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An Optimization Prototype for Distribution Planning

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Abstract — **One of the most important problems in the transportation networks is the physical distribution optimization. A huge effort has been invested in cutting the transport costs via computer optimization of vehicle routing. Abstractly, the task is known as the vehicle routing problem (VRP) and there exist many different algorithms for approximate solutions, with various tradeoffs. The main goal of the problem is to carry out deliveries from the central storage facility to all customers incurring minimal costs. Generally, putting VRP into practice presents a number of additional difficulties, from obtaining road network information, gathering data about shipments and packaging to efficient coding of algorithms. The purpose of this paper is to present development and implementation of a transport routing application for a special distribution centre and customer network, the environmental aspect being importantly represented in the model. Namely, the presented distribution optimization model can be a useful tool for trading as well as for manufacturing companies that face problems and questions related to distribution of goods and at the same time aim to be competitive from the eco-friendly aspect, as well. The paper presents new findings on further optimization options of goods distribution and new challenges for further research.**

Index Terms — **distribution. vehicle routing problem. optimization. simulation**

I. Introduction

In scientific and professional circles plenty of models and tools, used for various physical distribution optimizations, are known. These tools are tailored to customer specific needs and as such cannot be easily implemented in specific cases. Therefore the basic properties and principles of these models are presented first and in the continuation a structure of the model, used for the physical distribution optimization in the largest Slovenian company for energy products distribution, is shown. The work presented in this paper is a result of a part of the national research project “A Model for Technical and Economic Optimization of a Logistics System” that is financed by Slovenian Research Agency (ARRS), involved building a functional optimization tool for delivering goods from one storage house to several destinations in Slovenia on a daily basis, using available transportation vehicles and subject to certain conditions. The focus of the optimization is to minimize the transportation costs and environmental burdens, which typically linearly correlate with a distance travelled by transportation vehicles involved.

In the studied company the physical distribution optimization represents a special example of the problem, in professional public known as Vehicle Routing Problem (VRP) (Toth and Vigo 2002, Golden 2008, Laporte 1992). Many practical versions of the VRP problem are known, but all of them have in common that so far there are no efficient universal algorithms for the exact solution of an individual problem. Therefore the VRP problems are usually approached by constructing nonexact algorithms or combining various methods, respectively (Cordeau et al. 2005 and 2006, Gendreau et al. 2008, de Oliveira et al. 2008, Paessens 1988, Pisinger and Ropke 2007, Taillard et al. 1997,…)

In this VRP problem numerous goods have to be dispatched from a warehouse to the designated recipients by vehicles from the existing vehicle fleet, numerous specific conditions and factors being considered. So, in the concrete optimization properties of each individual vehicle (capacity, price per kilometer driven, maximum allowed driving time in accordance with the law, …), recipient or destination properties (warehouse capacity, allowed delivery time …), properties of an individual product (transport unit shape – pallet, box …, weight, volume, durability …) should be considered. The physical distribution optimization in the studied company is an especially difficult case. Combinations of various metaheuristics based on a local optimization, the 'tabu search' technique and certain methods from the genetic algorithms were used. In the continuation the methods and techniques used are presented in detail.d).

II. Collection, editing and preparation of data

At the beginning the presentation of the data that are included in the optimization model is discussed, as their suitability is a key factor for the correct optimization and interpretation of the obtained results and solutions. The optimization includes the following databases: the geographical information systems (GIS) of the road network: geometrical data summed up in charts that present road sections and coordinates of places, warehouses and locations of recipients, lists of goods to be delivered and parameters of vehicle fleets (capacity, price per kilometer, regions of activity).

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A. *The geographical information systems (GIS) of the road networks*

Today many different GIS data bases containing geometrical data of the road networks, where potential recipients are located, are available. Besides the geographical (geometrical) data from the GISs the distribution optimization requires databases that also include other data e.g. place names, road categorization etc. the GISs are usually supported by the databases that are a combination of the classic databases supplemented by the search mechanisms of geometrical objects in the two-dimensional (2D) or three-dimensional (3D) space (enquiries regarding location, closeness, initial distance etc.). In the GISs the geometrical data are presented as point objects, line objects (e.g. polygon lines) or panel objects (polygons). The road sections are presented as lines, where the coordinates of the initial and final destinations as well as the lengths of individual sections can be calculated – namely these data are key elements for the distribution applications. All data are presented in a cartographic coordinate system, so-called »Gauss–Krüger« coordinates. Although geometrical properties of the road sections (where they start, curved and straight sections, final destinations) are detailed described by the geographical data, a suitable combinatorial data structure should be derived from them, which would be appropriate for the algorithms regarding the optimal (the shortest) road sections.

