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# THE SIMULATION OF SOME PARCEL SHIPPING SERVICE OPERATION

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***Abstract:*** *Author in this paper describes the possibilities of solving some vehicle routing variants by genetic algorithm. Specifically, it is a classical capacitated vehicle routing problem (CVRP), vehicle routing problem with time windows (VRP-TW), vehicle routing problem with simultaneous deliveries and pick-ups (VRPDP) and their mutual combinations. Genetic algorithms are a search method used to find suboptimal solutions of complicated combinatorial problems including vehicle routing. Genetic algorithm (GVR) is quite universal due to the two-level representation of the problem – without major modifications it enables successful solving of CVRP, VRP-TW and possibly also other variants of the problem. GVR enables also fast search for new solutions – operators of crossover and mutations provide solutions whose adjustment is not time demanding, and quality of provided solutions is very good, GVR verified with standard data*

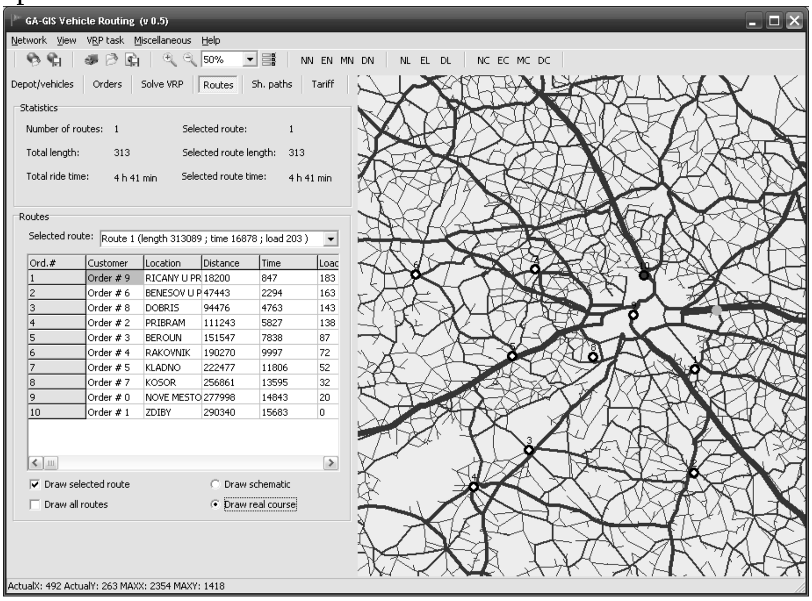
***Key words:*** *Vehicle routing, Optimization, Genetic algorithm, Parcel shipping service*

## 1 INTRODUCTION

The article focuses on possibilities of solving some vehicle routing variants by genetic algorithm. Specifically, it is a classical capacitated vehicle routing problem (CVRP), vehicle routing problem with time windows (VRP-TW), vehicle routing problem with simultaneous deliveries and pick-ups (VRPDP) and their mutual combinations. The obtained results are suboptimal, their quality depends on the instance size and type and on parameters of genetic algorithm. For testing the function of the concept the author created program called GA-GED Vehicle Routing using standard geodata (GIS map sources) to create a transport network model. Parameters of genetic algorithm can be modified in the program environment, the output routes can be presented as texts or/and in map. Each solution is described as the sequence of all customers, while every customer data is stored in binary form. The results calculated by genetic algorithm were verified with standard data. The program can also load selected file formats with standard data in addition to its own text file format. The author in this paper believes, that solving VRP allows to easily build a functional model of network traffic with currently readily available geodata and in real time can deal with finding shortest paths in very large networks.

## 2 GENETIC ALGORITHM GVR

Genetic algorithms are a search method used to find suboptimal solutions of complicated combinatorial problems including vehicle routing. They are based on simulation of natural evolution processes, repeated until reaching the required value for the objective function of pre-defined number of generations or maximum time necessary to find the solution of the problem.



