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USING A GENETIC ALGORITHM FOR THE DESIGN OF AN OPTIMAL TRANSPORT NETWORK

Summary. A transportation network serves the transport requirements of moving people and goods with different destination goals and relocation directions. The current network structure is usually a result of historically long adaptation process and the probability that it is not optimal is very high. Additionally it can be observed a growth of transportation needs. In these circumstances when a modernisation or expansion is required a number of competing designs must be evaluated. Combined total building expenses and maintenance costs are accepted among the evaluation criteria. Such a restriction does not guarantee an optimal solution as only a small fraction of the solution space is analysed. The input data for the optimisation problem cannot be entered in analytical form so it is natural to propose a genetic algorithm for performing the task.

ZASTOSOWANIE ALGORYTMU GENETYCZNEGO DO OPTYMALIZACJI SIECI TRANSPORTOWEJ

Summary. Sieć transportowa służy zaspokojeniu komunikacyjnych potrzeb ludności ukierunkowanych na różne punkty docelowe i różne kierunki. Ponieważ aktualna struktura sieci jest skutkiem długotrwałych procesów w przeszłości prawdopodobieństwo, że nie jest ona optymalna dla obecnych potrzeb jest duże. Dodatkowo, przewiduje się wzrost tych potrzeb. W takiej sytuacji, gdy wymagana jest modernizacja lub rozbudowa sieci transportowej z reguły rozpatruje się kilka konkurencyjnych projektów i następnie wybiera jeden z nich. Jako kryterium rozpatruje się łączne koszty rozbudowy i koszty użytkowania sieci transportowej. Taka procedura nie gwarantuje znalezienia rozwiązania optymalnego, gdyż nawet niewielki ułamek przestrzeni wszystkich możliwości nie jest poddany analizie. Ze względu na to, że dane wejściowe dla tego problemu nie mogą być zadane postaci analitycznej, naturalne jest zaproponowanie algorytmu genetycznego, jako narzędzia optymalizacyjnego.

1. TRANSPORTATION NETWORK DEVELOPMENT

Transportation network is the layout of connections, in a region, between communities of people developed in the course of interaction of economical and social as well as natural environment factors [1].

The current form of transportation network is the result of long term development, which started with the first settlements in the region. When in the course of history modernisation and expansion was done, it was to relieve temporarily grown transport requirements, and the work was based on the current structure of the transportation network. These temporary requirements mostly arouse due to random factors (economical, political, linked with natural environment changes), which as time went by ceased to prevail. In consequence the structure, as a rule, is not optimal.

An additional impediment, in modelling the development of transportation network, is the feedback between the distribution of settlements in the region and network structure:

- localisation of settlements generates transport requirements which affects changes of network structure,
- network structure affects the localisation of settlements.

The task of reconstructing the development of transportation network is complex and requires general historical knowledge. Considering the complexity of the problem successful results were obtained only in cases of railroads or highways [2].

In a simplified approach the historical processes are ignored and the optimal structure of the network is derived on the basis of current transport requirements. This model may be compared with the existing network for determining recommendations, which will bring it closer to the optimal structure. [3].

2. TRANSPORTATION NETWORK STRUCTURE OPTIMISATION

Transportation network structure, in a given region, treated as an isolated object, is the subject of optimisation. All interactions with neighbouring networks are modelled by introducing boundary nodes.

2.1. Assumptions used for defining the optimisation model

Transportation network is represented as a graph, edges represent road connections and vertices represent intersections. During the optimisation process the topology of the graph is modified – edges and vertices are removed or added, also the coordinates of vertices as well as the shape of edges may change. Additionally it is assumed that edges can have an extra attribute – class, which may also be optimised.

Some of the vertices are fixed and are not subject to modifications – these represent actual towns.

Objective function minimised in the optimisation process is the combined cost of constructing the network and of using it. Both constituents are examined over a long period of time in order to, after taking into account amortization, make comparisons plausible. Network construction cost is the cost of building all network connections, which is defined by the length of connections and unit costs of each connection dependent on its class.

Network usage cost is the cost of using all connections, which is defined by the length of a connection, the number of vehicles travelling and unit costs of each trip dependent on the connection class. The loads of particular connections are derived on the basis of a traffic intensity matrix. Traffic intensity matrix presents volumes of traffic streams between network towns. Volume values are measured or estimated using various tools [4].

