Route Selection Problem Based on Hopfield Neural Network

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Abstract. *Transport network is a key factor of economic, social and every other form of development in the region and the state itself. One of the main conditions for transport network development is the construction of new routes. Often, the construction of regional roads is dominant, since the design and construction in urban areas is quite limited. The process of analysis and planning the new roads is a complex process that depends on many factors (the physical characteristics of the terrain, the economic situation, political decisions, environmental impact, etc.) and can take several months. These factors directly or indirectly affect the final solution, and in combination with project limitations and requirements, sometimes can be mutually opposed. In this paper, we present one software solution that aims to find Pareto optimal path for preliminary design of the new roadway. The proposed algorithm is based on many different factors (physical and social) with the ability of their increase. This solution is implemented using Hopfield's neural network, as a kind of artificial intelligence, which has shown very good results for solving complex optimization problems.*

Keywords

Transport network planning, route selection problem, neural network, artificial intelligence.

1. Introduction

In the modern society, transportation of people and goods is one of the most important daily activities [1], [2]. Today, the speed and cost of transport, determined by the network infrastructure and logistic services [3], [4], have a great impact on the whole society. Transport Geography is a specific scientific discipline that analyzes the possibilities of using certain form or combination of means of transport [5], [6]. It is very important since in real life there are large fluctuations in all areas (demographic changes in a particular geographic area, changing demands of industry and population to traffic, technological innovation and infrastructure). In all these situations, a growing need for building new roads arises, as well as the expansion or relocation of existing roads [5], [7], [8].

A large number of factors that influence the construction of new roads and a large number of requirements make this problem very complex [3], [5], [13]. Regarding the fact that the construction of roads is directly connected with the budget, it is clear that it is necessary to make an optimal solution which is as cheap as possible, but is also fulfilling a large number of required conditions [3], [5]. These conditions could be based on social nature on the one hand, technical on the other hand and regulatory as the third. Further disadvantage is that these conditions can often be contradictory one to another, so it is necessary to balance all these requirements [3], [5]. In these circumstances it is necessary to find route which must satisfy the principles of Pareto optimization, so we can obtain an accurate solution [9], [10].

Factors that can influence the final decision on setting up the new road are very diverse and can vary in specific cases (the structure of soil, landslides, relief, presence of the river, presence of other roads, economic factors, social aspects, etc.) [3], [5], [6], [7]. Due to the relatively high number of initial and various factors, a solution that can dynamically adapt to specific requirements is needed [9].

In this paper, one sophisticated software solution will be presented, that aims to analyze, plan and make selection for a new roadway. The algorithm includes a possibility of analyzing an arbitrary number of conditions (ex. new road mustn't go throw hill, desert or across the river, etc.) and requirements (ex. road needs to go nearer to some town, mustn't go through some restricted area, needs to have specific width or sectors etc.) Because of the impact of a large number of factors, conditions and requirements, the decision making process will be assigned to a neural network [11]. The neural network is a form of artificial intelligence, the logic and structure of which is inspired by the work of human brain.

Neural network methods, coming from the brain science of cognitive theory and neurophysiology, offer a powerful alternative to linear models for increasingly complex and multidimensional environments. Artificial neural networks are a highly complex nonlinear system. They have achieved very good results in the field of optimization for many years [12]. Especially distinguishing is the Hopfield's neural network, which has been applied to solve more complex optimization *NP complete* problems [12], [13]. For this reason, Hopfield's neural network will be used in solving the problem of route selection.

2. Route Selection Problem

The primary problem in transportation is to find the shortest path between two points (*A* and *B*). Mathematically speaking it is the Euclidean distance, which is a straight-line trajectory, Fig. 1a. In the real transport, existing roads introduce limitations, and the shortest distance is defined by the minimum sum of individual length sections from point *A* to point *B*, Fig. 1b. The solution to this problem is defined by Dijkstra algorithm [14].

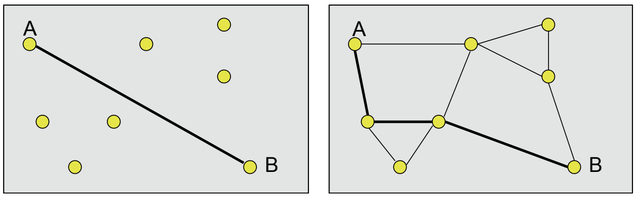

Fig. 1. The shortest distance between points *A* and *B*: a) Ideally. b) In realistic conditions of network infrastructure.

In the case that somebody wants to build a new roadway, in addition to the existing infrastructure, it is necessary to analyze all the factors that can affect the construction and environment. Even if there is only one factor that is realistic and spatially oriented, the distance between two points must be parametrically considered [5]. This is especially important if the observed factors can take different values in different spatial zones, Fig. 2.

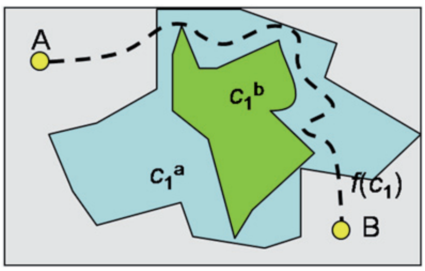

Fig. 2. Possible shortest distance between points *A* and *B*, in the case when a factor has two possible values, C_1^a and C_1^b.