Source: Author

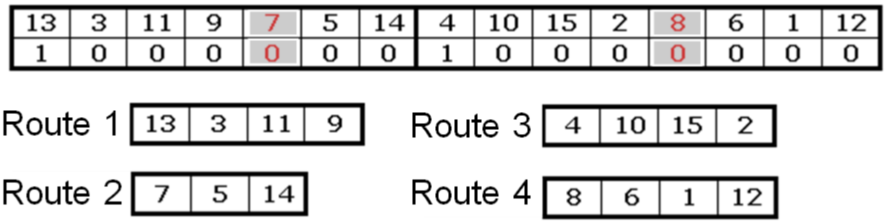
***Fig. 1:*** *Environment of the software GA – GED Vehicle Routing*

A genetic algorithm based on representation and operators GVR, , as described by Pereira et al. in [1], [2], [3] is implemented into the program GA-GED VR. GVR diagram is used for following reasons:

- GVR is quite universal due to the two-level representation of the problem – without major modifications it enables successful solving of CVRP, VRP-TW and possibly also other variants of the problem (Author carried out experimental modification of VRPDP),
- enables fast search for new solutions – operators of crossover and mutations provide solutions whose adjustment (it means obtaining a feasible solution) is not time demanding,
- quality of provided solutions is very good, verified with standard data, as described in [4], [5].

Solution scheme of the problem is simple. Each solution is described as the sequence of all customers, while every customer data (if he is or is not the first customer on the route) is stored in binary form. There are no requirements concerning routes and feasibility of the problem being solved, except that each customer must be served exactly once on one of the routes. Route demands (not exceeding vehicle capacity, maximum route time, time windows, etc) are checked during the interpretation of results; when the demands are not satisfied, a new vehicle with a new route is generated.

The situation is evident from Fig. 2: the chromosome contains two "routes": the first starts with the customer 13, the second with customer 4. The first "route" must be in interpretation divided into two routes, because it is not possible to serve the customer 7 without breaking some constraints (e.g. capacity exceeding). The same repeats in the case of the second "route" for the customer 8 (e.g. maximum travel time is exceeded).




*Source: Author*

***Fig. 2:*** *Route sets obtained using genetic algorithm*

Despite the fact that the problem of vehicle routing is NP-hard, genetic algorithms have a nice feature - the calculation time increases almost linearly with the instance size (number of customers). For example the calculation time of the problem of 500 customers will be approximately five times longer than in case of the problem with 100 customers. The calculation time depends on the pre-set number of generations. The author of the genetic scheme GVR used 50 000 generations; in such a case the calculation of the problem with 100 customers takes circa 50 seconds on a common PC (3GHz Pentium IV). Algorithm converges relatively quickly; a very good solution can be obtained at half the number of generations. The results calculated by genetic algorithm were verified with standard data, as described in [4], [5]; the program can also load selected file formats with standard data in addition to its own text file format.

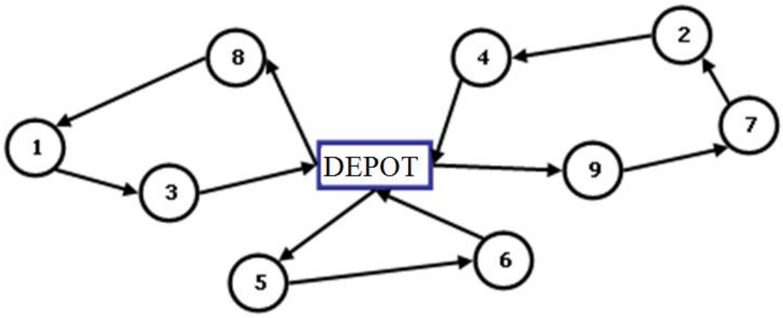
Parameters of genetic algorithm (number of generations, time stop criterion, probability of applying genetic operators) can be modified in the program environment, the output routes can be presented as texts or/and graph (in map).

## 3 INTEGRATED TYPES OF PROBLEMS

### Capacitated vehicle routing problem (CVRP)

Standard capacitated vehicle routing problem (CVRP) can be described in the following way: there is one central depot to serve customers ***J***, while we know the distances $d_{ij}$ between objects (depot and customers) on the transport network, number of vehicles ***V***, each of them with delivery capacity ***Cr*** to serve the demands of customers $b_j$. Each vehicle must start from the depot and return there, each vehicle can be used only once satisfying each customer by just one visit. The aim is to find a set of vehicle routes of minimal total length. Distances $d_{ij}$ can be substituted for time availability $t_{ij}$ - then the aim is not to search for the shortest routes but the routes with the shortest travel time.

