Practical Implementation of an Extended VRP Model

Rok Strašek, Alen Orbanić, Iztok Kavkler

***Abstract* — One of the most interesting problems in transportation networks is the Vehicle Routing Problem (VRP). Given a set of goods, a transportation network with delivery locations and a fleet of transportation vehicles the goal is to carry out deliveries from the central storage facility to all customers incurring minimal costs and subject to certain additional constraints. Computationally this is known to be a hard problem. However, with a computational technology of nowadays, it is feasible to find "good enough" solutions in a reasonable time. The purpose of this paper is to present one such prototype tool, which is focused on the road transportation in Slovenia.**

Transportation networks are usually modeled by weighted graphs. With development of Geographic Information Systems (GIS) geographic information concerning transportation networks and other geographic information relevant for logistics became available for research and practical purposes. In Slovenia, GIS data on transportation networks are maintained in Cadastral register of the economic public infrastructure.

During the efforts invested in optimization of processes of a leading Slovenian energy company, it turned out that the transportation costs represent an important component of a storage facility operation. In our case specific additional constraints have to be taken into consideration such as use of different types of vehicles, with different capacities (trucks and vans), different costs per kilometer and limitation of route duration to 8 hours due to regulations. As an additional constraint, some customers occasionally require delivery at a certain hour of day. With this constraint we have a well known and a well studied problem of VRP with time windows (VRPTW).

The initial situation involved a central storage facility from which a fleet of more than 20 vehicles coming from several regions in Slovenia carried out deliveries on a daily basis. A dispatching in the storage facility was manual and the delivery locations were first distributed to route regions. We have developed a practical prototype software implementation which uses the data from the information system of the storage facility, GIS data of the transportation network, integrated together with an open source tool for graphical representation and our own implementation of special purpose optimization algorithms. For optimization we use heuristics based on local optimization upgraded with some meta-heuristics like tabu-search. The system is operational but as it is further tested in practice, we expect yet unforeseen constraints to emerge.

The system represents a powerful tool for research in road transportation logistics in Slovenia. The emphasis is set on implementation of algorithms which have to be structured in such a way that incorporation of additional constraints in the future is possible. In our case additional constraints are included in the object function through penalization when particular constraint is not respected.

***Index Terms* — Transportation optimization. Vehicle routing problem.**

I. INTRODUCTION

Research in optimizations of the road network transportation involves several interesting problems, ranging from the simplest ones like the calculation of the shortest paths between two location to more complex problems including several variations of the Vehicle Routing Problem (VRP). While the research can be carried out on a completely abstract basis (development of algorithms, statistical methods, …), for the purpose of the logistics research in the particular geographical area and a particular type of transportation, the real life transportation network data is required.

Until recently such data was difficult to obtain, but with the development of the Geographic Information Systems (GIS) this became much more accessible to wider public. Such a research is highly interdisciplinary and involves experts in logistics, computer science and mathematics. The first step in such cooperation is establishing a functional research tool which will enable us to work on the specific transportation network equipped with all the data required.

It remains a constant challenge in the logistics to reduce the transportation costs. It is well known that certain transportation problems are computationally hard (NP hard), but with increasing computation power available, many instances of problems of practical size can already be calculated in a reasonable (practically acceptable) time, even on personal computers. Possibilities to access real transportation data and sufficient availability of computation power are sufficient conditions for a successful development of a computational research prototype system on which logistic analyses and research can be carried out. For a special purpose, such as in our case, integrating with a particular warehouse management systems (WMS) enables us to set up a platform on which full range of discrete computational analyses can be performed.

II. OPTIMIZATION MODEL

The work presented in this paper is a result of a part of the research project "A Model for Technical and Economic Optimization of a Logistics System", financed by Slovenian Research Agency (ARRS), involved building a functional optimization tool for delivering goods from one storage

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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 transportation costs which are typically in linear correlation with distance travelled by transportation vehicles involved.