For example, if spatial zone C_1 is between points *A* and *B*, with two different quantified areas (C_1^a and C_1^b), the distance between the observed points depends on the unit cost of construction through the area C_1^a i.e. C_1^b. Route selection problem in this case depends on the ratio price/length. In the case that the total cost in the C_1^b area is much larger than the total cost outside this area, optimal solution might be going around it, making a longer route, and vice versa, depending on the budget.

Route selection problem is multiplied when analyzing a large number of possible factors, especially when each factor can have its own divisions, Fig. 3.

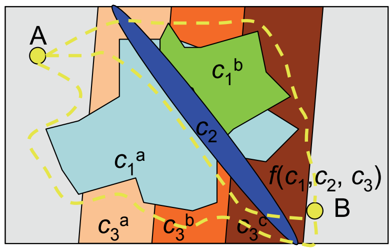

Fig. 3. Possible shortest distance between points *A* and *B* in the case when factors (C_1, C_2, C_3) are observed, C_1 having two possible values (C_1^a, C_1^b), C_2 with one possible value, and C_3 having three possible values (C_3^a, C_3^b, C_3^c).

In such cases, route optimization has to be done, since the number of factors and sections per factor is multiplied [5], [9]. A special problem arises when some of the factors do not influence the price of building the road in the same way. This occurs when one factor increases the cost of construction, and the other (which is on the same part of section) decreases.

For solving this type of optimization problems, we usually can't speak about the optimal solution, taking into consideration the existence of several possible solutions for different criteria. For that reason, the term Pareto optimal is used. A Pareto Optimal solution, or non-dominated solution, for a multiple objective optimization problem is one for which no objective function value can be improved without a simultaneous detriment to at least one of the other objectives [15].

In this case, balancing is conditioned by Pareto optimal choice, which should provide the maximum utilization of certain benefits and would not endanger some other factors or defined conditions [10].

Mostly, the set of conditions is defined by the need to increase or decrease the prices for the construction. This price is observed per kilometer of road [3], [5]. Some spatial zones require greater investments than others. This is caused by a large number of real constraints (landscape, physical barriers, environment, etc.) This solution has to find the optimal route between two points, according to various conditions and observed factors. According to the fact that some factors are of different nature, their impact is defined through a change in the price of road alignment.

3. GIS-T

GIS-T (*Geographic information systems and transportation*) is a very complex and sophisticated system for the application of information technology in solving transportation problems [5], [16], [17]. In general, topics related to GIS-T studies can be grouped into three categories [5], [16]: Data representations, Analysis and modeling and Applications.

Data representations aim to represent all segments of the transportation at GIS-T and find a way to represent all the data in a digital computing environment. This procedure can be implemented through two models:

1. Object-based data models, and
2. Field-based data models.

The primary difference is that the first model considers geographical area discretely (points and lines) and the other continuously.

Analysis and modeling cover a wide range of activities in the field of transportation analysis and methodology, which involves searching the shortest path, traffic routing, network flow problems, travel demand models, land use-transportation interaction models etc.

Applications include a large number of applications that are used in the transportation agencies and private companies.

In this way, main activities of GIS-T are related to collecting, storing, analyzing, and disseminating information about areas of the earth that are either used for, influenced by, or affected by transportation activity.

As the use of artificial intelligence aims to offer high quality solutions adaptable to different types of real requirements, the phase *Data representations* (GIS-T) can also be used for the proposed algorithm.

Phase Analysis and modeling cannot fully provide the required scalability for algorithms based on the work of the human brain, so it will not be used for the proposed algorithm. The goal of this algorithm is exclusively to do the analysis and planning of new roads and does not include the phases *Analysis and modeling* and *Applications* (according to GIS-T).

4. Proposed Algorithm

The proposed algorithm consists of three phases: terrain modeling, management (definition conditions, requirements and neural network parameters), and processing of data, Fig. 4.

4.1 Modeling

The modeling of the terrain requires digitization of real physical characteristics: relief, hydrographs, soil composition, the flora and other natural features. In addition, at this stage it is also necessary to quantify all other economic, social, environmental and similar elements that have to be engaged in the final analysis.

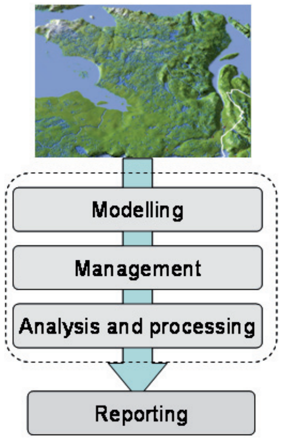

Fig. 4. Block scheme of proposed algorithm.

For the purpose of digitization, an object data model is used, as well as GIS-T [5], [16]. This implies that the spatial representation of a certain physical surface is made with a node, while the connection of two physical locations is realized with the line. Parameters associated with the descriptive lines have some quantitative characteristics of real physical and social impacts. In this way, by defining a larger number of nodes (noted by r) the structure of the terrain is shown with greater precision. As a result of digitization a matrix is obtained, with rank r x r, observed by every input factor. The element of this matrix at the position ij is representing the value of the observed factor at the i-th row and j-th column of the tessellated map.

At this stage, three sub-phases should be implemented:

a) Mapping of the physical characteristics of the terrain,
b) Quantification of the mapped area, and
c) Scaling the data to the range [0, 1].

Mapping procedure involves placing a virtual network over the geographic map of the region and dividing it. A map can be made with arbitrary dimensions of square shape r x r. By choosing larger values of the parameter r, the resulting regions are smaller and more precise solution is obtained. Such a region is the smallest form in which the algorithm works, and the obtained solution will be selected through a set of the regions that are proposed for the construction of road alignment.