2.2. Genetic algorithm as an optimisation method

Data characterising natural environment, localisation of settlements and intensity of communication between them in general cannot be described analytically so it is natural to optimise such a system by utilising a genetic algorithm.

Optimisation methods utilising genetic algorithms mimic evolution processes in living nature and are based on the following principles [5]:

- different solution versions compete with each other (individuals),
- structure of each individual is determined by a sequence of genes – genotype,
- genotype is subjected to random changes (mutations),
- randomly chosen individuals may exchange parts of their genotypes (crossover),
- fit function being a measure of adaptation determines the probability of passing to the next generation (selection pressure),
- combining random mutations and crossover with selection pressure leads to optimal solution.

In practice a genetic algorithm searching a scanty part of the solution space finds a solution as close as wished to optimal. Increasing values of fit function, in consecutive generations, are shown schematically in fig.1.

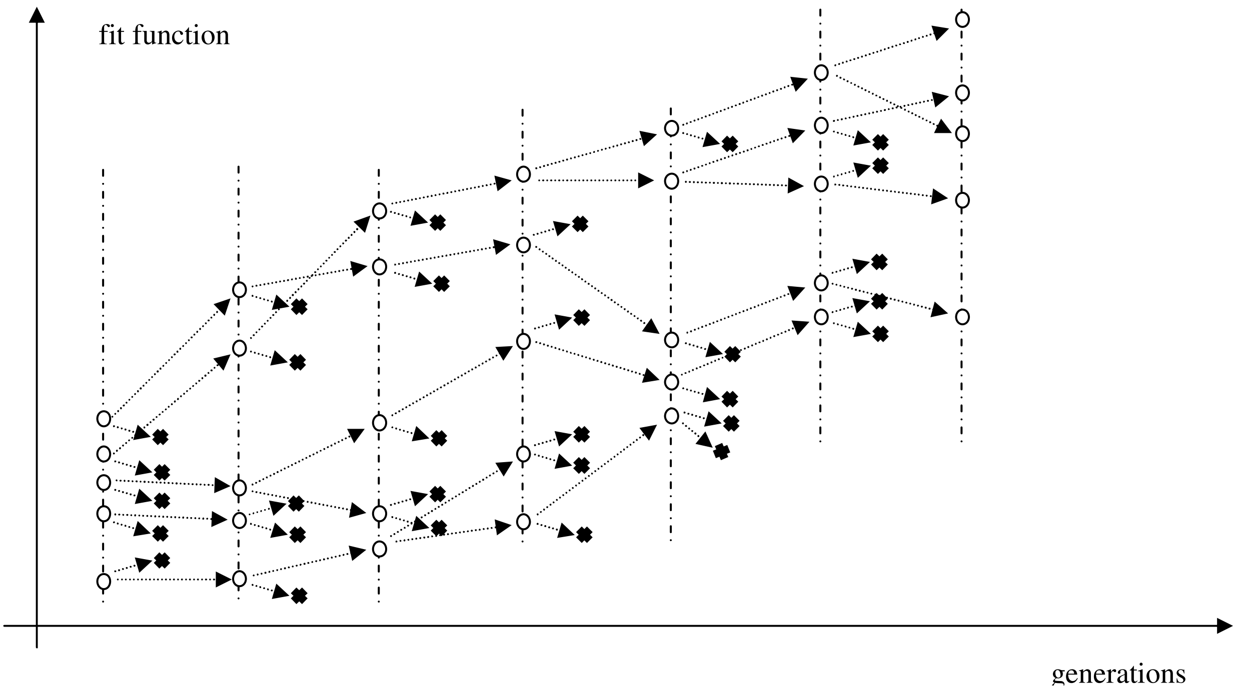

Fig. 1. Increase of fit function at successive generations
Rys. 1. Wzrost dostosowania w kolejnych pokoleniach

Optimisation method based on genetic algorithm surmounts the fundamental problem of optimisation issues: it heads to a global maximum avoiding getting stuck in neighbourhoods of local maxima. It happens, because individuals, currently poorly fit, but potentially close to optimal solution, may enter consecutive optimisation stages (although with smaller probability).

Optimisation process starts by setting up an initial population containing any individuals, next their genotypes undergo random mutations and crossover each other. In the next stage fit functions are calculated for each individual. Fit function is the inverse of the cost of constructing and of using a transportation network. The probability of an individual transition to the next generation is proportional to fit function value. After reaching a set number of generations or a set value of the fit function the optimisation process is stopped. Block diagram of the optimisation procedure is shown in fig. 2.

