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THE DESIGN OF THE PUBLIC TRANSPORT LINES WITH THE USE OF THE FAST GENETIC ALGORITHM

Aleksander Król

Silesian University of Technology, Katowice, **Poland**

ABSTRACT. **Background:** The growing role of public transport and the pressure of economic criteria requires the new optimization tools for process of public transport planning. These problems are computationally very complex, thus it is preferable to use various approximate methods, leading to a good solution within an acceptable time.
Methods: One of such method is the genetic algorithm mimicking the processes of evolution and natural selection in the nature. In this paper, the different variants of the public transport lines layout are subjected to the artificial selection. The essence of the proposed approach is a simplified method of calculating the value of the fit function for a single individual, which brings relatively short computation time even for large jobs.
Results: It was shown that despite the introduced simplifications the quality of the results is not worsened. Using the data obtained from KZK GOP (Communications Municipal Association of Upper Silesian Industrial Region) the described algorithm was used to optimize the layout of the network of bus lines located within the borders of Katowice.
Conclusion: The proposed algorithm was applied to a real, very complex network of public transportation and a possibility of a significant improvement of its efficiency was indicated. The obtained results give hope that the presented model, after some improvements can be the basis of the scientific method, and in a consequence of a further development to find practical application.

Key words: genetic algorithm, public transport, optimization, bus lines.

INTRODUCTION

Due to constantly increasing number of cars the congestion of city centers increases, resulting in worse conditions of life and work in these areas. In many affluent countries that have experienced this problem much earlier these disadvantages were significantly reduced with an emphasis on the development of the public transport. At the same time the central control in the public transport sector is often abandoned: local authorities and local governments grant the necessary authority to commercial organizations. As a result the economic aspects take on a very great importance in the management of the public transport [Zhao 2006].

STATE OF RESEARCH

So, having regard to the limited number of means of transport and staff the most important issues are: optimal routes planning, determine the frequency of courses and the allocation of the transport means [Ceder and Wilson 1986]. In fact, each of these issues is a complex optimization problem, but generally some routines without mathematical reasoning are often used to solve them [Quak 2003]. The first attempts of strict approach to these issues date from the first half of the twentieth century [Patz 1925], more advanced works were created in the 80s, which is related to a significant increase in performance and

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availability of computers [Magnanti, Wong 1984].

Formally, the problem of designing of routes and timetables is NP - hard, so the use of the strict algorithms for such tasks is virtually impossible, due to the extremely long computation time. It is therefore necessary the use of approximate methods, which do not guarantee obtaining the optimal solution, but lead to good solutions within an acceptable time [Bielli, Caramia, Carotenuto 2002]. Especially readily used here are the artificial intelligence methods inspired by the collective behavior of living organisms [Yu, Yang, Cheng, Liu 2005] or based on evolutionary concepts [Ngamchai, Lovell 2003]. Most authors boil down the optimization problem to simple choice of a subset from a predetermined set of established communication lines [Chakroborty, Dwivedi 2002].

In the present work the development of the artificial intelligence methods [Król 2012, 2013] used to solve the problem of routes designing, determine the demand for transport means and determine the frequency of courses is continued. In contrast to the above-mentioned approaches here the full flexibility in shaping the routes is allowed during optimization.

PUBLIC TRANSPORTATION NETWORK MODEL

The main element of the public transportation network model is a weighted directed graph, whose vertices correspond to the bus-stops and the edges correspond to the possibilities of direct transit between stops.

The next important element of the model is the transportation demands. They can be established in a static or dynamic mode. In the first case the transportation needs are described by the origin - source matrix. The elements of the matrix just specify the total number of passengers who want to move between pairs of stops. In the second case there is a sequence of records, which specify the groups of passengers appearing at subsequent times at various stops with the intention of traveling to the relevant target stops.