Suitable data structure for a road section is a weighted graph or a network, respectively. A graph is constituted by junctions and connections among them. In our case the junctions represent places, intersections, joining etc., while the connections represent road sections among the latter. In the weighted graph the junction network and/or connections give the additional information (weights). On the connections the weights are represented by the lengths of individual sections, the hierarchy of roads of these sections etc.

To create a graph from the given geometrical data for the road sections a robust algorithm had to be created, which considered minor errors in entering of the road section border points. One must be aware of the facts that in the GIS the road sections data are given, but they should end in the junctions. Due to the errors in entering the coordinates in the GIS, it can happen that the coordinates of two sections end points in an intersection can be different for a certain value. Even if this difference would be only e.g. 1 meter, the real life experiences show that this implies a contact of road sections. Therefore a version of the intersecting spheres algorithm is used, where each geometrical point of section end points is imagined as a sphere of any radius, e.g. 1 meter. If the spheres of two end points intersect, this determines a joint junction.

B. *Locations of warehouses and recipients*

In the studied problem an especially difficult process is represented by a geographical determination of recipient coordinates and their addresses. The addresses were obtained from the database of the studied company, while Gauss–Krüger coordinates for the GIS systems could in principle be searched by the use of the the GIS database. These addresses were entered by a free access online service http://geopedia.si, developed by a company Cosylab and is built on this database. This service was used for inventory of tens of thousands of recipients emerging in the studied period. The list of recipients in the studied period was obtained from the company information system.

Obtaining the Gauss-Krüger coordinates is a process that can be largely automated (computer uses enquiries in the GIS to search suitable coordinates for the given address list). Due to human errors in entering the customer information in the system, some of the addresses have to be determined manually. Generally, a rule, that while entering a new recipient in the company database coordinates for delivery have to be entered at the same time, should apply. Of course, customer coordinates do not match the junctions from the road network graph. Typically, recipients are located slightly away from the roads or by the road sections and rarely at the end of the road section. For the purpose of the combinatorial optimization in the graph (the shortest routes, deliveries) a road network graph must be created, where the recipients intersect. Then our problem is reduced to searching the shortest routes or deliveries according to the road network graph, respectively, where the recipients are presented as the junctions of this graph. Recipients can be added in the graph as junctions in such a way that they are placed by the coordinates on the nearest end of a certain section. If more accuracy is required, then the sections are subdivided on the nearest point of the nearest road section and a new point representing a recipient is inserted in the graph. It is useful that the junctions also include information regarding a direction, if it is a one-way street. So in fact a data structure of a directed road network, together with delivery locations, is obtained. The road network discussed in the paper is divided into over 100.000 sections. For the research purposes over 30.000 delivery locations had to be entered in the model.

Given all this, an appropriate database needed to be prepared. The construction of a platform on the open-code database PostgreSQL was outlined, which also supports the GISs by PostGIS. In the continuation the database is also used for storing other data (e.g. section lengths, categorization and delivery data, as well).

C. *Lists of goods to be delivered*

From the studied company data base the relevant data were summarized and exported in the PostgreSQL database. The inventory included transcription of the transport codes as well as the number and types (volume, weight, packaging type) of the transport units for each order. While the lists of the goods to be delivered (or. lists of orders, respectively) are essential components of all the PISs, quantification of transport units is typically left for the picking process in a warehouse. The number and type of the transport units is data, created during the order picking process and is not know until the process is finished. For further delivery optimization this data represents an essential input of the information system. Knowledge of the extent and type of transport unit that need to be delivered to the given locations is a prerequisite for the preparation of the automatic algorithms that in considering a capacity of transport vehicles properly distribute the load among the latter.