The quantification of the mapped area involves the procedure of assigning certain numerical value to each of the mapped regions. This value can be considered as a cost that is necessary to pay per unit length of the route in the observed region, or anything else of interest to planning. In this phase every factor should be quantified and assigned to every mapping area. In this way, in the regions which are favorable for the construction (suitable altitude, soil structure, availability, etc.), lower development cost is found, encouraging the region to accept the passage of a new roadway through it.

Scaling the data: As different types of input data can be used in this analysis (physical, social, economic, etc.) it is necessary to unify the various parameters and their ranges of real values. This is accomplished by scaling values entered in the range [0-1], where lower values indicate less money per unit length, while a value closer to 1 indicates the opposite.

4.2 Management

Management involves defining all the conditions and requirements, limitations and parameters of the proposed neural network, which can affect the final result, the accuracy of the obtained solution, the speed of the proposed algorithm, etc. This phase also involves defining the parameters required for the operation of the algorithm and the conditions imposed by the real environment. For example, these constraints may be related to the conditioning whether the route can pass through some town or area or must go around it, etc.

4.3 Analysis and Processing

In this phase all data from the previous two phases are used to create artificial neural network. For the purposes of this algorithm, a specifically defined logic that is based on Hopfield neural network (HNN) was created [18]. The task of HNN is to process all data and offer Pareto optimal solution that takes into account all the input factors [10]. The goal is to obtain a mathematical representation of the required solution suitable for graphic visualization. The solution has to give the optimal balance of all factors, their values, conditions, requirements, etc. Further on, it has to find an optimal solution for the construction of road alignment on initially mapped geographic region. As a result of this phase, an output matrix **V** [18] by dimensions *r* x *r* is obtained with the values 0 or 1. The value of 1 indicates that the mapped region is proposed for the construction of the road, while 0 indicates the opposite. Depending on the terrain model and the precision with which the classification is done, the obtained solution is more or less detailed.

5. Neural Network

Artificial neural networks are paradigm of a non-analytical way of solving problems which, due to their capabilities, is applied in different fields [11]. This system, inspired by biological nervous systems, is able to learn and make intelligent decisions without a precisely defined algorithm or a complete set of input data. Although the work of individual neurons is quite slow, complete neural network is very fast, which is due to the large neuronal connections and parallel processing [11], [19].

Special types of neural networks are recurrent neural networks [20]. These networks are characterized by a feedback of output to the input layer neurons, where that signal can be modified. Typically, this is the time delay of signal [11]. Hopfield's neural network is usually used as a representative of these networks [18], [21], the structure of which is shown in Fig. 5.

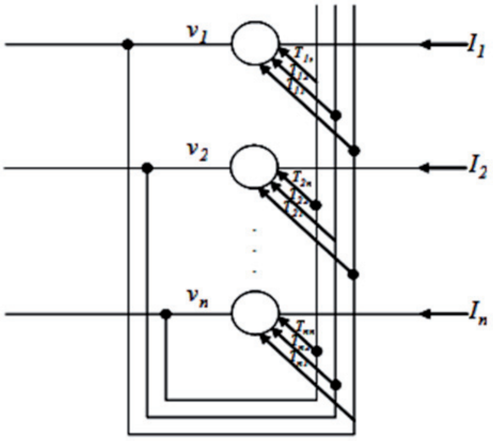

Fig. 5. Hopfield neural network model.

Main goal in the Hopfield neural network implementation is the possibility of hardware realization. For this purpose, the suggested realization is shown in Fig. 6.

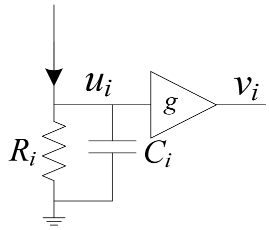

Fig. 6. Electronic circuit model of the Hopfield neuron.

Hopfield and Tank proposed a neural network structure [18] capable of solving different complex problems by using the network for which an energy function has to be defined. After its minimization, optimal solution for a given and defined problem is possible. This approach was demonstrated on the well-known and computationally very complex *Traveling Salesman Problem* (TSP) with 30 nodes [18]. Since then, many researchers have used a similar model in solving a variety of combinatorial optimization problems.

5.1 Hopfield Neural Network Implementation

Each neuron is realized as operational amplifier with an increasing sigmoid function relating the output V_i and input U_i of the *i*-th neuron. In this way, the network gets the characteristics of nonlinearity. Output values are scaled to range from 0 to 1. Activation function for each neuron is given as [18], [22]

$$V_{xi} = g_{xi}(U_{xi}) = \frac{1}{1+e^{-a_{xi}\cdot U_{xi}}} \tag{1}$$

where a is a constant that determines the declination of the characteristics.

In accordance with the rule of recursive networks, the output signal of the *i*-th neuron leads to any input for other neurons, except on its own entrance, through resistive connections. This connectivity is defined with the synaptic weights, matrix $\mathbf{T} = [T_{ij}]$. In addition to receiving signals from the output neurons, each of the input neurons operates with additional electrical signal (*bias current*) I_i. It adjusts the polarization of neurons [18]. Changes of the input signals are defined by the relation (2), Fig. 1,

$$\frac{dU_i}{dt} = -\frac{U_i}{\tau} + \sum_{j=1}^{N} T_{ij} V_j + I_i \tag{2}$$

where τ is the time constant.