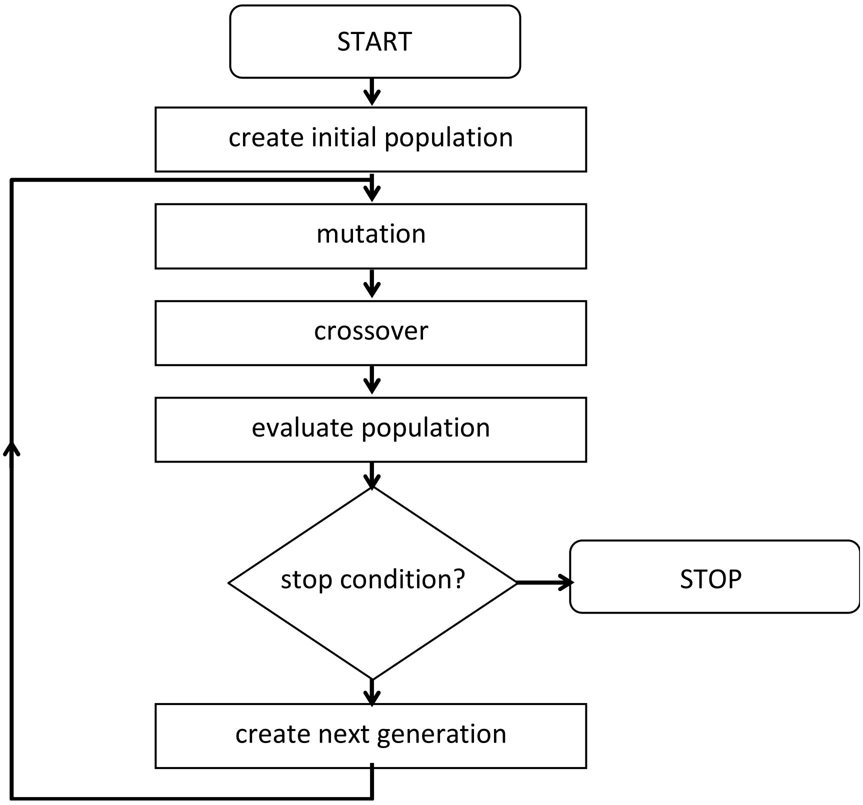

Fig. 2. Phases of genetic optimisation
Rys. 2. Etapy procedury optymalizacji genetycznej

2.3. Genotype coding a transportation network, mutation and crossover operators

The genotype of a transportation network cannot be a linear bit sequence, because it is a complex object freely changing its structure in the process of evolution. Graph representing a transportation network is coded as a co-occurrence matrix of its vertices. The genotype contains additionally, for each connection, a sequence of real values, coding its shape and an integer, coding its class.

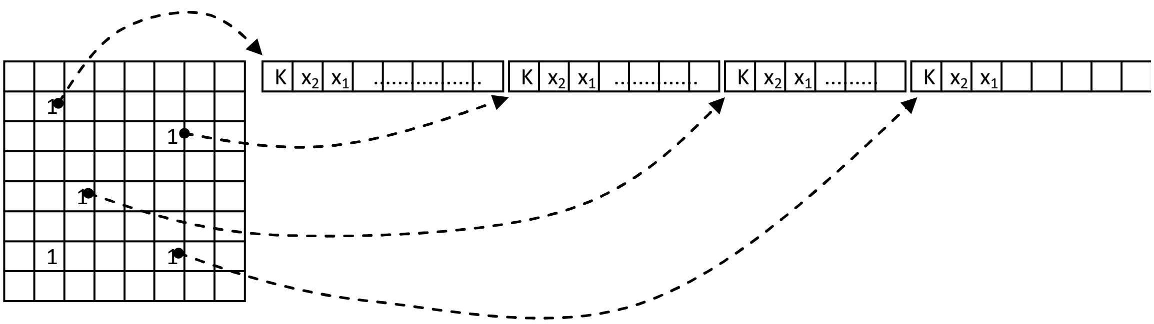

Fig. 3. Outline of genotype
Rys. 3. Schematyczny szkic genotypu

Mutations consist of random changes of genotype. To cope with the complex genotype structure several different mutation operators were utilised:

1. change of values in the co-occurrence matrix corresponds to addition or deletion of connections,
2. inserting and deleting columns in the co-occurrence matrix corresponds to addition or deletion of network nodes, nodes representing "towns" cannot be deleted,
3. change of the number of connection points and their coordinates corresponds to connection shape change,
4. change of connection class.

