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LOCATION PLANNING APPROACH FOR INTERMODAL TERMINALS IN URBAN AND SUBURBAN RAIL TRANSPORT

ABSTRACT

The aim of this study is to find a suitable methodology for planning the locations of intermodal terminals in an urban transit context. The location planning approach, which has been developed and makes this possible, consists of three phases. The first phase is the making of the geographic information system (GIS) database which enables determining the potential locations of intermodal terminals. For every potential location of the terminal, the number of citizens gravitating to a certain terminal is calculated, which at the same time represents the output from the first phase of the model. The second phase uses an optimization algorithm in order to determine the locations of the intermodal terminals. The optimization algorithm provides several solutions for a different number of terminals, and such solutions need to be evaluated. The main contribution of this research is in upgrading the location planning approach by introducing an additional step in assessing the solutions obtained by the optimization algorithm.

KEY WORDS

intermodal terminal; GIS database; optimization algorithms; multi-criteria analysis; location planning;

1. INTRODUCTION

The construction of urban rail transit system requires careful planning and significant investments. It is necessary to plan a transportation system that satisfies the existing demand, but also one that will provide adequate level of service in 10, 15 or 20 years and be able to satisfy the newly created demand. The stakeholders in the planning process of the urban transit system (traffic planners, operators, users, carriers, local administration authorities, maintenance engineers and others) often have diverse opinions and conflicting priorities when it comes to the objectives and limitations of the possible solutions. Furthermore, the available data can be unreliable and the costs of construction often exceed the initially planned budgets. This renders the planning and adds complexity to the process of designing the urban public transport network and finding the most suitable solution [1].

According to Vuchic [2], the stations in railway transport represent the infrastructure which requires high investments and their location has a significant impact on the environment. The number and distribution of stations on a line affect the speed of transport, time of transportation, comfort of transportation and operating costs. It can be concluded that finding the optimal location of stations plays an important part in planning urban transit.

In a wider context, planning of the urban transit network design consists of two interconnected elements. The first element is determination of the route of a part of or the entire urban transit network and the second is the determination of the location for stations on the route. In literature there are two approaches; the first one understands the positioning of the so-called main stations that are connected to a route and, parallel with this process, a decision is made on the location of the remaining stations on the route. The second approach is to first locate the route and then position the stations on it [3]. Laporte gives an overview of mathematical models and heuristic methods that can be used to determine the network design [4].

In the following, an overview of studies that refer to determination of route location is provided. Gendreau [1] studied the main criteria that are used while positioning the route as well as the role of the operating research in this process. Laporte dealt with a similar topic and gave an overview of the main methods from the domain of operating research that can solve the problem of siting and the location of stops [3]. Bruno [5] presented a mathematical model and a heuristic method which consists of two phases of siting the route in an urban environment. The paper refers to the algorithm which can generate several good solutions for the location of a route that can be later evaluated/ assessed according to other criteria as well. Laporte

[3] has presented the methodology of siting the route based on the information about origins (O) and destinations (D) of travelling (OD matrix). First, it was necessary to develop a model for the assessment of actual demand between two stops, after which simple heuristics is used for the route design, thus maximizing the trip coverage. The method is applicable to any OD matrix.

Dufourd [6] discusses the problem of siting the metro where it is necessary to locate the route and the stops that need to satisfy the conditions of minimal/maximal interstation distance. The function of the objective is the maximization of the population covered by the route, while the method used is the tabu search.

The problem of positioning the stations/stops can be considered by selecting only one among several potential locations of stations. This approach was implemented by Mohajeri [7], who studied how the decision on the location of the railway station was made. For this purpose, the analytic hierarchy process (AHP) and data envelopment analysis (DEA) have been used. During the research, four groups of criteria divided into 26 sub-criteria have been defined, and the selection was performed among five potential locations. The described approach of the selection methodology is not applicable to the type of problem that is studied in this paper. However, it highlights that the problem of defining the stops/station locations is the optimization one, and depending on how this problem has been defined, i.e., whether it is an NP-hard problem or not, it might be necessary to use meta-heuristic methods that yield solutions close to the optimal ones.

Samanta [8] approached the problem of positioning the stops as an optimization problem by minimizing an objective function (total costs of stops) using the ant algorithm and GIS for the calculation of the trip duration. The GIS database is connected with the optimization algorithm for achieving the optimal solution. Jha [9] studied the problem of positioning the stops on a known route by assuming that the starting and final points are known, and it is necessary to determine the number and location of interstops (interstations) by minimizing the total costs of the users, carriers and costs of the construction of the public transport system. Samanta [10] developed a model of siting the stops by using the objective function such as demand and costs since both parameters influence the planning of a railway line route. The genetic algorithm has been used as an optimization algorithm in combination with the GIS database. The first aim is to minimize the total costs of the system per person that include costs of the users, carriers and locations. The second objective function is the maximization of the population living within the catchment area of the station location.