Each neuron has its own entrance U_i, the output signal V_i and the polarization signal I_i, which defines the cell activation level. Feedback between outputs V_i and inputs of other neurons is achieved through the resistance R, $i \neq j$ (called synapses), and provides a change of state of the network, iteratively.

During the iterative process, network converges to a stable state. Neuron outputs are connected to the capacitor C_i. Changing of the voltage on the capacitor is given by the state [18].

$$C_i \frac{dU_i}{dt} = -\frac{U_i}{R_i} + \sum_{j=1}^{N} T_{ij} V_j + I_i . \tag{3}$$

Voltage at capacitor C_i acts at the input of the nonlinear differential amplifier, whose output signals are obtained by V_i and $\urcorner V_i$ of these cells, according to (1) [21].If the steepness of the sigmoid function is sufficiently large (for instance, $a_i > 100$), the stability of the network, in Liapunov sense, may be verified by observing the energy function, E, describing the state of the network [18]

$$E = -\frac{1}{2}\sum_{i=1}^{N}\sum_{j=1}^{N} T_{i,j} \cdot V_j V_i - \sum_{i=1}^{N} V_i I_i . \tag{4}$$

For the large reinforcement of an operational amplifier, the minimum energy at a given N dimensional space is allocated in 2^N distinct states associated with an N-dimensional hypercube with sides $V_i \in \{0,1\}$.

Then the dynamics of the i-th neuron, according to the relation (2), can be expressed as [17].

$$\frac{dU_i}{dt} = -\frac{U_i}{\tau} - \frac{\partial E}{\partial V_i} . \tag{5}$$

The relation (5) defines the change of the input signal and the energy change (in every iteration). It can be shown that this network provides a defined convergence to stable states [23]. Such a network is used as a basic network structure for solving optimization problems. A lot of authors used and modified originally given network model after Hopfield-Tank's work. Significant improvements have been done by Ali and Kamoun [22].

In Ali and Kamoun's proposed model computational network uses $n(n\text{-}1)$ neurons, where n denotes dimension of input square matrix. It is based on fact that the diagonal elements in matrix **T** are removed. During the iterations process, stable neuron states defined the shortest path between source (s) and destination (d) points. A suitable energy function is of the form

$$E = \frac{\mu_1}{2}\sum_{X}\sum_{\substack{i \neq X \\ (X,i)\neq(d,s)}} C_{Xi}V_{Xi} + \frac{\mu_2}{2}\sum_{X}\sum_{\substack{i \neq X \\ (X,i)\neq(d,s)}} \rho_{Xi}V_{Xi} + \frac{\mu_5}{2}(1 - V_{ds})$$
$$+ \frac{\mu_3}{2}\sum_{X}\left(\sum_{i\neq X} V_{Xi} - \sum_{i\neq X} V_{iX}\right)^2 + \frac{\mu_4}{2}\sum_{i}\sum_{X\neq i} V_{Xi}(1 - V_{Xi}) . \tag{6}$$

Coefficients C_{Xi} are the link costs from router X to router i and the terms ρ_{Xi} describe the connection between routers: the value is 1 if routers are not connected, and 0 for connected routers. The term μ_1 minimizes the total cost; μ_2 prevents nonexistent links from being included in the chosen path; μ_3 is zero for every router in the valid path (the number of incoming links is equal to the number of outgoing links); μ_4 forces the state of the neural network to converge to one of the stable states – corners of the hypercube defined by $V_i \in \{0,1\}$. The state V_i is close to 1 for router belonging to the valid path, otherwise the state is close to 0. The term μ_5 is zero when the output V_{ds} is equal to 1. This term is introduced to ensure the source and the destination routers belong to the solution (the shortest path).

The main contribution in their approach [22] was that synaptic conductance was constant (7), while the link costs and the information about the connection between nodes were associated to the bias currents I_i.

$$T_{Xi,Yj} = \mu_4 \delta_{XY}\delta_{ij} - \mu_3(\delta_{XY} + \delta_{ij} - \delta_{jX} - \delta_{iY}) \tag{7}$$

where $\delta_{ii} = 1, \delta_{ij} = 0$, for $i \neq j$. In this way the neural network algorithm becomes very attractive for real time processing, since bias currents may be easily controlled via external circuitry following the changes in actual traffic through the network.

A number of papers show that HNN gives good results in problems where finding the shortest path or optimal paths is necessary. Therefore, it was used in solving this problem. On the other hand, the primary disadvantage of this network is its possible instability (for initialization of the network with a noise signal) and the fact that the HNN does not always produce an optimal solution. However, as Hopfield showed, if obtained solution is not optimal it will be in a group of solutions that are very "close to" optimal.

5.2 Energy Function

Artificial intelligence carried through the Hopfield's neural network (HNN) has a major role in the proposed algorithm. The main tasks of this HNN are:

1. To find a Pareto optimal solution based on several factors.
2. To balance all inputs and defined conditions in the best manner.
3. To connect the start and end point, in a unique path, without interruption or blind ends.
4. To provide that each mapped area is assigned a numeric value, for each factors, based on which the optimization will be performed.

5. To enable the preference of certain inputs according to the wishes of the designer (and vice versa).
6. To provide unconditional passage through a mapped area, or if necessary, to override it.
7. To support the work with an arbitrary number of mapped areas, that is parameters r.
8. To enable each of the factors to be classified in arbitrary number of divisions.
9. To be able to choose the precision and speed of realization by changing parameters of HNN.
10. That, in the case of any fault, it is able to interrupt searching the path, and informing the user.