A single communication line is a series of stops forming a closed loop - ending at the initial stop. There are no restrictions on the course of the line: it can be either circular route, as well as the typical route "back and forth". The total number of available means of transport (buses) and their capacity is determined in advance. Also the initial number of the communication lines is given.

In the process of optimizing the number of the communication lines, their shapes, the buses allocated to them and the waiting times between consecutive courses are adjusted.

GENETIC ALGORITHM AS AN OPTIMIZATION METHOD

Optimization methods using genetic algorithms mimic the process of evolution in the living nature [Arabas 2004]. Different versions of the solutions (individuals who are members of the solution population) compete for the transition to the next generation. These solutions are subject to the random changes (mutations) and randomly exchange some parts of the structure (crossover). The combination of these random operations with the targeted, but also random selection pressure leads towards the optimal solution.

Each individual in the population exposed to the selection corresponds to one of the possible variants of the communication lines layout.

A mutation is random, usually a small change in the structure of solution. The probability that an individual will be subject to mutation is a parameter of the algorithm. Several types of mutations were assumed:

- change in the allocation of buses between the lines,
- change of the waiting time between courses on a randomly selected line,
- change of the number of the lines,
- change of the direction on a randomly selected line,
- realignment of the randomly selected line.

Crossover is the exchange of parts of the structure within randomly selected pair of individuals - randomly selected subsets of the lines are transferred.

If a mutation or crossover leads to the formation of an incorrect individual, the operation is cancelled.

As an unambiguous measure of the quality of a solution the total duration of the transport operation was established - the objective function is the time elapsed from the start of the first course till the delivery of the last passenger to his destination stop. During the optimization this time is minimized. Because the fit function must be an increasing function of the quality of an individual the inverse of the objective function is here used.

In previous works the procedure calculating this time has imitated the real behavior of the passengers [Król 2012, 2013]. Each evaluated individual in the populations, which is a variant of the solution determines the shape of the line and the waiting time between courses - it allows for the determination of the time of the events in the system: bus departures from the subsequent stops. These events are key moments during the simulation. In these moments, the passengers make decisions concerning the route choice and possible transfer stops. Their full knowledge of the schedule was here assumed, which allows them to plan a trip in order to reach the destination as soon as possible. For each just occurred event, for each destination (for passengers at the bus stop and in the bus) all future events of their interest (target and interchange) were calculated.

Such procedure, although well reflecting the reality was very time-consuming and the its application to the real communication networks containing hundreds of stops led to calculations requiring several weeks of CPU time. To make matters worse, the time needed grew very rapidly with the size of the task.

The present paper proposes a substantial simplification, which allows for significant acceleration of the calculations without any loss of quality. The essence of the new approach is the observation that in a real urban environment, with a high frequency of courses and crowded streets precise determination of the time of departure from any bus stop is generally impossible. There is much more important for passengers to be sure that the time interval between two successive departures of buses on the same line with the same stop is more or less constant. Thus, the bus line can be seen as a delineated in the communication network "channel" of a certain capacity and specific times of driving to the next stop (transfer or destination). In this case, for each event, it is a need to select only the most promising at the moment, "channel" (using Dijkstra's algorithm). If the transfer is required (this is a different line than the current one, for which the event occurred), the average waiting time equal to half the time between successive departures is added. Since the analysis of the situation for the event does not require the prediction of all future events, the number of travel options is very limited (each variant is uniquely determined by the current stop, the target stop and the chosen line). In this situation, further improvement was introduced: the best travel options are stored and where the repetition of the event occurs it is not necessary to re of the very time consuming analysis.

When creating the next generation the roulette wheel method is used: the probability of transition to the next generation of an individual is proportional to the value of fit function.

The initial population consists of the identical individuals, for which the shapes of the lines are determined by the popular heuristic procedure [Baaj, Mahmassani 1995, Fusco, Gori, Petrelli 2002]. Its principle is to search the two stops with the greatest transportation needs and the demarcation of the fastest route between them. Successive, due to transportation needs stops either already belong to the route, or are attached to it now. Buses are assigned to the lines evenly with the available pool. Optimization begins therefore from a relatively good solution.