D. Parameters of vehicle fleets (capacity, price per kilometer, region of the activity)

If the data regarding the number and type of the transport units, where each transport unit is delivered to one location only and the transport units are standardized (e.g. pallets, containers, boxes), quantified (volume, weight) or have a negligible volume or weight (smaller boxes, folders, letters etc.) are given, then quantity of the transport units that can be loaded to an individual vehicle can be automatically determined regarding capacity of the delivery vehicles (trucks, light delivery vehicles etc.).

As already mentioned, the loaded transport units largely determine the delivery route – only order of delivery destinations have to be determined. But each delivery vehicle has parameters that determine the final price of the delivery. Such parameters are e.g. delivery price per kilometer, price of an individual delivery and etc. Besides that, each vehicle has parameters that determine limitations, such as the maximal carrying capacity, the maximal volume and capacity to distribute the transport units of larger volume (e.g. quantity of pallets that can be loaded) etc. These data can be easily obtained and depend on a type of rented or owned vehicle fleet.

III. The model for the delivery optimization

In the concrete problem presented in the paper a set of n products $(g_1, g_2, \ldots, g_n)$ need to be delivered from the warehouse location l_0 to m recipient locations $L=(l_1, l_2, \ldots, l_m)$ through the road networks. The final destination of the product g_i is marked by $loc(g_i)$. As already mentioned, the road network is modeled by the weighted graph G. Besides the recipient locations, its junctions also represent the intersections of the road sections, while the connections (the sections) are typically directed. Each connection (the section) s is directed by the section length $len(s)$. Along each connection the information of the expected travel time along this section $dur(s)$ (or alternatively – average speed) is kept. Each product g_i has its own weight w_i and its own volume v_i. The vehicle fleet is consisted of k delivery vehicles $(V_1, V_2, \ldots, V_k)$. The maximal load weight of each vehicle V_j is $wcap_j$ and total volume is vol_j. Its specific price per kilometer is c_j. Let x_{ij} be an integer variable with value 0 or 1, which reflects whether a product g_i is loaded on the vehicle V_j (in the selected solution). Let $X_j=(x_{1j}, x_{2j}, \ldots, x_{nj})$ and let $L_j=\{loc(g_i)|x_{ij}=1\}$ be a set of delivery locations for the goods on the vehicle V_j. For each X_j a sequence of deliveries Z_j is defined, as well. $len(X_j, Z_j)$ marks the length of the shortest tour in the graph G, which begins at the warehouse location l_0, visits all the locations in L_j in an order determined by Z_j, and in the end returns to l_0. The length of the tour is obtained by addition of all the connection lengths (segments, $len(s)$) that were visited. Similarly, let $dur(X_j)$ present time needed for such a tour. Then a criterion functions can be defined as

$$f((X_1, Z_1), \ldots, (X_k, Z_k)) = \sum_{j=1}^{k} c_j \cdot len(X_j, Z_j).$$

The optimization solutions (X_j and Z_j) must meet the minimum of the criterion function. Typically, price is directly proportional to the total length of the route driven by all the vehicles and can depend upon a number and type of all used vehicles and a number of pauses made by an individual vehicle (regarding the fixed costs). If a vehicle V_j is not used, the associated list Z_j remains empty.

Usual limitations in VRP include limitations regarding the total weight and the total volume of the goods loaded to a truck.

$$\sum_{i=1}^{n} x_{ij} w_i \le wcap_j, \text{ for each vehicle } V_{ij}$$

$$\sum_{i=1}^{n} x_{ij} v_i \le vol_j, \text{ for each vehicle } V_j$$

Besides these limitations a product is allowed to be loaded on one vehicle only. For practical purposes some additional limitations are sensible, as well. As an example – in the studied case the professional drivers were limited to eight hours of driving per day, therefore $dur(X_j)$ must not exceed this time for all the vehicles. The tour is entirely defined by the variables X_j and Z_j. So, the aim is to find an optimal tour in the given limitations and possibilities. Generally, some more complicated versions of VRP exist, where there are additional conditions. Beside the mentioned criteria and conditions some other criteria that determine the optimal tour also with respect to energy consumption and gas emissions from the transport units, can be included in the model.