When the location of the route is known, but the siting of the station/stops needs to be defined, the problem is not much simpler. Laporte [11] studies the problem of siting the station/stops on a new line or a section of a line when the location of the route is known. The stop location is determined by maximizing the population living within the catchment area of the stop (maximizing the total population coverage) by calculating the longest trip in the graph. Yoshikaya [12] solves the issue of stop siting by minimizing the total costs of all the users. The user cost is expressed as a function of distance from the trip origin to the closest stop, trip destination and the respective closest terminal. Furthermore, the authors assume that the location of the route of the public transport, which requires the siting of the stop, is known. Hamacher [13] adds one or several stops on the existing network taking into consideration the closeness of the stop to the population and maximizing the total saving in the trip duration for all the users. Decisions regarding the right locations (a warehouse, for example) have become important strategic decisions that every company must face. In addition to macro and micro aspects that influence site location process, other factors need to be considered, such as: transport links, transport infrastructure, trade in goods and total costs [14].

A stop/station needs to be sited so that it is physically accessible to a significant number of potential users. This raises the question of determining the stop/station coverage area. In determining the catchment areas of stations and stops, the GIS technology has offered a new approach which enables the use of the actual network traffic routes (roads, pedestrian and cyclist paths, tram and bus lines...). Landex [15] also dealt with this issue. If the station/stop can be reached by a passenger car as well, then a park and ride (P&R) system has to be located next to the station/stop. Horner [16, 17] dealt in more detail with the issue of siting a P&R system next to the railway stations/stops.

Sun et al. [18] studied the influence of the catchment area of a station/stop on the user. Sun [18] developed and tested the tools that are meant to objectively measure the conditions of walking on the routes leading to the stop of an urban-suburban railway. If the pedestrian feels safe and the environment is interesting, the users are more prone to walk longer to reach the public transport network. This directly affects the increase of the stop catchment area and raises the competitiveness of public transport in relation to the use of passenger cars.

Cadarso [19] states that, when designing the public transport network, the decision-makers also have to take into account the fact that the potential user will use the network if the total costs are lower in comparison to other transportation options. In other words, the impact of other modes of transport on the user's choice is also significant.

Dewilde [20] has developed a model which, apart from planning the design of the public transport network, also includes the planning of lines, necessary number of vehicles and other values that are usually related to the system capacity. This exceeds the frames of the area of interest of this paper and will not be analyzed.

Through an analysis of the previous studies, one may conclude that the studies are oriented to determining the route location and the respective terminals by using one of the optimization methods. In the majority of cases, the entire problem of research ends after having generated one or several solutions (depending on the type of optimization method). In this paper, the researchers have gone a step further and have considered a set of solutions obtained by the optimization algorithm. These solutions have been pairwise assessed in order to find the one that satisfies the needs of a wider group of stakeholders to the largest extent. For this, the multi-criteria decision method has been used. Furthermore, to achieve this it is also necessary to define an additional set of criteria.

The next section presents the basic problem and the model of terminal location planning, as well as the notation that will be used in the paper. The following section gives a more detailed insight into the model and elaborates the applicability of the model with the description of all the relevant criteria and sub-criteria in the decision-making process. The last section of the paper includes a discussion about the applicability of the proposed model and the concluding remarks.

2. METHODOLOGY

The aim of this research is to find a methodology of planning the location of intermodal terminals. The developed approach can be used for planning the location of a terminal in the case of the construction of a new system of urban public transport, in the case of the need to extend the route of the existing system, as well as in the case of adding one or several terminals on the already existing line. The proposed model consists of three interconnected steps as shown in *Figure 1*.

The input data in the first step of the model are the data about the traffic network of the observed area, the data defined by urban plans and data from the statistical yearbook. The GIS database is used to determine a set of potential locations of terminals. The set of such potential locations is designated by S_L and it can be written down as $S_L = \{1, 2, n_{max}\} \subseteq \mathbb{N}, |S_L| = n_{max}$, where n_{max} is the number of potential locations.

For every potential terminal location, the number of citizens who have access to the terminal is calculated $V(n)$ for $n \in S_L$ in relation to other locations. This represents a set of possible solutions. The optimization algorithm is applied to the set of possible solutions. One solution r, obtained by the optimization algorithm, is acquired by the permutation of elements of set S_L and can be written formally in the following way:

$$r = S_{LF} \cup R^*, \ |r| = b_t \tag{1}$$

$$R^* \subseteq S_L \setminus S_{LF}, \ |R^*| = b_t - |S_{LF}| \tag{2}$$

An algorithm has been developed so that it also recognizes the locations of terminals that have been predetermined, i.e., known prior to the application of the optimization algorithm. These known locations of terminals are called fixed terminals or fixed locations and the set of these locations is noted as S_{LF} and it holds $S_{LF} \subseteq S_L, |S_{LF}| \leq b_t$, where b_t represents the number of terminals that need to be sited. If $|S_{LF}| = b_t$, the solution is trivial.