RESULTS

At the first stage the fast new version of the algorithm with the existing one was compared. The subject of the tests was a simple model of the public transportation network consisting of 20 stops [Król 2013]. To meet the transportation needs the 20 buses of a capacity of 60 passengers each were allocated, initially distributed between 4 lines. The transportation needs were established in a static mode, the total number of passengers was 2595. Figure 1 shows the graph of the network with the transportation needs for individual stops (the radius of the circle is proportional to the number of passengers for which the stop is an initial or a destination stop).

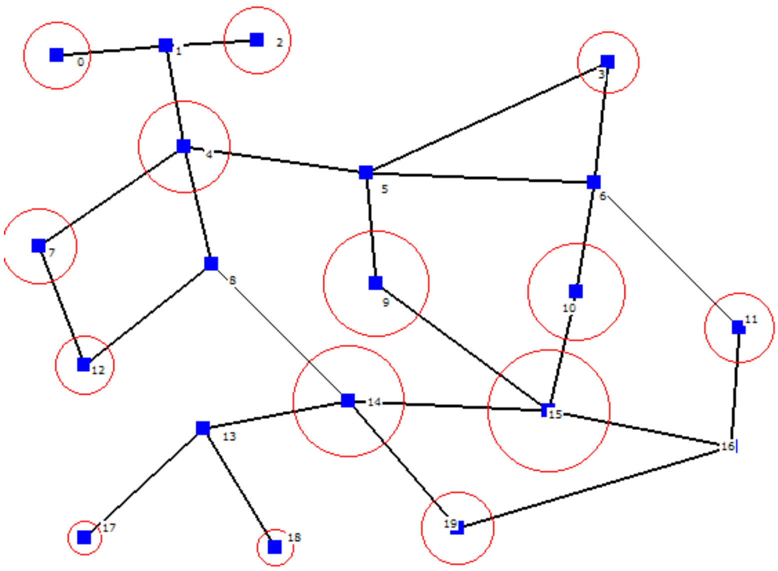

Fig. 1. Graph of the tested public transportation network and the transportation needs
Rys. 1. Graf testowej sieci komunikacji publicznej i potrzeby transportowe

For a fair comparison of the both algorithms, each of them was running several times (genetic algorithm is non-deterministic procedure). The obtained results are gathered in Table 1. As an output of the algorithm the total time of realization of the transportation needs (in minutes) was selected.

Table 1. Comparison of the results obtained using both algorithms
Tabela 1. Porównanie wyników otrzymanych przez zastosowanie obu algorytmów

Criterion	Algorithm	
	Full	Fast
Computation time	9’20”	1’04”
The best result	137’	140’
Average result	150’	148’
Standard deviation	6.7’	7.0’

While analyzing the optimization process it also can be seen that a fast algorithm reaches the final solution much sooner - since about 30 generations the solution has not been practically improved. Meanwhile, the solution of the full algorithm became stable only at about 70 generation. Figure 2 shows the comparison of the average values of the fit function during the optimization for the both algorithms. Thus, the advantage in speed of the fast algorithm is even greater. In addition, the time consumed by the fast algorithm increases with the square of the number of stops, in the case of the full algorithm, this increase is much steeper.