In order to implement a prototype tool, its architecture has to be considered first. In the first place this involves establishing the data model. With a good data model relevant data are easily accessible as an input to optimization algorithms and for statistical analyses. In our case or research purpose is focused on the logistic processes linked with the distribution of a central storage facility.

The most important data sources for our optimization model are the following:

a) digitalized network,
b) relevant data on goods which have to be transported,
c) specification of processes involved including their requirements and constraints.

In recent years Surveying and Mapping Authority of the Republic of Slovenia established Cadastral register of the economic public infrastructure of the Republic of Sloveniain which the data from geographic information systems covering Slovenian road infrastructure is stored. It is easily accessible to research community in Slovenia. The geospatial data includes complete Slovenian road network in the form of categorized road segments. According to the relevant laws, all Slovenian roads are categorized. The categorization can be used to determine expected velocity of vehicles on the road segments. We are aware that this is a rather poor approximation for real situation on the road segments as the real expected velocity of the traffic is a function of many variables like inclination, curvature, quality of the road, position relative to the closest intersections, time of the day, etc. We believe that with further data collecting about the road segments on the national level will improve the informatization of our road network enabling us to carry out certain optimization with data of high quality.

The information on goods that have to be distributed is usually easily obtained from the information systems of storage facilities. Managing of such facilities without adequate information system is nowadays unimaginable. In our case, such system contains all the data about daily orders, destinations and other characteristics of goods like weight, size, packaging, etc. The orders typically contain the address of the customer. Through address the GIS coordinates of the location can be calculated enabling us to position the customer into the digital road network.

In the process of the delivery we assume that the goods orders are distributed to transportation units each with a single destination. Transportation units are packaged in the form of a few standard packings (pallets, boxes, containers,…). In our case we divide transportation units into two groups, namely the ones with a significant weight and volume (like pallets, containers,…) and the others in smaller packings (smaller boxes, envelopes, …). The latter group includes the transportation units that do not occupy significant weight and volume capacities of transportation vehicles. We assume that the number of smaller units is so small that only the "heavy" transportation units are to be considered to occupy transportation vehicle capacities. For instance, if one truck can take 15 pallets, usually several smaller boxes more can be loaded on to or beside the palettes.

Our classification reduces to goods on pallets (or in containers) and the goods without significant weight and volume. Nevertheless, each transportation unit loaded on a transportation vehicle implies that the vehicle's visit of the unit's destination is mandatory.

But even using the simplification above, the actual packaging is not known in advance (i.e. before actual packing in the the storage and distribution centre - SDC). Before the packing, only estimates on the number of the transportation units can be done using the information about orders. Optimal packaging itself is a hard optimization problem, which is not addressed in this paper. The real number of pallets is known only after the pick to order process for one particular order is accomplished. In general this should not be a significant problem. But in our case the information on the actual number of pallets was not available in the digital form. The actual packing was considered irrelevant for the SDC, as the deliveries were outsourced. This type of information would be very helpful in testing and fine-tuning of the optimization algorithms since the results could be directly compared with the real costs, in particular with the actual cost charged to SDC by the transportation companies. The lack of this type of data turned to be the biggest data bottleneck of the system.

Without proper considering of processes involved in delivery the data model could not be realistic. Studying the process of delivery reveals certain conditions that have to be met if the optimization results are to be acceptable. A driver can deliver a limited number of goods depending not only on the capacity of his transportation vehicle but also on his limitations on working time and the length of the route. Certain customers may require deliveries in certain time windows. Relevant data is also certain knowledge 'embedded' in drivers. For instance, while our system may propose a certain route, an experienced driver may know that at this time of the day a particular road segment is terribly congested. All customers are not easy to reach at all the times as well. The knowledge about the drivers work processes is also necessary to take into account all time consuming little tasks that have to be done when delivering transportation units. From this point of view we still have a long way until incorporating all that knowledge. On the other hand, optimization algorithms may not look just for an optimal solution but also for less optimal solutions which are more robust in terms of changes required in cases of sudden change of plan.