The objective function assumes the expression $F(r)$ for $r \in R$, where $F{:}R \rightarrow \mathbb{R}^+$, and in this concrete case it can be determined as:

$$F(r) = \sum_{n \in r} V(n) \tag{3}$$

The task of the optimization algorithm is to find the solutions for which $F(r) \rightarrow max$ provided $b_t^{min} \leq b_t \leq b_t^{max}$, $b_t > 0$, $0 \leq d_{min} \leq l_t$, where:

b_t – number of terminals that need to be sited;

d_{min} – minimal distance between two successive terminals;

l_t – length of the railway line route on which the locations of terminals are determined.

The set of all solutions to the problem can be written down as:

$$S_R = \{r_1, r_2 \ldots r_{max}\}, \ |S_R| = \binom{n_{\max}}{b_t} \tag{4}$$

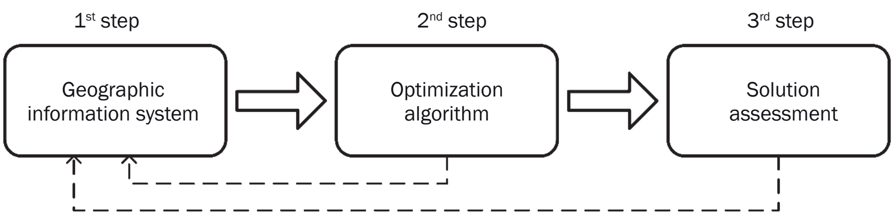

Figure 1 – Planning of a passenger terminal location in phases (steps)

It should be emphasized that not all solutions are acceptable since there is a limitation in the algorithm expressed in defining the minimal distance between two successive terminals (d_{min}). Therefore, it is also necessary to define the acceptability of a single solution:

$$\chi_{S_{PR}} = \begin{cases} 1, r \in S_{PR} \\ 0, r \notin S_{PR} \end{cases} \tag{5}$$

For the problem of determining the optimal location of the terminal, there exists a set of feasible solutions S_{PR}. A solution is feasible if the following condition is satisfied:

$$S_{PR} = \{ r \in S_R \colon \forall n_1, n_2 \in r, d(n_1, n_2) \geq d_{min} \}, \quad S_{PR} \subseteq S_R \tag{6}$$

where d_{min} is the minimal distance between two successive terminals and $d_{min}>0$ is valid.

The issue of siting a terminal is a multi-criteria problem and it should be considered and solved by recognizing different criteria that affect the siting. The solutions obtained by the optimization algorithm, with only one objective function, need to be assessed by the multi-criteria decision-making approach. The solutions obtained by the optimization algorithm become alternatives among which the selection is made in the solution assessment procedure.

3. TESTING THE MODEL APPLICABILITY

The GIS database is used in order to determine the set of potential locations of terminals. The assumption is that this refers to intermodal terminals that are available to potential users with different transport modes (passenger car, bicycle, walking, urban public transport). For every potential location of the terminal the number of citizens to whom the terminal is accessible using available transport modes is calculated. The data for this step of the model have been collected for the city of Zagreb, i.e., the data about the traffic network, urban plans and statistical yearbooks are for the city of Zagreb. The first step of the siting model is presented in *Figure 2*.

After the data collection step and their processing in GIS environment, the potential locations of intermodal terminals in the observed corridor need to be defined. According to literature [21], the set of potential locations of terminals need to be analyzed since every potential location has its characteristics that must be considered and analyzed. The most frequent characteristics of a potential location include:

- Accessibility and environment;
- Topography;
- Existing infrastructure;
- Allocation and land use;
- Existing vegetation;
- Drainage;
- Type and composition of soil;
- Current utilities;
- Weather conditions.

Regarding the characteristics of potential locations, it is necessary to determine whether there is a possibility of physical siting of the terminal and the auxiliary facilities in the observed corridor. If there are special requirements such as the existence of over-/underpasses, closeness of road or public transport, such requirements need to be defined and all locations that do not comply are to be excluded from further considerations.

After determining the locations in the observed corridor that can be regarded as potential locations of terminals, it is possible to calculate the physical accessibility of these locations to the users. Each potential location of intermodal terminals can be accessed by one or several modes of transport, and this refers mainly to walking, cycling, using a passenger car and urban public transport. Terminals that are accessible on foot and/or by bike require pedestrian and/or cycling paths, whereas terminals accessible by