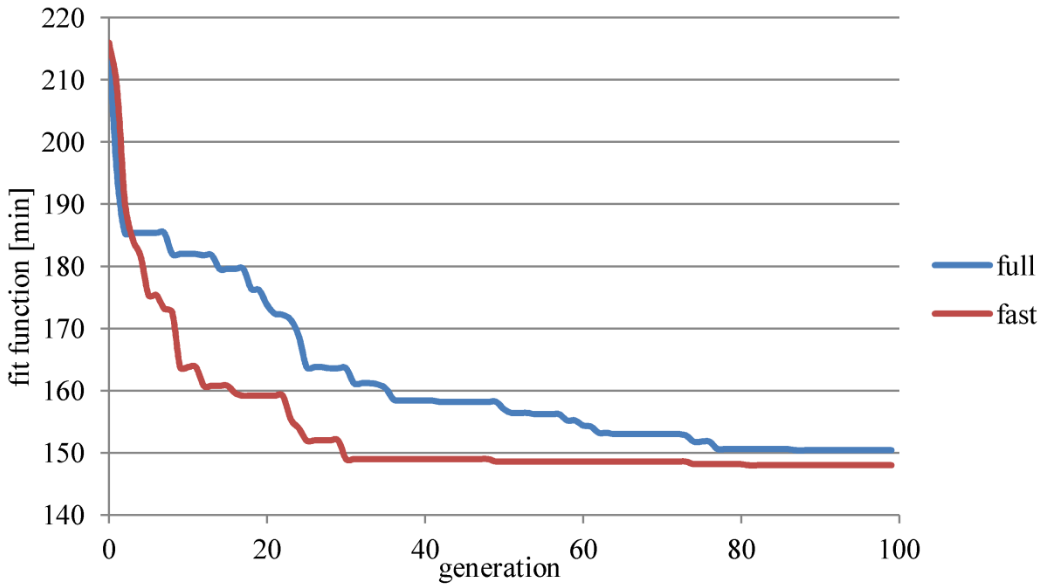

Fig. 2. Comparison of the optimization progress for the both algorithms
Rys. 2. Porównanie przebiegu optymalizacji dla obu algorytmów

After comparing the both algorithms the fundamental research phase was implemented: the fast algorithm was applied to a real, very complex network of public transportation. As the subject of the study a part of the bus lines network of Communications Municipal Association of Upper Silesian Industrial Region (KZK GOP) located inside the city of Katowice was selected. The data acquired from KZK GOP under the work of Giejsztor [2014] was here used. Figure 3 shows a simplified graph of the public transportation network within the Katowice. Transportation needs have been introduced in a static mode, in the form of a source - destination matrix, and values of the elements of this matrix are based on the actual measurements of fillings in buses in March 2011. These values were adjusted using a simulated annealing algorithm so as to get the best accordance with actual fillings. The obtained values describe the average numbers of passengers who want to start their trip in one hour of morning rush time. Since the routes of many lines cross the borders of Katowice and lead to other cities in the region, the summed external transportation needs were assigned to the border stops. As can be seen most passenger intends to travel to and from the city center, lots of traffic is also associated with several stops located on large housing estates on the outskirts of the city. The participation of the trips crossing the borders of the city is much smaller. The details describing the model are summarized in Table 2.

Table 2. The data describing the communication network model of Katowice
Tabela 2. Dane opisujące sieć komunikacyjną w Katowicach

Parameter	Value
Number of stops	281
Initial number of lines	80
Number of buses	350
Capacity of a bus	120
Total number of passengers	24839
Initial time of realization of the transportation needs	225’

The values in Table 2 correspond to KZK GOP resources involved in the operation of bus lines in the area of Katowice. The initial layout of communication lines has been generated by the heuristic procedure mentioned above.