By correct dimensioning and connecting synapses, the relation between physical and mathematical description of the observed problem throw energy function of HNN could be established. Starting from (6), stable state corresponds to the minimum of energy function, and may represent an optimal solution for the observed problem. It is given in (8).

$$E=\sum_{\alpha}\left(\frac{\mu_\alpha}{2}\sum_{X}\sum_{\substack{i\neq X\\(X,i)\neq(d,s)}}C_{\alpha_{Xi}}V_{Xi}\right)+\frac{\mu_2}{2}\sum_{X}\sum_{\substack{i\neq X\\(X,i)\neq(d,s)}}\rho_{Xi}V_{Xi}+$$
$$\frac{\mu_3}{2}\sum_{X}\left(\sum_{i\neq X}V_{Xi}-\sum_{i\neq X}V_{iX}\right)^2+\frac{\mu_4}{2}\sum_{i}\sum_{X\neq i}V_{Xi}(1-V_{Xi})+$$
$$\frac{\mu_5}{2}(1-V_{ds}) \tag{8}$$

By following the Ali-Kamoun's work [22] we derived several algorithms for routing in communication networks with neural network assistance [24-28]. For this purpose we suggest the HNN with generic energy function, through the first part of (8). In (8) the summands with coefficients μ_2-μ_5 are taken from Ali-Kamoun's modification of energy function, while the first summand is a generic add-on for any number of factors (α) that are analyzed when designing routes. Parameter μ_α makes it possible to change the influence of α observed factors through it (in the final route), while matrix C_α represents discretized values of these α factors in the resolution r x r.

Indexes X and i refer to region positions, while s and d denote the source and destination place.

Energy function in (8) is used for neural network realization. This network is realized as a programmable function, and can be called by means of different factors.

6. Results

For test purposes, complete code of the proposed algorithm was implemented in Matlab 7.0, without using the toolbox and involved complex functions, and can easily be converted into any other programming language. The proposed algorithm has a fully graphical interface and is easy to use. The code supports import or export of data in all standardized data formats. The algorithm was tested on a large number of real terrains and with different types of factors, conditions and requirements. All simulations were performed on a PC (2 GHz, 1 GB RAM and 80 GB HDD), which should be considered when measuring the speed of the response of code. In these circumstances, the maximum time for each of the cases was 15 minutes, while the average time was about 2 minutes.

The dimension of NN, is n x n neurons, where n corresponds to the range of input factors. In this case, it is defined with parameter r, so the dimension of the network is r x r. Structure of NN is created every time when algorithm is started.

This algorithm should be an additional tool to facilitate complex tasks and for making studies of planning and environmental impacts, which is regularly carried out in making travel route. Further, it should confirm possibility of HNN in solving optimizations problems.

6.1 The Analyzed Factors

Construction of new road requires analysis of many different factors. Formally, the proposed algorithm can support a large number of arbitrary factors, but for the needs of this work five typical inputs will be analyzed, as in the problem which follows [5]:

1. *Relief* (soil structure)

Primary role in the construction of road alignment has geomorphic form and structure of the observed ground. Preparatory activities for development include completely different prices for different forms of relief, and the cheapest path will not always be the shortest. Neural networks are expected to find an optimal solution for the case where the classification of the terrain is made in an arbitrary number of fields depending on the altitude (soil structure) and concerning physical constraints (soil type). After mapping the area on r x r areas, each area should be given a numeric value that defines the cost of construction per unit length depending on the considered soil structure. These data are organized into a matrix **Ct**, dimensions r x r, so that the value of the matrix C_{ij} corresponds to the numerical value of the mapped area on the map at the position ij (intersection of the coordinates of latitude and longitude).

2. *River network*

Bearing in mind that the river network is an integral part of the field, and that the river valleys are often very suitable for the construction of the road network, all this is taken into consideration. Analysis of river networks is considered from the point of crossing the road route across the river, i.e. the need to build bridges. The construction of the bridge is relatively expensive, with further aggravating factor - the width of the river and the availability of a particular location, so this also has to be analyzed. These data are organized through the matrix **Cr.**

3. *Environment*

In most countries, the competent ministry defines the area of natural importance to the population (national parks, nature reserves, forests ...) and environmental protection. Passing the travel route through or near some of these areas is considered as a threat to the environment, and the price that has to be paid eventually is in the proportion with damage. With different types of soil, the loss is reflected through the destruction of flora and fauna, or soil devastation, or destruction of biomass, air pollution etc. In some areas that are of particular importance, the construction is not permitted at all, or is permitted in strictly defined requirements, so it is essential that the algorithm is able to take this into consideration. These data are organized in a matrix **Cz.**

4. *The economic impact*

Observing the economic situation leads to the conclusion that some areas (located around the cities) are more or less suitable for the passage of the travel route by (or through) them. In this sense, there are areas whose citizens, on their own initiative, want better road connections, because their development will increase, so citizens are willing to partly fund the route around their city. On the other hand, states define the development strategy for each municipality and provide the budget for allocation of additional funds for the encouragement and development. Funds allocated by states are much higher than those given by the citizens, so those areas are defined with lower price, while the most expensive areas are the ones that nobody donates. In any case, the economic impact of new travel routes to individual cities plays an important role in determining the travel route. These data are organized through the matrix **Ce**.