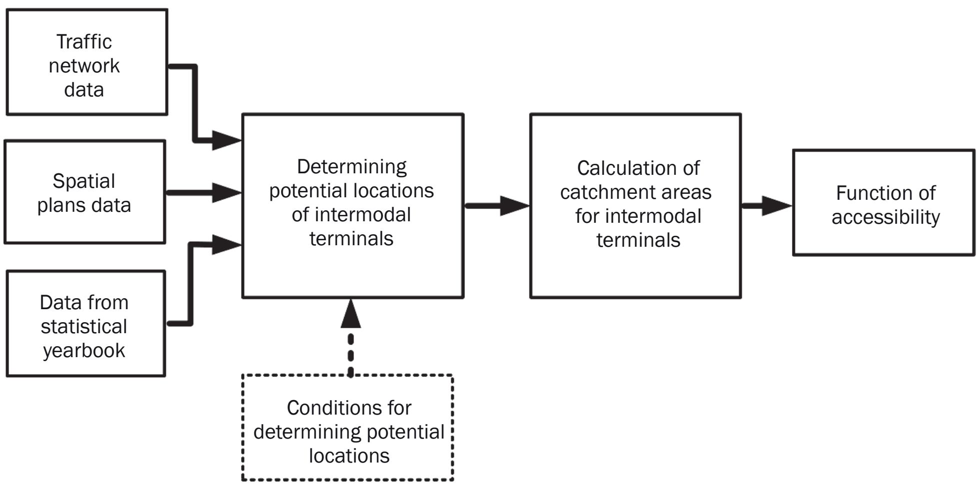

Figure 2 – The first phase (step) of terminal location planning

passenger cars and/or urban public transport need adequate access infrastructure. Arrival by passenger cars and buses requires a network of roads with respective bus lines and stops, whereas tracks are necessary if the terminal is accessible by some mode of rail transport. Apart from this, it is also necessary to provide a physical location of stops of urban public transport and the P&R system in a direct vicinity of the terminal.

For siting a P&R system, every city has to be considered separately in the context of available road infrastructure, natural barriers and other specific characteristics that can influence the decision-making on the location of such a system. Strategic siting of a P&R system as part of traffic facilities can give incentive to the users of passenger cars to leave their cars and to continue their journey by public transport. The location of a P&R system is also defined with the aim of intersecting the strong road traffic flows at the beginning of their trips towards the destination [17]. The siting of P&R systems needs to also consider the capacity and the speed on access roads so as to avoid the generation of traffic congestion due to the usage of a P&R, since this would only discourage the users. The conditions for siting a P&R system have been analyzed in the work of Horner (2001) [16].

To determine the catchment area of the terminal, the actual traffic network, i.e., actual distance instead of approximation, such as Euclidian or some other type of distance, have been used. The GIS database stores data about the lengths of traffic networks for every transport mode. For these data, it is necessary to assign the speed of movement regarding the method of arriving to the facility. By simple analyses, it is possible to calculate the time of arrival to the facility separately on foot, by bike, a passenger car or urban public transport. For precise calculation of time of arrival, it is necessary to classify the roads according to the speed limits or, even better, according to actual speeds, if such data are available. The classification of roads based on the obtained speeds can be found in more detail in the paper [22].

For the calculation of the catchment area, the Dijkstra algorithm is used. The algorithm is used to determine the shortest paths from one network node to all other nodes. In calculating the catchment area, the aim is for the algorithm to return a set of nodes which are within the given network resilience. In the context of the traffic system, the resilience to a trip can be expressed as the cost of this trip (regarding time or finances) and/or distance. Graphically, this can be presented as lines that follow the plotted network of roads to a specified resilience, then as polygons plotted around these lines or both.

For the calculation of the number of citizens it is necessary to generate the polygons around the traffic network that will cover an area corresponding to the given network resilience (e.g. five and/or ten minutes of walking). The assumption is that all locations of house numbers are known and geolocated and that the average number of citizens per house number of the observed area is known. After the polygons for the defined network resilience have been generated, each polygon has to be overlapped with the geolocated data of the house numbers. The result of the cross-section between the polygons and house numbers is the total number of households (citizens) that gravitate to the potential locations of terminals within the defined time of arrival. The catchment area of a potential location of a terminal is presented in *Figure 3*.

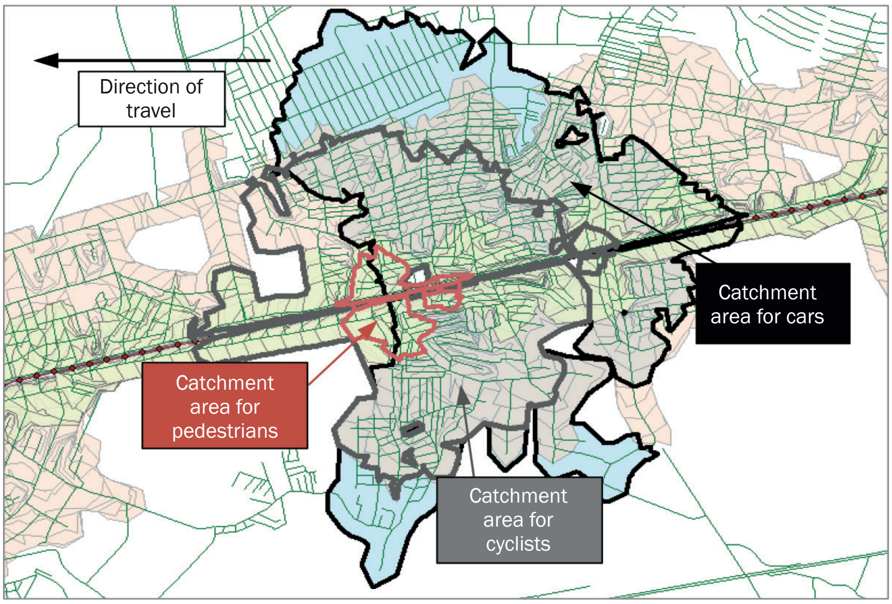

Figure 3 – Catchment area (example - city of Zagreb)

The accessibility function, i.e., the output from the GIS database, represents the input in the second step of the model. The accessibility function expressed through the number of potential users has to be corrected in order to obtain a realistic and expected number of users. The optimization algorithm is applied on such a corrected function by finding the solutions for which $F(r) \rightarrow max$ provided $b_t^{min} \leq b_t \leq b_t^{max}$, $b_t > 0$ $0 \leq d_{min} \leq l_t$. The second step/phase of the model is presented in *Figure 4*.