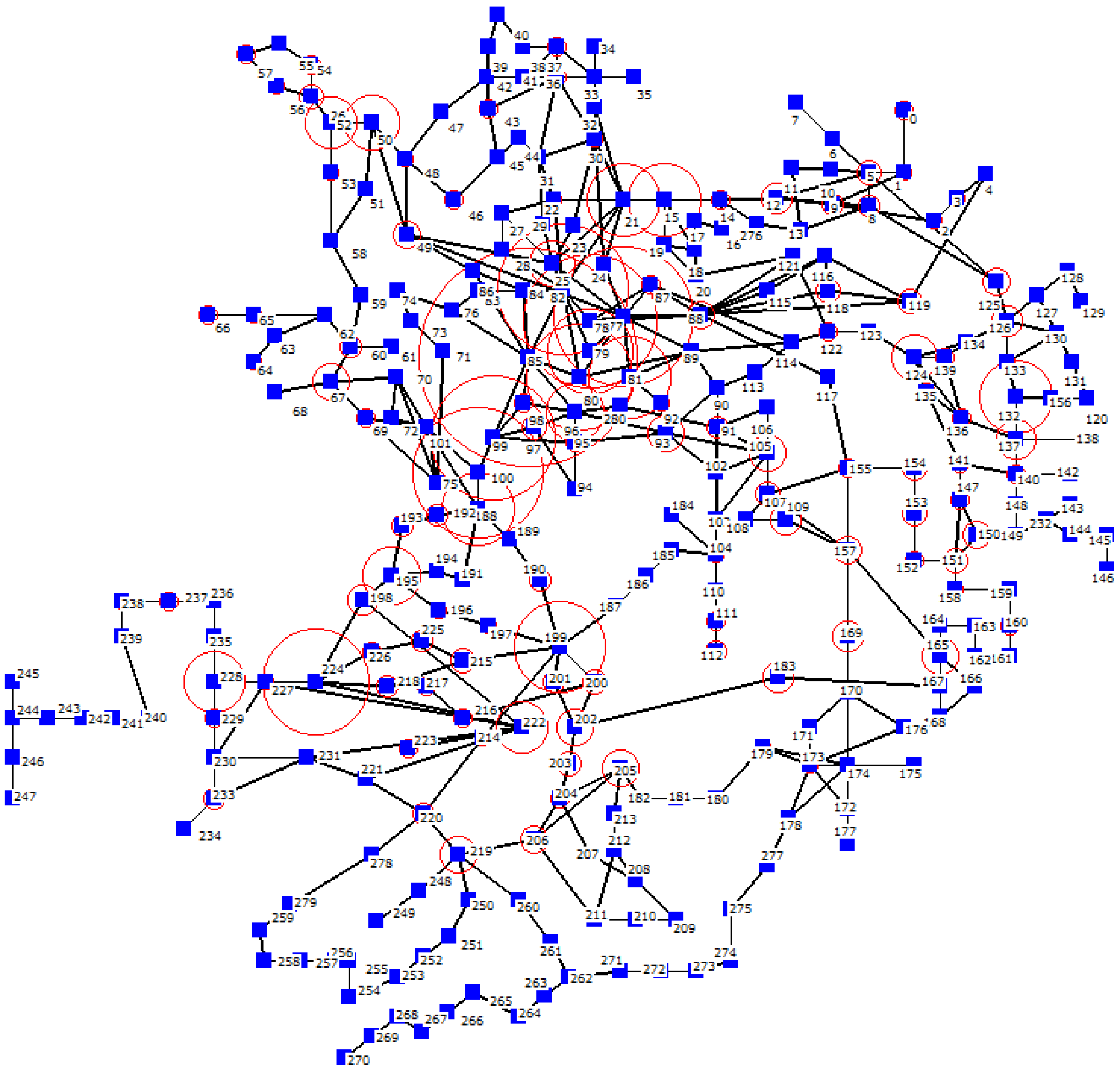

Fig. 3. Graph of the public transportation network and the transportation needs of Katowice
Rys. 3. Graf sieci komunikacji publicznej Katowic i potrzeby transportowe

As a result of the optimization of the communication lines layout the reduction of the time of realization of the transportation needs to 152 minutes was achieved (an improvement of 33%). CPU time required to obtain such result was on the order of a few hours.

In a further series of tests the actual layout of bus lines was optimized. Already preliminary comparison suggests that it is far from optimal. The initial time of realization of the same transportation needs in this case was about 320 minutes. After optimization, the result obtained was similar to the previous (an improvement of more than 50%).