From the computability theory it is known that the above defined VRP represents a difficult computational problem or NP-hard, respectively, if the terminology from the theoretical computer science is used (Garey and Johnson 1979). A practical NP-hard problem means that there is no algorithm (or is unknown, to be precise) that would surely solve the general problem instance in the time that is smaller than the exponential time dependent on the extent of the problem, in our case measured by the list length. Therefore the nonexact algorithms are usually used, which give good solutions relatively quickly. The latter are significantly better (and faster created) as the solutions searched by the empirical norm. If a problem is looked at intuitionally, a solution is searched through the following steps:

- the initial, still acceptable tour is created;
- the operation family is defined, which from the given tour constructs the »neighboring«, similar tours; the operations can be imagined as a set of ways how new tours are created from the existing ones;
- the best tour regarding the criterion function is identified by checking the neighboring tour; then the procedure of generating the neighboring tours is repeated from this new tour; this enables better and better tours;
- when the tour, from which the operations do not create no better tour, is reached or when potential tours are checked »long enough« (regarding the calculated

capacities that are still acceptable), the procedure is finished and we return to the best determined tour.

The above mentioned procedure is an example of a pragmatic solving of problems that cannot be solved in any other way, but with a systematic check of as many possibilities as possible. The NP-hard problems are of the same type – with a very weak internal dependence among individual solutions, so that even from the calculated data few conclusions can be made to ease the search.

The above procedure that is slightly more formally and consistently formed is called »local optimization« and works on the following principle: each tour, good or bad, allowed or no allowed (admissibility is applicable, if additional limitations are added), is called a »configuration«. In our case the configuration is defined by a vehicle, distribution of goods to individual vehicles and by determining a rout for individual vehicles. Over the configuration family a set of operations is given, which are used to create new configurations from each configuration. These operations are usually reversible and the set of operations contain finite number of those. The set of all the configurations, which are obtained by the operation application to the given configuration, is called a » neighborhood" of the given configuration. Within the selected local optimization the neighborhood of the given configuration is checked and the spot is then moved to the optimal configuration in the neighborhood. Then this procedure is repeated in a new configuration. The above described procedure always leads to a better configuration or to a configuration that is the best of ala the configurations in its neighborhood and is the optimal one (the local optimum).

In general, the local optimization procedure is relatively easy. It has to be stressed out that with an unfortunately chosen initial configuration the local optimization procedure leads only to the local minimum. In NP-full problems there are lot of the local minimums when choosing any sensibly small neighborhoods (small enough families of operations). So, one can be easily stuck in one of those. There are many alternatives to address these problems. One of the possible solutions is to repeat the procedure several times, but using different initial configurations. The procedure can be repeated regarding the processor time as many times as needed. Finally, the best of the local optimums is selected. More effective approaches are so-called »metaheuristics«. Metaheuristics can be imagined as managing strategies of enquiries in the local optimization. These strategies enable more effective search of the local optimum. Examples of such metaheuristics are the genetic algorithms, simulated annealing and tabu search. Algorithms that use the tabu search were proved to be relatively easy and effective for the problems, related to VRP. Today the most contemporary algorithms are so-called »hybrid« algorithms that combine various different metaheuristics (Toth and Vigo 2002).

In our case the genetic algorithms and simulated annealing were not used, because the tabu searched proved to be effective enough. A well thought neighborhood check was also carried out, where parts of the neighborhoods, which were not checked yet, were reviewed. A concrete way of installation of the tabu search in our algorithm is slightly more complex, since it is necessary to prohibit implementation of certain operation combinations with regard to the search method. The detailed review can be found in Taillard et al., 1997. The criterion function is very important in such a search as well as a decision what the allowed configurations are. Some configurations could not be allowed, because the cycles are too long or too many vehicles are used etc. If certain configurations are declared to be inadmissible, when the configurations, barely admissible, are used, the generated neighborhoods are often smaller. In fact this limits the search space in a relatively robust manner.