The optimization algorithm generates solutions for a different number of intermodal terminals (*Figure 5*). The upper graph shows the input function in the optimization algorithm, whereas the lower graph represents the process of searching for the solution using the optimization algorithm. The solutions obtained by the optimization algorithm need to be compared according to the second set of the defined criteria. It is thus achieved that the problem of siting the terminals, which in its nature is a multi-criteria one, is precisely considered through several criteria. Firstly, this was done by using the optimization algorithm according to the criterion of maximizing the number of citizens who gravitate to the terminals, and secondly, by pairwise assessment of such solutions using the multi-criteria decision-making methods. The third step of the model is presented in *Figure 6*.

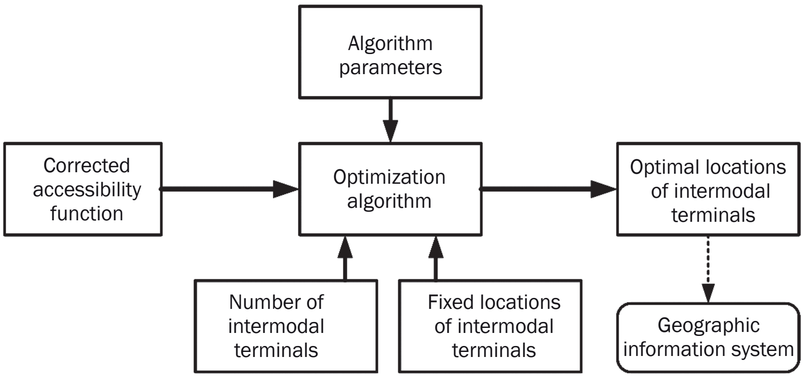

Figure 4 – The second phase (step) of positioning an intermodal terminal

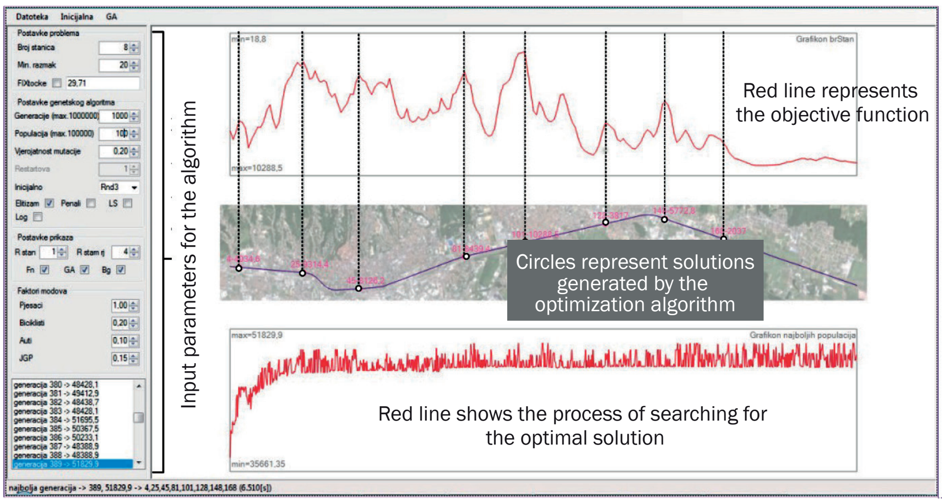

Figure 5 – Solutions obtained by the optimization algorithm

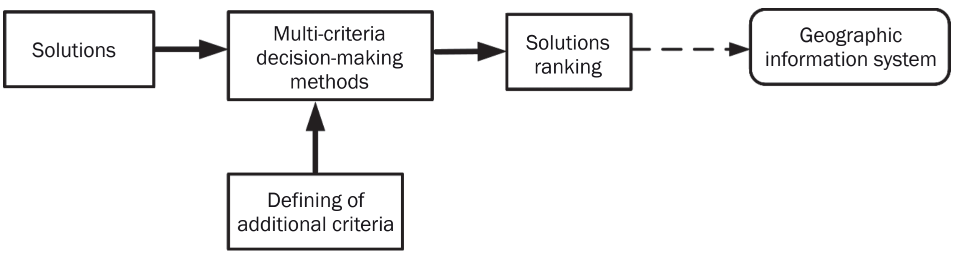

Figure 6 – The third phase (step) in the terminal location planning

In the location selection process, mathematical methods are limited to predefined parameters. In order to complement and improve the decision-making process, new data that could be qualitative and quantitative should be introduced [23]. The additional group of criteria that is defined in order to be able to compare the solutions from the optimization algorithm belongs to several groups. The mentioned criteria are of economic nature, sociological nature and from the domain of traffic and ecology. The hierarchic structure of the problem is presented in *Figure 7*, and the criteria are explained further in the text.