CONCLUSIONS

The paper presents the application of the modified genetic algorithm for the design of the communication lines and the timetable. The proposed algorithm is based on the earlier works, and the essence of the introduced changes is the "macroscopic" look at a public communication line - as a channel of a certain capacity instead of the considerations of movement of the individual vehicles. Tests have shown that both approaches yield identical results, and the new algorithm is many times faster.

The proposed algorithm was applied to a real, very complex network of public transportation and a possibility of a significant improvement of its efficiency was indicated.

The obtained results give hope that the presented model, after some improvements can be the basis of the scientific method, and in a consequence of a further development to find practical application.

REFERENCES

Arabas J., 2004, Wykłady z algorytmów ewolucyjnych [Lectures on evolutionary algorithms], WNT, Warszawa.

Baaj M.H., Mahmassani H.S., 1995, Hybrid route generation heuristic algorithm for the design of transit network,Transportation Research, C 3, 31-50.

Bielli M., Caramia M., Carotenuto P., 2002, Genetic algorithms in bus network optimization, Transportation Research, C 10, 19 - 34.

Ceder A., Wilson N. H. M., 1986, Bus network design, Transportation Research, B 20, 331-344.

Chakroborty P., Dwivedi T., 2002, Optimal route network design for transit systems using genetic algorithm, Engineering Optimization 34/1, 83-100.

Fusco G., Gori S., Petrelli M., 2002, An heuristic transit network design algorithm for medium size towns, Proceedings of the 13th Mini-EURO Conference, Bari.

Giejsztor K., 2014, Zastosowanie metod sztucznej inteligencji do projektowania linii komunikacji publicznej. praca dyplomowa magisterska [The application of the artificial intelligence methods for the design of public transportation lines. Master's thesis], Katowice.

Król A., 2013, Metody sztucznej inteligencji w projektowaniu harmonogramu przewozów dla dynamicznych potrzeb transportowych [Artificial intelligence methods in the design of scheduling for dynamic transportation needs], Autobusy 3/2013, 1369–1384.

Król A., 2012, Zastosowanie algorytmu genetycznego do projektowania harmonogramu przewozów [Application of the genetic algorithm to design of the transportation scheduling], Technika Transportu Szynowego 9/2012, 569-581.

Magnanti T.L., Wong R.T., 1984, Network design and transportation planning: models and algorithms, Transportation Science 18/1, 1-55.

Ngamchai S., Lovell D., 2003, Optimal time transfer in bus transit route network design using a genetic algorithm, Journal of Transportation Engineering 129/5, 510-521.

Patz A., 1925, Die richtige Auswahl von Verkehrslinien bei großen Straßenbahn-netzen [The proper choice of transport lines for large tram networks], Verkehrstechnik 50/51.

Quak C. B., 2003, Bus line planning. Master's Thesis, Delft University of Technology, The Netherlands.

Yu B., Yang Z., Cheng C., Liu C., 2005, Optimizing bus transit network with parallel ant colony algorithm,Proceedings of the Eastern Asia Society for Transportation Studies, 5, 374-389.

Zhao F., 2006, Large-scale transit network optimization by minimizing user cost and transfers, Journal of Public Transportation 9/2, 107-129.

PROJEKTOWANIE PRZEBIEGU LINII KOMUNIKACJI PUBLICZNEJ ZA POMOCĄ SZYBKIEGO ALGORYTMU GENETYCZNEGO

STRESZCZENIE. **Wstęp:** Rosnąca rola komunikacji publicznej przy jednoczesnym nacisku kryteriów ekonomicznych wymaga zastosowania nowych narzędzi optymalizacyjnych do procesu planowania transportu publicznego. Problemy te są bardzo złożone obliczeniowo, więc korzystne jest zastosowanie różnych metod przybliżonych, prowadzących do uzyskania dobrych rozwiązań w akceptowalnym czasie.