It is possible to solve the above-mentioned problem type in the GA-GIS environment by two different algorithms - well known Clarke-Wright method and genetic algorithm GVR (see below), which can also contain solution obtained by the Clarke-Wright method in the set of solutions.



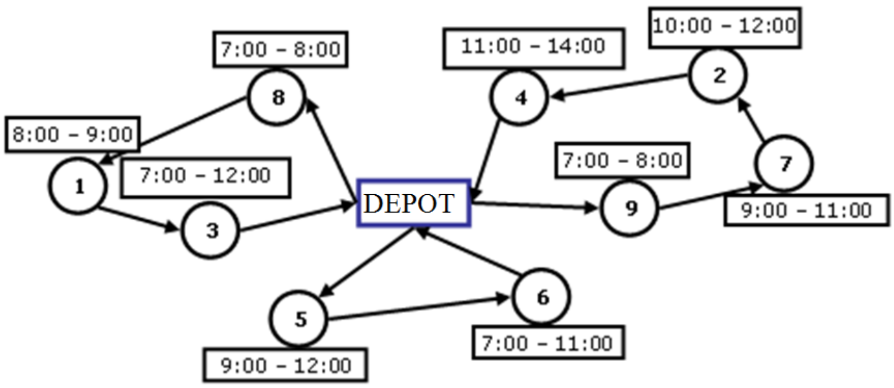

*Source: Author*

***Fig. 3:*** *Standard vehicle routing problem*

**Vehicle Routing Problem with Time Windows (VRP-TW)**

Vehicle Routing Problem with Time Windows (VRP-TW) can be viewed as a combination of vehicle routing problem and problem of scheduling. It is an extension of the basic problem for “time windows“. For every customer it specifies the time interval ($e_i$, $l_i$), in which it is necessary to satisfy the customer‘s demands within the route. Each customer service usually involves a specified service time $f_i$ and maximum travel time $T_{max}$ valid for any vehicle. Practical application is evident (limited storage working hours, requirements to defer the order until the specified time, etc.).

Problem with time windows can be solved only by genetic algorithm with a modified method of the routes sets for individual vehicles (plus checking time demands).




*Source: Author*

***Fig. 4:*** *Vehicle routing problem with time windows*

**Vehicle Routing Problem with Simultaneous Delivery and Pick-Up Service (VRPDP)**

Vehicle Routing Problem with Simultaneous Delivery and Pick-Up Service (VRPDP) is specific because each vehicle can provide delivery and pick-up simultaneously. According to particular customer demand - some customers require pick-ups only, some deliveries only and some both services.

These problems again can be solved only by modified genetic algorithm. This means a new application of GVR genetic scheme to find solutions for this variant of the problem. Detailed analysis of the quality of obtained results has not been carried out yet.

## 4 MODIFICATIONS MADE TO THE GVR ALGORITHM

As written above, all demands on vehicle routing are considered during interpretation of results. Genetic operators of crossover and mutation are proposed to ensure that the permutation of customer sequence will contain all customers and each customer exactly once.

Such solutions can always be interpreted as valid solutions, when the beginning of each route has been defined. Every time when inserting a new customer into the existing route violates some constraint (vehicle capacity, travel time, customer time windows), another route of another vehicle will be started with this customer.

**Modification of Vehicle Routing Problem with Time Windows (VRP-TW)**

GVR algorithm has been already used to solve the problem with time windows by its authors (Pereira, F.B., Tavares, J., Machado, p. Costa, E.) where a slightly different crossover operator (then for the problem without TW) has been successfully used, as described in [3]. Necessary modifications in relation to the solution of VRP-TW arose from the demand for solving different combinations of problems, specifically how to keep the time window constraint simultaneously with the maximum travel time. For time $t_i$, (arrival time to the customer i) these possibilities can happen:

- $t_i$ lies within the time interval ($e_i$, $l_i$) – in such a case it is possible to start servicing the customer immediately;
- $t_i$ is lower than the value of $e_i$ – in such a case the vehicle waits for the time $e_i$, waiting time $w_i$ equals difference between $e_i - t_i$.
- $t_i$ is higher than the value of $e_i$ – in such a case the vehicle cannot service the customer $i$, this customer will be served first in the new route.