The total travel time observed from the aspect of travel time by means of public transport consists of the travel time from the origin of traveling to the terminal, transfer time and waiting time for the transport means, time of riding on the transport means and time from the destination terminal to the trip destination. The time of riding depends on the number and distribution of terminals along the railway line, time of arrival and departure from the terminal depend on the methods of arrival/departure, whereas the waiting time is related to the level of service on the observed line.

The costs of construction and maintenance of the facility are certainly among the significant items in the process of planning the terminal location. The costs of construction of the facility are affected by many factors and they depend on the exact location on which they are to be constructed. Thus, it may occur that the costs of construction on two different locations are different (e.g. if a facility is near residential buildings and additional protection against noise is required). These costs are known only after the exact location of construction is known and they consist of:

- Costs of land purchase;
- Costs of preparing the land for the construction of the terminal (land consolidation, complexity of construction depending on the type and quality of soil);
- Costs of terminal construction that depend on the terminal category (existence of a P&R system, stops of urban public transport);
- Costs of connecting the terminals to the existing traffic network (connecting with road, cycling, pedestrian network and public transportation);
- Costs of connecting the terminals to the existing electric grid, utility network and similar.

The privatization of railways in the United Kingdom resulted, among other things, in a drastic increase of the costs for new railway stations and stops. This means that the construction of every new station or stop has to be financially justified, i.e., that the profit of these stations and stops will be significantly higher than the cost of construction [24].

Costs of maintaining the facility are also a significant item since they are due during the entire exploitation life of the facility. The maintenance costs include all costs related to the maintenance of the facility (building) and costs of maintaining the instruments and the plant on the terminal. In the first years of exploitation, the maintenance costs will not be high if the facilities, instruments and plants are new, but over the years these costs will increase. The maintenance costs also depend on the size of the facility as well as on the accompanying facilities. If two facilities are compared, one of which contains a P&R system, and the other one does not, it may be expected that the former facility will have higher maintenance costs for the item of P&R system maintenance.

Operating cost of carriers represents costs of the operation of a certain line of railway transportation. According to Vuchic [2], the operating costs of carriers include the following items:

- Salaries of the operating staff with allowances;
- Costs of fuel and energy;
- Costs of maintenance, including the employees, premises and equipment for maintenance;
- Costs of transport documents;
- Information, promotion and marketing;

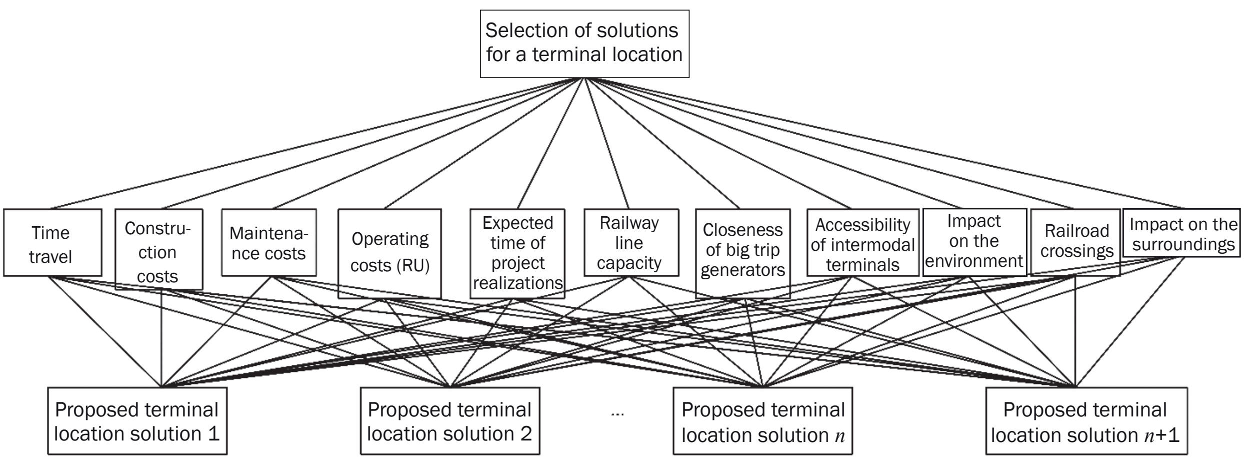

Figure 7 – Hierarchic structure of criteria

– Purchase, licensing and registration of a vehicle;
– Insurance costs;
– Costs of administration, including staff, office premises and other costs related to the operation of the transportation agency.

Depending on the specific situations, in certain countries it is possible that all the mentioned costs do not belong in the operating costs of the carriers, and also that there are certain costs that can be related to a certain line which have not been mentioned here.