III. Optimization Method and Its Implementation

A. The algorithm

With an appropriate data model established we were able to approach the optimization problems. The optimization problem to be solved is a variant of a well known Vehicle Routing Problem (VRP) with certain additional constraints [1]. The usual presentation of VRP consists of a set of items that have to be delivered to a matching set of customers with a fleet of transportation vehicles in such a way that the overall transport cost is minimized. Each item has a corresponding

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item weight and each vehicle has a *capacity*, the maximum total weight it can carry. The road network is represented as a graph with weighted edges, where edge weights represent the cost of travel along that road (usually, the cost is proportional to the length of the road). For each customer and the initial distribution center there is a corresponding node in the graph (though the graph can have many more nodes than that).

For the standard VRP, vehicle capacities are the only constraints considered. Moreover, all vehicles are assumed to have the same capacity and the size of the vehicle fleet is not limited. In practice, more limitations have to be taken into account. The vehicle fleet is limited and inhomogeneous, with price per kilometer depending on the vehicle size. The driver has a limitation on the number of working hours per day and in most cases the route has to be finished within that time. A particularly nasty additional constraint is the requirement by certain customers to have deliveries at certain times (the difficulty arising from the fact that it makes the optimization space much sparser). The later problem is known as VRP with time windows (VRPTW).

Even the simple VRP is a hard problem from the computational point of view. Namely, it is NP-hard which means that no polynomial time program for producing exact solutions exists. In fact two well known NP-hard problems – travelling salesman and bin packing – are actually special cases of VRP [2]. For this reason, exact solutions of VRP exist only for very small examples (~20 customers) or for certain artificially constructed graphs. In our application, the number of customers often exceeds 500 and the road graph is quite arbitrary.

Luckily, the nonexistence of exact solutions is not a serious problem in practice as long as good enough approximate solutions can be found in reasonable time. After all, even the approximate solutions found using the computing power of a modern computer is usually much better than most ad-hoc solutions that can be constructed by hand. There exist a number of methods for finding approximate solutions of both VRP and VRPTW. Most are based on the idea of local optimization: start with an arbitrary configuration (assignment of customers to vehicles) and proceed by making small changes like reassigning a customer from one vehicle to another or exchanging the order of delivery for two customers on a single route. The simplest local optimization algorithm starts with a randomly generated configuration and at each step chooses the small change that most decreases the total cost. To prevent the violation of constraints, local optimization algorithms use the idea of penalties: every broken constraint carries an additional cost. By properly assigning penalties we can be quite certain that the algorithm will converge to a solution that respects the constraints.

The simple local optimization algorithm has the shortcoming that it always finds the nearest local optimum, which is usually much worse than the global optimum. An easy remedy is to repeat the algorithm many times with different random starting configurations. But there exist better strategies of avoiding local optima, so called metaheuristics [3]. The technique we implemented is known as tabu search [4]. Unlike simple local optimization, tabu search allows considering configurations with worse cost than the current; however, it prevents the same configuration to be checked again, thus safeguarding the program against falling in an endless cycle. Tabu search does not end after finding the first local optimum – it continues searching, always choosing the best configuration that has not been considered before. In this way it can take much longer than local search, but often finds much better solutions.

B. Implementing the optimization method

Even on today's fast computers the local optimization with tabu search for several hundred customers can be a time consuming task. A number of program optimizations are required to make the program run in acceptable time (a few minutes for a typical instance).

First useful observation is that even though the road graph can be huge, only the shortest roads between customers and the depot can be used in an optimal solution. Therefore a much smaller graph can be precomputed that contains as nodes only customers and the depot and as edges only the shortest routes between each pair of such nodes. The shortest path calculation uses a combination of Dijkstra's algorithm and A^* algorithm for fastest running time.

Another observation that can save a lot of time is that the cost can be recalculated incrementally after every change in configuration. To make further use of this, it is useful to maintain a list of best candidates for next configuration change, and at every step update only the part of list that has changed. Unfortunately, there is a tradeoff in the last technique: it can make the program significantly more complicated and difficult to adapt to changes in specification, especially changes in constraints.