5. *Political influence*

In addition to physical factors and influence of the state, there is also a human factor. It is reflected through the lobbies with an interest to the land that may be part of the travel route. In this sense, these lobbies are willing to donate part of the costs if the road passes by their area of interest. On the other hand, there are groups (usually marked with *NIMBY* - Not In My Back Yard) that oppose the building of a road in their area, and publicly try to cause delays and obstruction. This makes additional costs to investors. Certainly, political lobby has a very important role in all spheres of life and must be analyzed concerning making decision about new roads. These data are organized through the matrix **Cp**.

6.2 Proposed Energy Function

In accordance with the used factors (defined in 6.1.), and starting equation of energy function (8), the energy function suggested for this purpose is

$$E = \frac{\mu_1}{2}\sum_{X}\sum_{\substack{i\neq X\\(X,i)\neq(d,s)}} Ct_{Xi}V_{Xi} + \frac{\mu_2}{2}\sum_{X}\sum_{\substack{i\neq X\\(X,i)\neq(d,s)}} \rho_{Xi}V_{Xi} + \frac{\mu_4}{2}\sum_{i}\sum_{X\neq i} V_{Xi}(1-V_{Xi})$$
$$+\frac{\mu_3}{2}\sum_{X}\left(\sum_{i\neq X}V_{Xi} - \sum_{i\neq X}V_{iX}\right)^2 + \frac{\mu_5}{2}(1-V_{ds}) + \frac{\mu_6}{2}\sum_{X}\sum_{\substack{i\neq X\\(X,i)\neq(d,s)}} Cr_{Xi}V_{Xi}$$
$$+\frac{\mu_7}{2}\sum_{X}\sum_{\substack{i\neq X\\(X,i)\neq(d,s)}} Cz_{Xi}V_{Xi} + \frac{\mu_8}{2}\sum_{X}\sum_{\substack{i\neq X\\(X,i)\neq(d,s)}} Ce_{Xi}V_{Xi} + \frac{\mu_9}{2}\sum_{X}\sum_{\substack{i\neq X\\(X,i)\neq(d,s)}} Cp_{Xi}V_{Xi} \quad (9)$$

Constants $\mu_{1\text{-}9}$ play a key role in the stability of HNN and finding the final path. These constants are used for making impact on certain parts of the energy function [18], [22], [24-28.]. As in our previous studies, constants μ_1- μ_5 are first analyzed as well as their impact on the stability of HNN. Initially, intervals defined in the papers [18], [22] were used. In accordance with the proposed values in [24], [26], [27], empirical testing and stability limitations defined in [28], the following values: μ_1= 1800, μ_2= 2200, μ_3= 3500, μ_4= 480, μ_5= 2500 were chosen. During this testing, only factor Ct was used. The values of all other input factors were 0, in order not to affect the result. Since the constant μ_1 has the impact only on factor Ct, and coefficients $\mu_{6\text{-}9}$ have similar impacts on the other input factors, their initial values are set $\mu_6 = \mu_7 = \mu_8 = \mu_9 = \mu_1$. In this way, each of the input factors is treated equally. By changing the value of the corresponding coefficient $\mu_{i,\ i=1,6,7,8,9}$ the appropriate input factor has more or less effect on the final solution. We found the optimal interval for $\mu_{i,\ i=1,6,7,8,9}$= [700, 2100], by this empirical testing.

6.3 Problem Definition

The proposed model is tested in real conditions, on the example of two towns in Serbia: Novi Sad and Valjevo. These two cities are chosen to demonstrate the possibility of the proposed algorithm:

1. Direct route is not appropriate because there is a mountain south of Novi Sad - Fruška Gora, and it is expected that the algorithm shows the possibility to make route around this mountain,

2. The area south of Mount Fruška Gora is a National Park that makes further complications,

3. The route from Novi Sad to Valjevo has to pass over certain rivers, and this includes the selection between several rivers as additional criteria (Danube, Tisa, Tamiš, Sava, Kolubara, Drina, Morava, etc.)

4. Valjevo is surrounded by mountains from all sides except one, so we need to test the ability of the algorithm to find that side. On the other hand, this approach should include route over the river Kolubara or trace the valley of the river.

5. A large number of towns between these two observed cities and their different economic development

make it possible to define different economic and political demands for trace changes in final route.

For this example, we used the map of the Republic of Serbia in the scale (1:1 250 000). This original map is cut so cities Novi Sad and Valjevo are to the north, i.e. south of the final map. In this way, we have obtained a quadratic map, as shown in Fig. 7.

Fig. 7. Map used for simulations.

In accordance with the stages in the proposed algorithm, the modeling was performed first. The initial map was divided into the r = 5 (25 areas), and r = 10 (100 areas). The value of the parameter r is not explicitly limited in software and depends on planner needs. In this case, this has been done to demonstrate the ability of the algorithm to increase the accuracy of defining final route.

To each area, for each factor, a numeric value scaled in the interval from 0 to 1 is assigned. The value of 0 specifies that for the construction of the road alignment the cost is 0, while the highest possible value of 1 marks maximum costs. These values are assigned by the free will of the author in accordance with the available materials that define each of the obtained factors.

6.4 Data Quantification

For the purposes of relief, the classification is done through the high altitude zone (elevation) and soil structure (six of them) obtained from a physical map, Tab. 1. The lowest zones have the smallest price while the highest ones have the largest price.

For the purposes of the river network, a physical map is considered in the following way: starting position within each area is the northwest. If it is possible to start from this position of observed area to the same position of the surrounding area, without crossing the river, the price is zero. Otherwise, if we need to cross the river, the value depends on river size (width of the river). Rivers are classified into two groups: large (Danube, Drina, Sava, Morava) and medium (Tisa, Tamis, Begej, and Kolubara). Other smaller rivers are not considered.