The railway line capacity, according to UIC E406, can be defined as: total number of possible train routes in the defined time frame, while also taking into consideration the so-called route combination, total number of the possible train routes in the nodes, single lines or just one part of the network and the total number of possible train routes with market-oriented quality. The mentioned method calculates the usage of the track capacity by measuring the occupancy of the infrastructure in the defined time period and adding the time reserves for the stabilization of the schedule and time for track maintenance. The total time of occupancy, according to UIC E406, is $k=A+B+C+D$, where:

k – total time [min];
A – infrastructure occupancy [min];
B – additional times (added for the sake of schedule stability) [min];
C – reserve for single-track lines [min];
D – reserve for maintenance [min].

The closeness of facilities that attract and generate a large number of trips is a criterion that favors those locations that are in direct vicinity of schools, hospitals, shopping centers and similar types of facilities whose characteristic is that they are strong trip generators and that they attract a large number of citizens.

The expected time of project realization is a criterion that takes into consideration the time and financial components of constructing the infrastructural facility. The advantage goes to those locations on which the costs of construction are lower and that do not require several years of preparation and construction.

Impact on the surroundings is a criterion used to assess whether the construction of the planned facility is in compliance with the development plan of the area and allocation of land, and what is its relation to other facilities in the vicinity of the potential location. Special attention should be paid to whether the existing land use (as residential area, for agriculture, rest and recreation) has been preserved and to what extent, and there should be no construction on locations of historic and/or cultural significance. Favorable will be those locations on which the planned facilities fit better into the landscape of the city and the close surroundings. This criterion is more of a qualitative nature.

Impact on the environment is a criterion which speaks about the ecological aspect of constructing a new route or expanding the existing one. It is necessary to consider how the construction of the route and respective terminals affect the land, sources of potable water and the flora and fauna. It is also necessary to know the impact of noise and pollution during the very construction of the route and especially during the forecast exploitation era.

From the safety aspect, it is necessary to avoid the intersection of the route with roads since this results in the construction of the railroad crossings that represent weak points or high investments. On the places where this is possible, the levelled railroad crossings are constructed, and although they are protected, they represent a threat to the participants primarily of road transport. On places where this is necessary, the grade-separated railroad crossings are built but they raise the price of constructing the route.

Accessibility of intermodal terminal takes into consideration the adaptation of the terminal location to those who will use the facility (in this case, the passengers). The adaptation of the location is reflected through the simplicity of the arrival to a terminal regarding the method of arrival. Thus, for instance, users who will arrive by passenger cars consider the physical compliance of the position of the parking area with the surface intended for public transport, their distance and possible vertical barriers to pedestrian communication [9]. From the safety aspect, the potential conflicts between the flows of motor and pedestrian traffic are assessed as well as the accessibility for passenger cars conditioned by the position of the P&R facility in relation to roads, and by the very quality of the road network which leads to the selected P&R facility. Those users who arrive on foot or by bike need to have an adequate infrastructure that they can use for safe and unobstructed movement, and it is especially important for cyclists that there is a guarded bicycle storage within the facility. Regarding those users who arrive by some mode of public transport, the tendency is to position the public transport stop in the close vicinity of the intermodal terminal and that there is the possibility for a fast and seamless connection between different public transport modes.

The decision-maker has the freedom of giving different priorities to certain criteria. There is also a possibility of group assessment of the solutions, so that several interested parties participate in the assessment procedure where the parties do not have to agree on the criterion priority. The acceptability of the obtained solution can be assessed by performing the sensitivity analysis, i.e., change of the values of critical parameters of the model. The critical parameters are those variables whose variations, either positive or negative, can have the biggest influence on financial or economic results of the project. The criteria of determining the efficiency of the project start from the assumption that all the taken parameters in the calculation are actual and also in the prospect at the moment of calculation. However, it is very difficult to assess the value of single input parameters for a closer, and especially farther, future, i.e., for the time of determining the efficiency of the project, which is a period of 10 to 30 years, which is why an additional analysis of the project efficiency is performed, i.e., analysis of sensitivity or sensibility. For instance, in the AHP method the sensitivity analysis is performed by changing the priorities of criteria in relation to the initial model. This enables the development of the calculation and presentation of relations between changes of alternative priorities as a function of criterion significance. Therefore, it is possible to change the priorities of the criteria and analyze the impact these changes have on the final solution.

4. DISCUSSION AND CONCLUSION

The purpose of this research is to create a framework in which the decision-makers are presented with several feasible solutions of terminal locations, but in such a way that it is possible to simply follow the impact of the changes in the importance of a single criterion on the final solution. The scientific contribution of this research lies in the upgrading and improvement of the model of planning the terminal locations by introducing an additional step in assessing the solutions obtained by the optimization algorithms with a new set of defined criteria.