Metody: Jedną z takich metod jest algorytm genetyczny, naśladujący procesy ewolucji i doboru naturalnego w przyrodzie. W prezentowanej pracy sztucznemu doborowi podlegają różne warianty układu linii komunikacji publicznej. Istotą proponowanego podejścia jest uproszczony sposób obliczania wartości funkcji dostosowania pojedynczego osobnika, co przynosi stosunkowo krótki czas obliczeń nawet dla dużych zadań.

Wyniki: Pokazano, że mimo wprowadzonych uproszczeń, jakość uzyskanych rezultatów nie ulega pogorszeniu. Korzystając z danych uzyskanych od KZK GOP (Komunikacyjny Związek Komunalny Górnośląskiego Okręgu Przemysłowego) zastosowano opisywany algorytm do optymalizacji układu części sieci linii autobusowych znajdujących się w obrębie miasta Katowice.

Wnioski: Zaproponowany algorytm zastosowano do rzeczywistej, bardzo złożonej sieci komunikacji publicznej uzyskując znaczącą poprawę jej efektywności. Otrzymane rezultaty dają nadzieję, że prezentowany model po udoskonaleniu i może być podstawą naukowej metody, a w konsekwencji dalszego rozwoju znaleźć praktyczne zastosowanie.

Słowa kluczowe: algorytm genetyczny, transport publiczny, optymalizacja, linie autobusowe.

PROJEKTIERUNG VON FAHRSTRECKEN IM ÖFFENTLICHEN VERKEHR ANHAND EINES SCHNELLEN GENETISCHEN ALGORITHMUS

ZUSAMMENFASSUNG. Einleitung: Die wachsende Rolle des öffentlichen Verkehrs bei gleichzeitiger Beeinflussung von wirtschaftlichen Kriterien bedarf für die Planung des öffentlichen Transports der Anwendung von neuen Optimierungswerkzeugen. Die Problemstellungen sind hinsichtlich der Berechnungen sehr kompliziert, daher ist die Anwendung von unterschiedlichen Approximationsmethoden, die zur Erzielung von guten Lösungen in einem akzeptablen Zeitraum führen, sehr brauchbar.

Methoden: Eine solche Methode stellt der genetische Algorithmus, der die in der Natur auftretenden Evolutionsprozesse und die natürliche Selektion nachzuahmen vermag, dar. Verschiedene Varianten von Fahrstrecken-Verläufen im öffentlichen Verkehr unterliegen in der vorliegenden Arbeit einer künstlichen Selektion. Der Swchwerpunkt der vorgeschlagenen Vorgehensweise beruht auf einer vereinfachten Berechnungsmethode des Funktionswertes der Anpassung eines Einzelwesens an einen gewissen Sachverhalt, was eine relative kurze Berechnungszeit, auch im Falle von größeren Berechnungsaufgaben, gewährleistet.

Ergebnisse: Es konnte projiziert werden, dass trotz der eingeführten Vereinfachungen die Qualität der gewonnenen Berechnungsresultate aufrechterhalten blieb. Aufgrund der Daten, die vom Kommunalen Verkehrsverband des Oberschlesischen Wirtschaftskreises gewonnen wurden, hat man den ausgearbeiteten Algorithmus für die Optimierung eines Teiles von Buslinien innerhalb des Verkehrssystems der Stadt Katowice in Anspruch genommen.

Fazit: Der vorgeschlagene Algorithmus wurde innerhalb eines wirklichen, sehr komplizierten, öffentlichen Verkehrsnetzes eingesetzt, wobei man eine bedeutende Verbesserung dessen Effektivität erzielte. Die dabei gewonnenen Resultate lassen die Hoffnung entstehen, dass das projizierte Modell nach weiterer Vervollkommnung zu einer wissenschaftlichen Methode werden und in Folge einer weiteren Entwicklung eine praktische Anwendung finden kann.

Codewörter: geneticher Algorithmus, öffentlicher Verkehr, Optimierung, Buslinien

Aleksander Król
Faculty of Transport
Silesian University of Technology
44-100 Katowice, Krasińskiego 8, **Poland**
e-mail: aleksander.krol@polsl.pl