Environment is analyzed in accordance with the type of soil and areas designated for parks or protected areas. This means, each non-cultivated land (named as Other in Tab. 2) has the smallest price while national parks have the highest price.

Elevation [m]	Cost	Symbol on the map
0-100	0.05	
100-200	0.15	
200-400	0.35	
400-600	0.55	
600-1000	0.75	
1000-1500	0.9	

Tab. 1. Classification and quantification of relief.

Type of land	Cost	Symbol on the map
Other	0.15	
Agricultural	0.2	
Forest	0.5	
Natural preserve	0.7	
National park	0.9	

Tab. 2. Classification and quantification of impact to environment.

Economic investments are a realistic indicator of the region development. Estimates which are obtained by government analysis indicate which areas are of interest and need additional treatment in the form of road infrastructure. In this sense state policy defines the field of interest and stimulates the individual zones to develop. In addition, the desire of citizens to have a road next to their city (the environment) should be considered. The donations of individual cities or states define the cost of certain areas, so the most expensive areas are not donated ones, Tab. 3.

Method of financing	Cost	Symbol on the map
The area that is not funded	0.95	
The area financed by citizen with less money	0.75	
The area financed by citizen with more money	0.5	
The area financed by government with less money	0.25	
The area financed by government with more money	0.05	

Tab. 3. Classification and quantification of economic influence.

The political map reflects the influence of some structures that have an interest that travel routes pass close to or away from cities.

Type of lobbying	Cost	Symbol on the map
Lobbying for route go through city	0.05	
Lobbying for route go around city	0.2	
Neutral	0.6	
Lobbying for route don't go around city	0.8	
Lobbying for route don't go through city	1	

Tab. 4. Classification and quantification of political influence.

In this way, by the lobbying and allocating additional resources to meet their requirements the route selection can be directly affected. For the purposes of this study, several cities were randomly selected: one group wanted road near their city (for which it was positively lobbied) and the other one did not (negative lobbying), Tab. 4.

6.5 Methodology

First, the individual parameters used for optimization are introduced as input factors for the proposed algorithm (landscape, environment, economic, political). For each, individually, the optimal path is required from Novi Sad to Valjevo (map for 5 x 5 and 10 x 10).

Then, all parameters are monitored simultaneously for both maps. The resulting Pareto optimal solution has to show that it cannot be obtained by simple arithmetic combination of individual solutions, or their interpolation. This shows the ability of neural network to "balance" from the available inputs and the given parameters.

6.6 Simulation Results

In accordance with the described methodology, Fig. 8a) and Fig. 8b) show the results obtained for $r = 5$ and $r = 10$, when only the relief factor is analyzed. The proposed algorithm was able to recognize the areas with low price and make logical route selection.

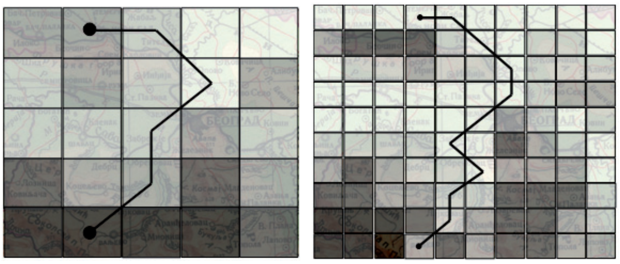

Fig. 8. Optimal route when factor relief is analyzed for a) r=5 and b) r=10.

River as parameter, next to the relief, is the only physical parameter, so in Fig. 9a) and Fig. 9b) these two parameters are considered together. The solution would be the ultimate in terms of structure and topology of the terrain, but will further change the other requirements. The river as parameter is not viewed separately, as cost areas where there is no crossing of the river are defined as 0 (areas with smaller rivers have 0.3 and larger rivers 0.6).

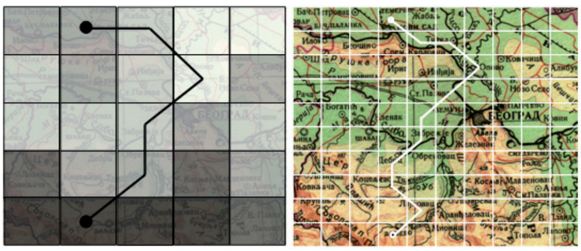

Fig. 9. Optimal route when factors relief and river network are analyzed for a) r=5 and b) r=10.

Based on defined values, the proposed algorithm selects areas suitable for a new road. There are two necessary crossings the rivers and the remaining part of route should pass through the river valley.

In accordance with the mapping of data for the environmental influence, the obtained routes are shown in Fig. 10a) and Fig. 10b).

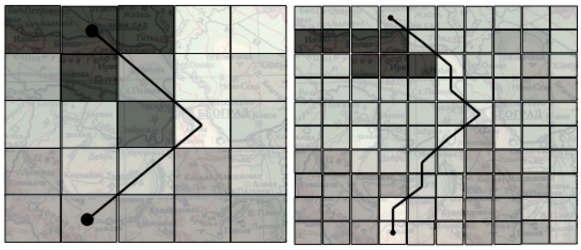

Fig. 10. Optimal route when factor environment is analyzed for a) r=5 and b) r=10.

The analysis of the economic situation of individual regions and proposed route is shown in Fig. 11a) and Fig. 11b).