Fig. 4 demonstrates examples of mutation effects.

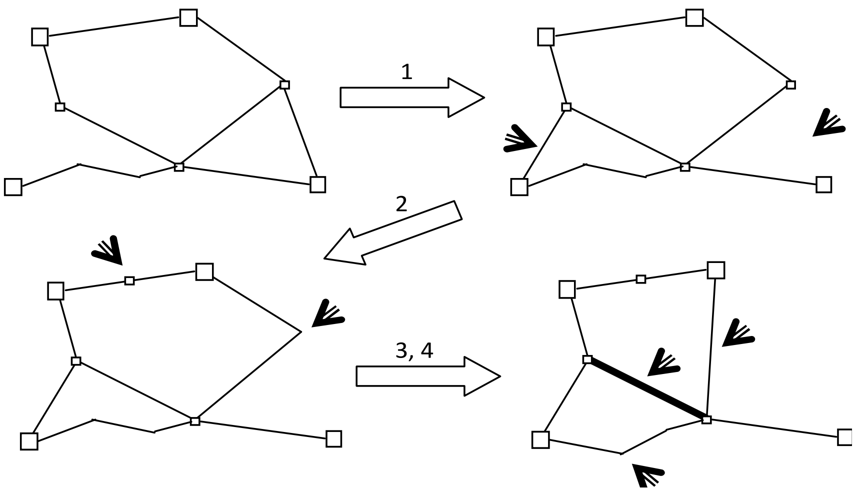

Fig. 4. Examples of mutations
Rys. 4. Przykładowe mutacje

Crossover operators cannot function completely randomly and exchange any parts of genotypes, because this could give abnormal genotypes which do not represent networks. This problem was solved by introducing procedures searching, in the graph, for autonomous segments span between equivalent subsets of towns. If a set of such segments, for two individuals, is found their genotypes are exchanged. The process is presented in fig. 5.

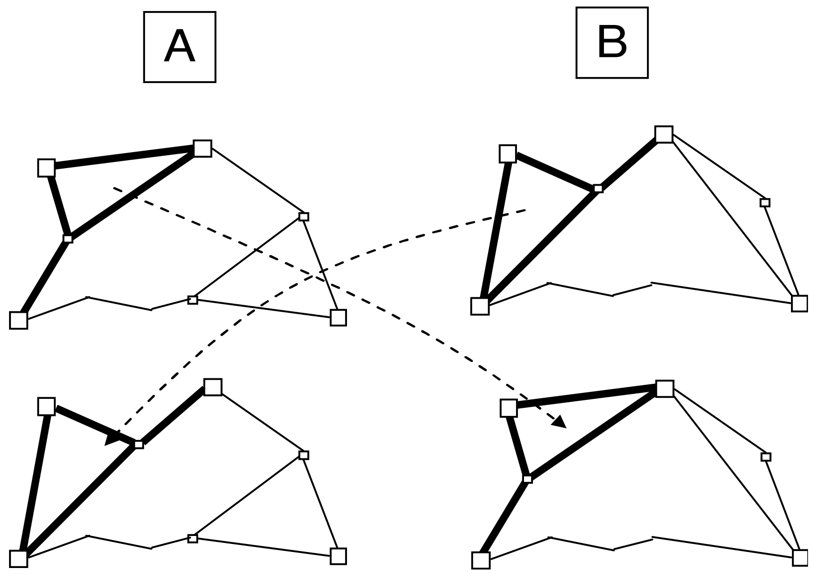

Fig. 5. Crossover
Rys. 5. Krzyżowanie się osobników

2.4. Determination of fit function

The value of fit function for an individual was defined as the inverse of the cost of constructing and of using a transportation network. The calculation of construction cost causes no difficulties since it depends only on easy to derive length of connections and unit cost for a given class of connection:

$$K_{Bi} = D_i k_u[cl]$$

A much harder task is calculating network usage costs on the basis of traffic intensity matrix. The most significant problem is determining the load of all connections that is the number of travelling vehicles. In this case usage cost is the product of normal unit cost (dependent on the class of connection) and the number of vehicles (load) in a given period. When load surpasses set limits extraordinary unit cost is used instead (both unit costs depend on connection class).

$$K_{Ui} = \begin{cases} O_i k_u^{norm}[cl] & when \quad O_i \leq g[cl] \\ O_i k_u^{extra}[cl] & when \quad O_i > g[cl] \end{cases}$$

In reality not all vehicles travelling between chosen network nodes go by the shortest or cheapest route so the determination of alternative route usage is a complex optimisation subtask [3,6].