In the classical alternative approach some configurations are not declared as inadmissible, but rather punished in the criterion function. This creates a slightly more complex criterion function that has more parts. In configurations that appear to be sensible, only the criteria related to the problem itself is considered. In the configurations that break the restrictions (and would otherwise be declared as inadmissible), an inadmissible component is additionally punished and this causes that the configuration is unfavorable and the algorithm will try to »escape it«. In such a manner too long routes, too many trucks, unevenness in the distribution of truck etc. can be punished. This allows much greater freedom to find solutions with respect to much more complex restrictions. Here, adding additional restrictions is facilitated. Namely, this is the way to deal with the more complex versions of VRP, that is VRP with an additional restriction of a route length (this is sensible thing to do, because trucks are allowed to drive eight hours per day, only) and restrictions with respect to delivery terms (e.g. if some customers require deliveries in the defined time window). Both mentioned problems are known as VRPD (VRP with duration) and VRPTW (VRP with time windows).

To assure the best possible computational intensity, it is sensible to calculate the shortest routes simultaneously and rather kept them than to calculate them in advance. Usually, the classic Dijkstra's algorithm enabling the search of the shortest routes from one point to the other ones in the graph is used. Although number of locations equals few thousand, the graph has much more points (intersections, junctions etc.). To the existing sub-graph the Dijkstra's algorithm systematically adds connections to new junctions. To this graph (tree) of the shortest routes with the root in the selected start junctions a connection to the next point is added by a principle that this connection creates the shortest route from the start junction to the u junction, using the mentioned tree. In principle, all the shortest routes, from the start junction to all other junctions, are calculated in such a manner, which represents a lot of unnecessary work, since the primary interest is the distance between the two points. By considering the straight lines among places the junction checks can become uneconomic, due to too large air distances. The search is postponed, because one hopes in the meantime to find the shortest route and that discussion of those junctions and possible routes through would not be necessary. The algorithms that search possibilities in such a way belong to a family of so-called A* algorithms. The shortest route is searched by a hybrid between the Dijkstra's and A* algorithms, where the shortest routes are calculated simultaneously, if needed, and stored for the later use. One must be aware that storing the shortest routes in the network containing some 10.000 junctions, cannot practically be performed, because too much of the memory would be used to store several 100 millions of different shortest routes..

IV. SIMULATIONS AND TESTS

Finally, visualization is also important for the customer using the program tool for delivery optimization, because it enables the user to carry out the analysis. In our case the GIS data is presented by using the open-code program SharpMap. The same program was used for visual simulations of the calculated tours.

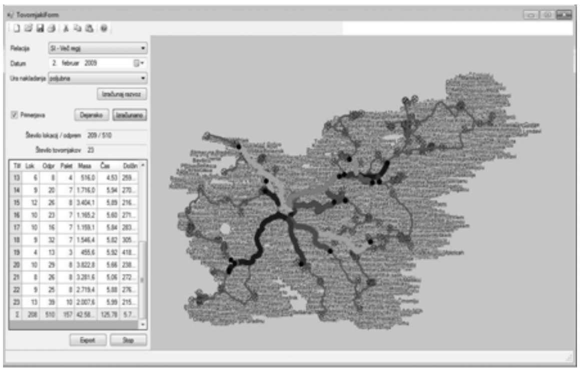

FIG 1. The optimized route is presented by using the customized software SharpMap. Source: adapted from Strašek et al., 2011.

The simulations showed that problems with approx. 1.000 delivery locations can be solved within few minutes by using the classic computer. So, the algorithms used can be assessed as very effective. The latter is confirmed by the results of the researches, carried out by the eminent researches who estimate the obtained results differ from the optimal ones for 1 % at the most.

V. POSSIBILITIES FOR FURTHER RESEARCH

At first glance, the distribution optimization appears to be an easy problem and the majority first thinks about reductions in the transport costs or physical distribution. As can be read in the paper it can be a really complex system, where transport is only one of many functions. Unfortunately, the presented model cannot be evaluated, because some data from contracts with external transportation companies and data with respect to cost prices of routes are in the studied company considered as business secrets. It is worth to mention that the proposed solution represent savings up to 30%.

While creating the presented optimization model we came across a mass of new ideas for further research in this field. The optimization model can be extended by considering additional criteria for assessment of optimal routes and considering the storage function of the distribution process. Namely, the storage function enables plenty of optimization possibilities, e.g. increase in goods warehouse flow and installation of an in-depth information support for both meeting orders as well as knowledge of the goods in the warehouse. The extended criteria would be sensible with respect to adaptation of the relevant criteria and considering the economic and political guidelines as well as with respect to economic views on diversification of the used transport means (e.g. railways, water transport).

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