Finally, in order to take advantage of current multicore hardware we need to make the implementation parallelizable. This can be done either by processing several configurations in parallel or by running several instances of the program in parallel and choosing the best of the achieved solutions.

C. The prototype application

To test the usability of the optimization method, we have built an application in C# that obtains the data about actual orders from company's information system and proposes optimal routes for delivery vehicles.

The geospatial data from the Cadastral register has been converted to PostGIS [5] format and stored in a PostgreSQL [6] database with the PostGIS extensions. For faster execution, some data about road distances has been preprocessed and is stored separately. To visually present the customers' locations and the solution we have created a GUI using SharpMap [7], the C# binding to PostGIS. Figure below shows the result of the optimization for the deliveries in one region of Slovenia.

For operational data, we currently use a snapshot of the depot's database which contains all the data about the delivery items. The information about vehicle sizes has been obtained from the contracts with transporters. Unfortunately, the information system does not contain the data about actual transports that have been used, which complicates our evaluation of quality of the prototype application. Since the only information about the actual transport cost are monthly

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reports by the transporters, we cannot compare it with the calculated cost on daily basis; we can only compare the monthly cumulative.

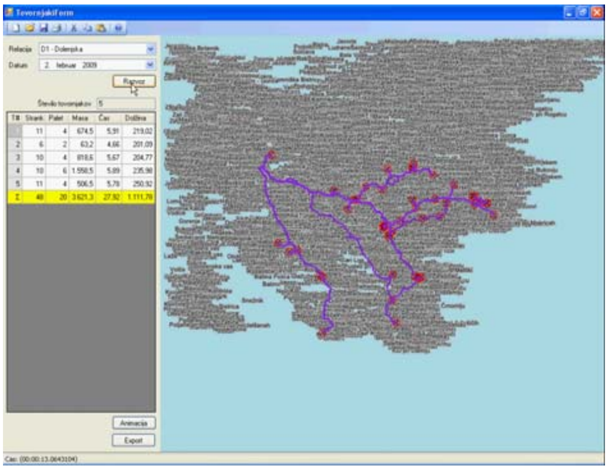

Figure 1: A screen shot from our prototype tool implementation showing the choice of the trucks and the routes to be taken.

IV. Further Work

The current result is an implementation of the optimization algorithm along with connections to snapshots of real data. To make the application practical, we need to improve it in two directions: first, by comparison of obtained results with some known near-optimal solutions we can tune the algorithm to find better solutions. Second and more important in practice, we need to obtain and use the information about further constraints for which we have no data yet, such as road restrictions for different vehicle types, traffic congestions, actual average times needed to travel a certain road, and times needed to unload items from vehicle. Finally we need to compare the prototype results with actual data to estimate whether the reduction in transportation costs justifies deploying the application for everyday use.

References

[1] Toth, P., Vigo, D., *The vehicle routing problem.* SIAM, Philadelphia, Monograph on Discrete Mathematics and Applications, Philadelphia. 2002.

[2] Garey, M. R., Johnson, D. S. *Computers and Intractability: A Guide to the Theory of NP-Completeness*, 1979, W. H. Freeman & Co., New York.

[3] de Oliveira, H.C.B., Vasconcelos, G.C., A hybrid search method for the vehicle routing problem with time windows, *Annals of Operations Research*. Springer, 2008

[4] Taillard, E., Badeau, P., Gendreau, M., Guertin, F., Potvin, J.-Y. (1997) A Tabu Search Heuristic for the Vehicle Routing Problem with Soft Time Windows. *Transportation Science* 31, p. 170-186.

[5] PostGIS, Available: http://postgis.refractions.net/

[6] PostgreSQL, Available: http://www.postgresql.org/

[7] SharpMap – Geospatial application Framework for the CLR, Available: http://www.codeplex.com/SharpMap

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ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)