It was assumed that vehicles travel by the least costly route determined using Dijkstra's algorithm. When the total load of any of the connections surpasses a set limit alternative routes are searched for, bypassing such connections. Streams of vehicles are distributed among different routes using a modified SIMPLEX algorithm. This process is repeated till a state is reached where no route is overloaded or the graph becomes incoherent. The principle of searching for alternative routes between towns is presented in fig. 6. dotted segments represent overloaded connections.

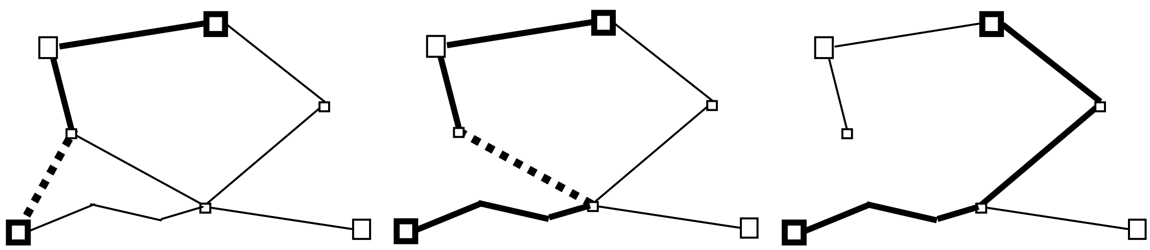

Fig. 6. Searching for alternative paths
Rys. 6. Wyszukiwanie dróg alternatywnych

2.5. Results

The presented method was applied to a number of sets of test data. Solutions required about thousand iterations for a population of a few tens of individuals.

One of the examined configurations consisted of seven towns and solutions for extreme assumptions were sought for:

a. small traffic intensity,
b. very high traffic intensity (about 100 times higher)

For such a simple task it is possible to compare the results with solutions derived using other tools. The comparison shows that it is very close to optimal.

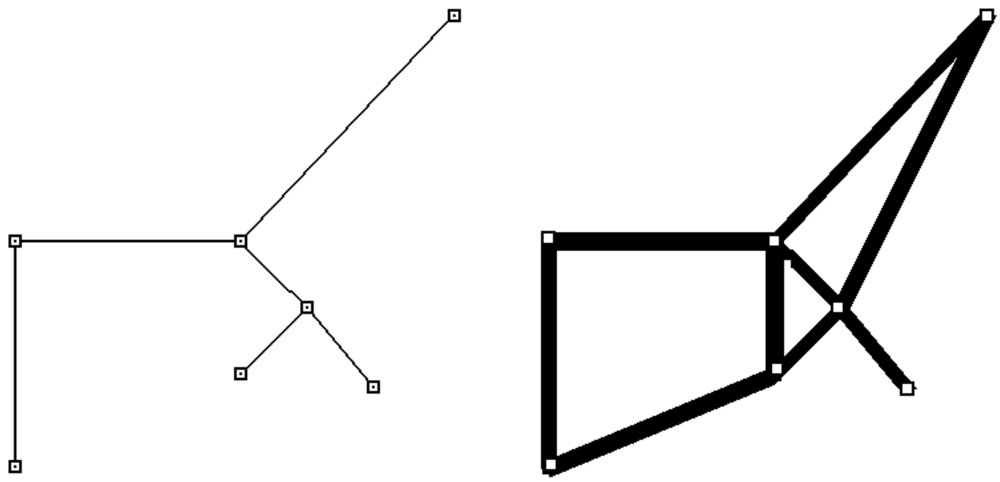

Fig. 7. Solution for set of 7 towns
Rys. 7. Rozwiązanie dla zbioru 7 miast

3. SUMMARY

The work proposes an effective method for designing optimal transportation networks. Achieved results confirm the usefulness of genetic algorithm for solving this type of problems. Relative ease of modelling transportation networks by applying different sets of input data brings about many solution variants for consideration.

Further development of the proposed method will concentrate on investigating building costs in relation to regional topography and on improving algorithm details.

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