$$w(p_{\check{z}k} = 1, p_{ak} = 2, p_l = 1) = 0.95, \tag{8}$$
$$w(p_{\check{z}k} = 1, p_{ak} = 3, p_l = 1) = 0.7. \tag{9}$$

By adding into the latest model calculation (using the weighted average time):

$$L = min \{L_{p_{\check{z}k} p_{ak} p_l}(p_{\check{z}k}, p_{ak}, p_l)\}_\Omega \tag{10}$$

The optimal solution is obtained. By adding the variant 1 values, L equals 13 minutes and 43 seconds. By adding the variant 2 values, the L is 6 minutes and 1 second. The optimal solution is, therefore, variant 2, which has the minimum L.

6. CONCLUSION

For the connectivity between locations to be better, transport modes need to be integrated. The better organization of an integration point, i.e. where a terminal meets transport branches, the better the functioning of the integrated passenger transport. Timetables can be aligned more easily, journey quality from the passenger transport will increase, the transport service offer will be expanded, and the bottlenecks arising from separating terminals into maritime, bus, and railway transport will be reduced. This has been shown in the paper by using the proposed variants. A model was devised to carry out the optimization of integration points, which leads to an increase in mobility. This increase in mobility is seen by enlarging the integration point and reducing the journey time. By adopting the mathematical model used in the article, the optimal system of terminals was selected based on the shortest walking time. Three types of passengers were comparatively analyzed, and the family group was chosen as the optimization-relevant type. The integration point cannot be planned based on a single passenger and thus restrict the future transport offer.

The aim of this case study was to select the optimal configuration of individual terminals within the point of integrated passenger transport using the methodology presented in this paper. The core of the methodology is a mathematical model based on the successive counting theorem, which takes into account the main parameter (in this case time distance) and external criteria (technical and traffic–technological criteria) related to individual terminals within the point of integration of transport modes. The applied methodology will be applicable to any proposed configurations using the selected parameters and external criteria irrespective of which transport mode terminal changes its location.

The results indicate that variant 2 is the better option. Apart from providing more favorable values for time distances, it also ensured better values when compared with external criteria. The methodology used to obtain the solution takes into consideration the base parameter – time distance – as well as the weight of external criteria. The external criteria tip the scales in favor of choosing better solutions in case the base parameters are of equal values. The optimization of time distance between passenger terminals ensures better timetable integration. This, in turn, provides the possibility of

increasing departure frequency due to reduced waiting times (passengers wait to board another transport mode). The research objective was achieved, pointing to the possibility of increasing mobility through the optimization of the time distance between passenger terminals.

Future research should focus on a quantitative determination of the possibility of increasing mobility as a result of reduced waiting times. This could help to determine the potential frequency increase per hour or day when passengers spend less time transferring between transport modes.

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