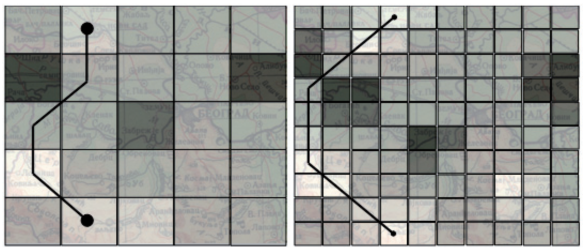

Fig. 11. Optimal route when factor economic impact is analyzed for a) r=5 and b) r=10.

In order to find as short as possible route but at the same time as cheap as possible, algorithm makes good selection of white (cheaper) areas for the new route for both environment and economic impact.

Political influence is realized through three cities for which the "positive" lobbying is done and three which have a "negative" lobbying. For this case we selected the following assumption: cities Ruma, Šabac and Belgrade do not want the travel route to pass through them, while cities Lazarevac, Smederevo and Obrenovac do want. In accordance with those requirements, the obtained routes are shown in Fig. 12a) and Fig. 12b).

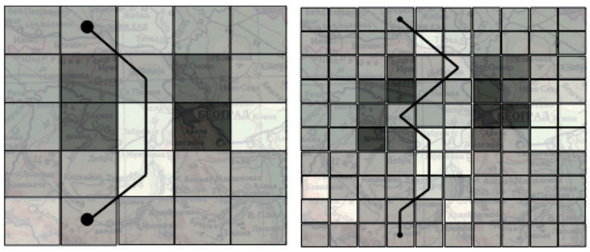

Fig. 12. Optimal route when factor political influence is analyzed for a) r=5 and b) r=10.

All previous results were obtained analyzing the individual factors. All displayed routes could be modified by changing assigned values to every area, parameter r, parameters μ_2 - μ_5 or making the other classification in some factors. These possibilities are addressed to designer and his own requirements.

However, the essence of the proposed algorithm is to obtain a solution that fully balances all individual factors and requirements, although they are completely opposite in some parts of displayed routes. In accordance with the defined phases of the proposed algorithm, the methodology and the classification of observer factors, the final route should involve and analyze all factors. It is clear that final solution could not be a simple interpolation of individual routes or some estimated curve.

We use opportunities of artificial intelligence and analyze all conditions and requirements through proposed algorithm. This final solution is shown in Fig. 13a) and Fig. 13b).

Fig. 13. Final optimal route when all five observed factors are analyzed for a) r=5 and b) r=10.

Through the final route, Fig. 13b), several observed facts are successfully realized:

1. The Mountain (south of Novi Sad) is bypassed,

2. The National Park Fruška Gora is not threatened,

3. The route crosses over only two rivers, which is minimal possible,

4. Algorithm successfully recognizes only one way to avoid the mountains around Valjevo city,

5. The route traces the valley of river Kolubara,

6. Cities Ruma, Šabac and Belgrade are excluded from the final route,

7. The route goes near cities Lazarevac, Smederevo and Obrenovac, which was one of requirements,

8. All observed physical factors are completely satisfied,

9. The route is a solid line without any blind ends or branching and

10. The minimum price requirement is satisfied as much as possible, according to Pareto efficiency.

The final solution, Fig. 13b), is displayed by connecting the centers of selected areas. If we make additional interpolation, we can get a more precise trajectory shown in Fig. 14.

Fig. 14. Interpolated final optimal route when all five observed factors are analyzed on the map.

Since the final solution was obtained by artificial prediction, it was not a simple arithmetic sum of individual solutions. In Fig. 15 and Fig. 16, we comparatively presented a layered view of all the individual parameters, used maps and final route obtained by the proposed algorithm.

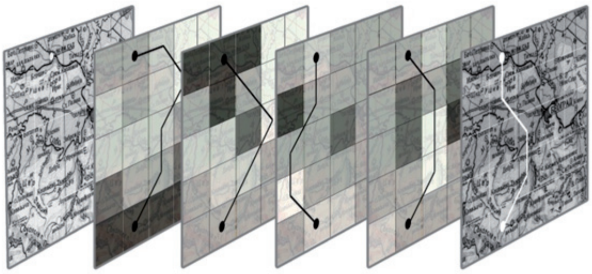

Fig. 15. Group view of individual optimal routes (based on factors: Ct & Cr, Cz, Ce and Cp) and final suggested route for r=5.

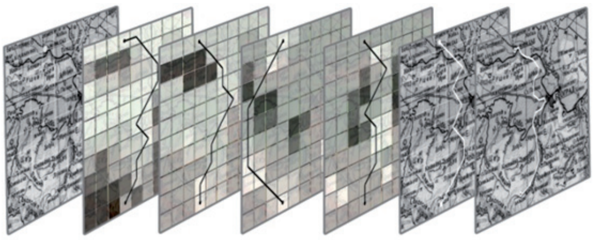

Fig. 16. Group view of individual optimal routes (based on factors: Ct & Cr, Cz, Ce and Cp), final suggested route and interpolated route for r=10.

7. Conclusion

This paper presents a software solution for the route selection problem based on artificial intelligence. The proposed algorithm aims to find a Pareto optimal path with arbitrary number of observed factors. In addition to factors, that make direct influence on the final choice of route, the algorithm offers the ability to involve a large number of conditions and requirements by which planners can further modify the final route. The proposed algorithm should make the complex job of planning routes easier as well as to analyze various types of impacts on the constructions of new roads. Further work will be focused on implementation and optimization of logistics services of transport of goods and services.

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