To minimize the vehicle travel time, the vehicle departure from the depot is scheduled to reach the first customer exactly on time $e$. Together with this is calculated maximum permitted delay value. For the customer $1$, the maximum permitted delay value is the difference between $l_1 - e_1$, for other customers then $l_i - (t_i + w_i)$. Every time the vehicle visits the following customer, maximum permitted delay value is recalculated according to the time window constraints valid for that customer and diminished if necessary. Every time when the vehicle is supposed to wait for the time $w_i > 0$ and together with it the relevant permitted delay $i_s > 0$, maximum piece of the delay is used to minimize the waiting time, it means that the departure time of the vehicle from depot is postponed until later.

**GVR algorithm in solving vehicle routing problems with simultaneous delivery and pick-up (VRPDP)**

Probably for the first time has the GVR algorithm been used for solving vehicle routing problems with simultaneous delivery and pick-up. When checking time data, it does not matter if the customer demands delivery or pick-up service; the difference is only when checking the vehicle capacity exceeding:

- If the customer demands pick-up, it is necessary to check only if the load of certain weight at given time did not exceed the vehicle capacity;
- If the customer demands delivery, the load of certain weight is loaded already in the depot; so it is necessary to check if the vehicle had sufficient loading capacity for the whole previous route, it means for all the customers served before this customer (including depot).

## 5 VALIDATION OF APPLIED APPROACH

**CVRP and VRPDP problem – standard data**

Tab. 1 compares the quality of results obtained with some data instances presented by the Augerat et al. [4]. These data are intended for testing algorithms for CVRP; because in the time of publishing the article the Author did not have any available results for standard data of VRPDP, they used the same data as Augerat et al. Every fourth (25%) or second (50%) order is delivery to the depot and the others are pick-ups from the depot. Genetic algorithm was set for 50 000 generations and run only three times for every instance. Presented value of the objective function corresponded to the best solution. It is possible to reach further improvements of the results when extending the number of generations or with multiple repetition of algorithm running. In the objective function the made distance is minimized, the number of routes is not optimized nor constrained. The quality of results obtained when solving VRP-TW has not been presented. It would be in accordance with results presented by Pereira in [3].

***Tab. 1:*** *Quality of results obtained with some data*

| Data instance[1] | CVRP The best know solution | CVRP (GVR) | VRPDP 25 % (GVR) | VRPDP 50 % (GVR) |
|---|---|---|---|---|
| A-n39-k6 | 831 | 835 (6 routes) | 726 (5 routes) | 702 (4 routes) |
| A-n48-k7 | 1 073 | 1 098 (7 routes) | 907 (5 routes) | 823 (4 routes) |
| A-n60-k9 | 1 354 | 1 385 (9 routes) | 1141 (7 routes) | 957 (5 routes) |
| A-n65-k9 | 1 174 | 1 193 (9 routes) | 967 (7 routes) | 895 (5 routes) |
| A-n69-k9 | 1 159 | 1 171 (9 routes) | 961 (6 routes) | 961 (6 routes) |
| A-n80-k10 | 1 763 | 1815 (10 routes) | 1 591 (8 routes) | 1342 (6 routes) |

*Source: Author*

**Model example - VRP-TW, VRPDP, VRPDP-TW**

For the purposes of modeling the real life problem, random demands from the area of one the Czech regions were generated; random allocation of demands respected distribution of inhabitants in given area. Formulated problem contained 305 delivery demands, 39 pick-ups, average consignment weight was 10 kg, vehicle capacity 2 000 kg, maximum travel time 8 hours. Time windows were randomly generated, all with the same time (120 min). The results are presented in Tab. 2.

The effect of randomly generated, relatively short time windows is evident. Dramatic increase of the number of routes together with made distance. Simultaneous pick-ups and deliveries can, on the contrary, reduce the costs and number of routes substantially.