Data that have been used in the model, such as data on the traffic network, data from urban plans or data from statistical yearbooks, have been obtained for the area of the city of Zagreb. This has been done in order to check the applicability of the planning model of intermodal terminal locations on a case study. The previously described methodology of calculating the catchment areas of the terminals remains the same, but the values of single terminals depend on the specific characteristics of the city to which the methodology is applied.

In this research, the GIS database has been used for determining the coverage area. The input data in the GIS base are the data on the traffic network of the studied area, data defined by the urban plans, data from the statistical yearbooks and data necessary in the phase of solution assessment. Within a selected corridor, all locations that are candidates for the locations of passenger terminals need to be defined. For every potential location, the number of citizens within the catchment area needs to be calculated. This defines the accessibility of the terminal, depending on the method of arrival to the terminal (on foot, by bike, a passenger car, additional modes of public transport) and time of arrival. Around every potential location coverage, areas are generated whose size depends on the time of arrival to the terminal, and the shape and topology of the existing traffic network of other traffic modes. After having generated the catchment areas, one needs to determine the number of citizens within these areas. The results are functions of the number of citizens to whom the terminals are accessible on foot, by bike, a passenger car and additional modes of public transport. These functions need to be corrected since some catchment areas overlap and it is not realistic to assume that all the citizens will also use the terminal that they can access. The corrected output function from the GIS database represents the input function in the optimization algorithm.

The optimization algorithm has been developed for the case where on the observed corridor the location of no terminal is known in advance and for the case where the locations of some terminals are known. One solution represents a set of terminal locations. The optimization algorithm operates so that it is given in advance the number of terminals that need to be located with minimal distance between two succeeding terminals. Apart from this, one also has to define the work settings of the optimization algorithm. The two mentioned parameters are very important because, regarding the defined number of terminals that need to be located and the distance, different solutions can be found. The decision-maker can search for the solution in order to locate six, seven or eight terminals with a minimum distance of 2,000 m between them and compare the mentioned solutions to one another. Based on the analysis of these solutions by means of one of the multi-criteria decision-making methods it is possible to see how much each terminal brings in the number of potential users and what the costs of such a terminal would be. Thus, for example, there may be a case in which the difference in the potential number of users between the solutions with seven and eight terminals is minimal, whereas an additional terminal has a significant influence on other criteria, such as the costs of construction and maintenance, traveling time, impact on the environment and others. In this case, the decision-maker could opt for the solution that offers the least number of terminals, since the value in the number of potential users is similar as in the solution with eight terminals, but the former solution is better regarding other criteria, defined for the third step of the model.

For the algorithm, the decision-maker can define the locations of high importance which require existence of the railway terminal and, moreover, allow the algorithm to locate the remaining terminals by maximizing the objective function. By changing the value of distance between two successive terminals, different solutions can be compared, e.g. for six terminals with different interstation distances. Thus, the value of the function of objective for the distance of 1,500 m amounts to 48,202, for the distance of 2,500 m it is 41,054 and for the distance of 3,500 m it is 29,963. Also, by changing the distance, it is possible to plan the locations of stops on other rail modes of transport such as metro or tram systems.

Every solution obtained by the optimization algorithm, the one the decision-maker wants to compare in the third step of the model, has to go through a comprehensive analysis according to all the defined criteria. In the process of assessing the solution, all the interested parties may participate. This represents a challenging task, both regarding time and finances, and special attention has to be paid to this part.

Since every model represents the reality only to a certain extent, the same happens with this model as well. This leaves room for the upgrading and continuation of research. The direction in which the research can be continued refers to determining the factors of correction of the output function from the GIS database, i.e., the input function in the optimization algorithm, in order to model the actual state as faithfully as possible. In addition, through further upgrading of the optimization algorithm, the model could be applied to more complex network topologies, potentially allowing solving of the problems of terminal locations on major traffic networks.

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PLANIRANJE LOKACIJA INTERMODALNIH TERMINALA U GRADSKO-PRIGRADSKOM ŽELJEZNIČKOM PRIJEVOZU

SAŽETAK

Cilj ovog istraživanja jest pronaći odgovarajuću metodologiju za planiranje lokacija intermodalnih terminala javnog prijevoza u gradskom okruženju. Razvijeni pristup planiranju lokacija sastoji se od tri međusobno povezane faze. Prva faza jest izrada GIS baze podataka koja omogućuje određivanje potencijalnih lokacija intermodalnih terminala. Za svaku potencijalnu lokaciju terminala izračunat je broj stanovnika koji gravitira terminal, što istovremeno predstavlja izlaz iz prve faze modela. U drugoj se fazi koristi optimizacijski algoritam kako bi se odredile točne lokacije intermodalnih terminala. Optimizacijski algoritam daje više rješenja, ovisno o broju terminala i takva rješenja potrebno je vrednovati. Glavni doprinos ovog istraživanja ogleda se kroz nadogradnju pristupa planiranju lokacija i to uvođenjem dodatnog koraka vrednovanja rješenja dobivenih optimizacijskim algoritmom.

KLJUČNE RIJEČI

intermodalni terminal; GIS baza podataka; optimizacijski algoritam; višekriterijska analiza; planiranje lokacija;

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