***Tab. 2:*** *The results*

| | |
|---|---|
| **CVRP problem (Clarke-Wright algorithm)**<br>Delivery: 1 184 km / 40,38 hours / 6 routes<br>Pick-up: 497 km / 9,3 hours / 2 routes<br>Total: 1 681 km / 49,68 hours / 8 routes | **CVRP problem (GVR algorithm)**<br>Rozvoz: 1 162 km / 40,1 hours / 6 routes<br>Pick-up: 421 km / 8,43 hours / 2 routes<br>Celkem: 1 583 km / 48,53 hours / 8 routes |
| **VRP-TW problem (GVR algoritmus)**<br>Delivery: 2 292 km / 99,47 hours / 21 routes<br>Pick-up: 610 km / 17,63 hours / 4 routes<br>Total: 2 902 km / 117,1 hours / 25 routes | **VRPDP-TW problem (GVR algorithm)**<br>Total: 2 589 km / 113 hours / 23 routes<br><br>**VRPPD problem (GVR algorithm)**<br>Total: 1 302 km / 45,01 hours / 6 routes |

*Source: Author*

[1] Standard test data come from the VRP Web (presented by Auger et al. in [4, 5]). This is the data of classic problems of capacity limited with a single depot. Designation indicates the number of customer demands and number of available vehicles (eg A-n39-K6 corresponds to the situation with 39 points and 6 service vehicles).

## 6 CONCLUSION

Created environment for solving VRP problems enables easy building of functional transport network from currently easily accessible geodata and is able to cope with searching for the shortest routes even in extensive networks in real time. Implemented algorithms for solving CVRP, VRP-TW and VRPDP provide satisfactory results. Nowadays GA-GED VR has been constantly developed and tested, in the future there will be other problem and algorithm types implemented.

The benefit of this paper is primarily creation of new program and modification of the program to other types of problems that has already been published. Namely, to improve the algorithm for the vehicle routing problem with time windows (VRP-TW), where arrivals were optimized vehicles to customers in order to best farmed with limited duration of the route. Furthermore, the algorithm was modified so that it can be used to address the role of the current collection and distribution (VRPDP).

## 7 ACKNOWLEDGEMENT

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**References**

[1] Pereira, F.B., Tavares, J., Machado, P. Costa, E.: GVR: A New Genetic Representation for the Vehicle Routing Problem. (2002). In: Proceedings of the 13th Irish Conference on Artificial Intelligence and Cognitive Science, Springer-Verlag.

[2] Pereira, F.B., Tavares, J., Machado, P. Costa, E.: GVR: On the Influence of GVR in Vehicle Routing. (2003). In: Proceedings of the 2003 ACM Symposium on Applied Computing, ACM Press.

[3] Pereira, F.B., Tavares, J., Machado, P. Costa, E.: GVR: GVR Delivers It on Time. (2002) In: SEAL02 4th Asia-Pacific Conference on Simulated Evolution And Learning.

[4] The VRP Web [on line]. (2011). [cit. 2011-08-12]. Available from: <http://neo.lcc.uma.es/radi-aeb/WebVRP/>.

[5] VRPTW Benchmark Problems. (2011). [cit. 2011-07-10]. Available from: <http://web.cba.neu.edu/~msolomon/problems.htm>.

[6] Shapefile C Library V1.2 (2011). [cit. 2011-06-19]. Available from: <http://shapelib.maptools.org/>.

[7] Alumur, S., Kara, B.Y. Network Hub Location Problems: the State of the Art. (2008). European Journal of Operational Research, Elsevier, ISSN 0377-2217.

[8] Černá, A., Černý, J. Teorie řízení a rozhodování v dopravních systémech. (2004). Institut Jana Pernera, o.p.s., 1. edition,159 pp., ISBN 80-86530-15-9.

[9] Janáček, J. Optimalizace na dopravních sítích, 2. prepracované vydanie. (2006). Žilinská univerzita v Žiline, Žilina, 248 pp. ISBN 80-8070-586-0.

***Review:*** *Reviewer name*