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Bridging the Gap Between Theory and Practice in the Vehicle Routing Research [#]

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Abstract: Research studying effective planning and optimization in the vehicle routing field has increased tremendously in the last few decades. Advances in technology and computational power have encouraged researchers to consider various vehicle routing problem types and constraints, and to experiment with new algorithmic techniques that can be applied for the automation of vehicle planning. Despite this, research in the vehicle routing domain is often accused of being too idealistic. Given the difficulty of solving vehicle routing problems, many simplifying assumption are being incorporated into problem solving techniques, in order to make the solution approach more manageable. In this paper we discuss some real life constraints that the research community should be aware of when addressing vehicle routing problems. We highlight how theoretical research in this area can be integrated into commercially applicable software. An overview of future trends in scientific research tackling this issue is also provided. This paper tries to give an insight into how developing richer vehicle routing models can help in realistic settings to improve logistic planning.

Keywords: *Vehicle Routing, Intelligent Systems, Intelligent Transportation Systems, Decision Support Systems, Optimization.*

1. Introduction

Efficient transportation has become vital for today's dynamic society. In the European Union, the transportation sector constitutes more than 10% of Gross Domestic Product (GDP) and employs more than 10 million people [1]. Transportation volume continues to increase rapidly every day, as a result of economic growth and globalization, compared to a limited expansion in roads and networks capacities. In 2011, a European Union Commission White Paper [1] indicated that: "New technologies for vehicles and traffic management will be key to lower transport emissions in the EU as in the rest of the world. The race for sustainable mobility is a global one. Delayed action and timid introduction of new technologies could condemn the EU transport industry to irreversible decline. The EUs transport sector faces growing competition in fast developing world transport markets."

Transportation demand is not always geographically balanced. In addition, the lack of coordination between manufacturers, shippers and carriers in supply chains can lead to inefficient usage of natural and human resources. In many cases, transportation planning is done manually. However, the advent of today's technology- including high speed computers, digital cellular phones, Geographic Information Systems (GIS), Geographic Positioning Systems (GPS), navigation and tracking technologies, wireless data communication, digital mapping and web-based services- has increased the demand for more efficient commercial software for route planning. If applied on a large scale, commercial software can lead to enormous savings, both economically and environmentally. Vendors of software tools claim that the reduction in cost may range from 5% - 30% [2]. Given the huge volume of today's transportation, such cost reduction is in fact very significant. Besides cost reduction, efficient routing can greatly reduce the environmental impact of transportation. For example, in a survey of UK brewery, Paragon Software Systems, Inc. identified savings of more than 2.5 million miles- corresponding to 3,700 tons of CO_2- a year, as a result of more efficient routing [3].

To meet this demand, research in vehicle routing and scheduling has grown substantially in the last few decades [4]. A huge number of problem variants, different problem constraints, and operating scenarios have been investigated by the research community. In fact, research in this field is central to the development of efficient decision support tools that can be adopted in the transportation industry. Despite this, research in vehicle routing is often accused of being too idealistic. The majority of published research tackles simplified problems, based on, for example, Euclidean distances, homogeneous fleets, hard constraints, fixed service times...etc. Unfortunately, most of these assumptions do not hold in reality. Industrial aspects of vehicle routing have recently started to gain the attention of researchers, and are increasingly being incorporated into models and solution methods that address these problems. Thus, the current trend is towards 'holistic' approaches that are capable of solving richer and more realistic vehicle routing models. It is important from a realistic perspective to understand the relationship between theoretical research and commercial applicability in everyday business requirements. To this end, we discuss in this paper some industrial aspects that may be considered by the research community when addressing vehicle routing problems in Section

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2. Section 3 describes the basic components of commercial software that are adopted in the transportation industry, and explains how theoretical Computer Science and Operations Research (OR) may be integrated within its framework. Examples of commercial software products and applications in the transportation sector are provided in Section 4. Section 5 summarizes some future trends in vehicle routing research. Finally, Section 6 concludes this paper with a summary and some brief remarks.

2. Industrial Aspects of Vehicle Routing

The Vehicle Routing Problem (VRP) is at the heart of scientific research involving the distribution and transportation of people and goods. The problem can be generally described as finding a set of minimum cost routes for a fleet of vehicles, located at a central depot, to serve a number of customers. Each vehicle should depart from and return to the same depot, while each customer should be visited exactly once (see Fig. 1 for a simple illustration).

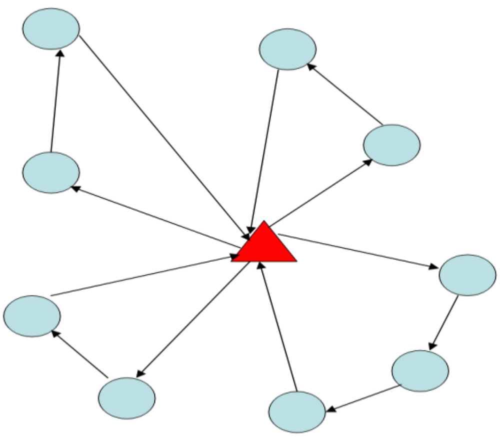

Figure 1. The Vehicle Routing Problem

Since the introduction of this problem by Dantzig and Fulkerson in 1954 [5] and Dantzig and Ramser in 1959 [6], several extensions and variations have been added to the basic VRP model, in order to meet the demand of realistic applications that are complex and dynamic in nature. For example, restricting the capacity of the vehicle and specifying certain service times for visiting clients are among the popular constraints that have been considered while addressing the VRP. As mentioned above, research in vehicle routing is now shifting towards solving non-standard and rich VRP models that will facilitate decision-making in real-life situations. The advancement in computational power in the last few decades has encouraged researchers to consider industrial aspects of vehicle routing, in order to meet the demands of transportation service providers and fleet management companies. Rich VRP models allow general and more realistic features to be incorporated, as opposed to conventional OR models which are simplistic in nature. Some industrial aspects of vehicle routing are summarized below [7] [2]:

Heterogeneous Fleet: Most of the VRP research makes the assumption that the operating fleet is homogeneous, with identical characteristics and operating costs. In reality, though, this is often not the case, since companies usually benefit from versatility in their fleet. A rich VRP model should allow non-homogeneous vehicles, such that not only the optimum number of vehicles is determined, but also the optimum number of each vehicle type and the cost for vehicle acquisition/depreciation.

Drivers' Working Time: In real life applications, drivers' working hours are governed by certain legislation rules. Hence, a rich VRP model should create working plans that conform to these regulations, such that the allocation and exchange of drivers is also taken into consideration while determining the optimum routing decision.

Depots and Service Locations: Basic VRP models usually assume that there is only one central depot, such that each vehicle's journey should start and end at that depot. Nevertheless, this assumption does not hold in many situations, since there might be multiple depots or arbitrary starts and ends for vehicles. In addition, customer locations are sometimes not fixed, with alternative service locations being permitted in the routing plan.

Order Types: In the basic VRP variants, order types are either pickups or deliveries. In addition, split deliveries are usually not allowed, and each customer can only be visited once. In real life applications, a customer order may be both a pickup and a delivery. Also, some orders may not require the transportation of goods, but only a certain service type (e.g. maintenance). Allowing such variants adds to the complexity of the problem but makes it more realistic from a business point of view.

Distances and Times: The assumption that all distances under consideration are Euclidean distances is not adequate in real-life scenarios. Network characteristics, traffic, vehicle speed, and travel costs should also be taken into consideration. Moreover, service times for clients are not fixed in reality. Variable service times, depending on order types and volumes, should be allowed in rich VRP models.

Time Windows and Capacity Constraints: Most VRP models deal with time windows as a hard constraint, with no violation permitted in the underlying routing plan. Time windows in reality are not always that rigid. They are often defined by preferred visiting times, with some cost penalty for visiting outside the specified period. Another extension to the basic model is multiple time windows, where different alternative visiting periods are given. Also, some applications require certain vehicle capacity and loading restrictions. For example, a specific loading sequence may be enforced in order to facilitate un-loading, or to protect fragile items.

Uncertainty and Dynamic Situations: Dynamic vehicle routing refers to the situation where routing decisions are affected by input data arriving in real time. Information about orders, travel times, service times, vehicle breakdown…etc., arriving while the routing plan is being executed should be taken into consideration in most real-life applications, and often necessitates an immediate response. Uncertainty and stochastic variables- for example while planning a certain emergency situation- also add to the complexity of rich VRP models.

3. Commercial Transportation Software

A commercial software package for decision support in the transportation industry usually integrates an underlying algorithm with an efficient user-friendly interface for optimum usage. A survey of commercial vehicle routing software [8] identifies the basic software capabilities as:

1. Geocoding addresses using a digital map database, i.e., determining the coordinates of a location using its address or postal code;
2. Determining the best driving route between pairs of geocoded points;
3. Solving the VRP, i.e., assigning stops to vehicles and routing vehicles between stops, and

4. Displaying the results in both graphical and tabular forms, such that the dispatcher can communicate the solution to the drivers and edit these solutions with a 'drag-and-drop' feature if necessary.

Step 3 in the above list is where theoretical research takes its part. It is in fact the 'core' or the 'engine' of the software tool, sometimes referred to as a VRP solver. In [7] a VRP solver is defined as: "A software component with functionality for modelling instances of targeted variants of the VRP and finding feasible, optimized solutions to a given instance. The effect of a given routing tool is highly dependent on its VRP solver."

The efficiency of a VRP solver can be generally attributed to the richness of the VRP model (problem) it is trying to solve, in addition to its algorithmic capabilities measured in terms of the quality of the objective and the processing time needed.

4. Examples of Commercial Vehicle Routing Tools

Some examples of commercial vehicle routing software are: ILOG Dispatcher, Paragon Routing and Scheduling System, Direct Route, DISC, and JOpt.SDK. Notable installations of these and other commercial software include companies like: Sainsbury's, Argos, Tesco, Royal Mail, the Home Depot, Samsung, Kraft, Dunkin Donuts, Coca-Cola, BP, TNT, and many others [3].

One example of a rich generic VRP solver is SPIDER [7], which was developed by SINTEF Applied Mathematics research institution in Norway. SPIDER VRP solver is capable of solving a number of vehicle routing problems and its variants, such as the VRPTW (Vehicle Routing Problem with Time Windows), the PDPTW (Pickup and Delivery Problem with Time Windows), and the multiple-depot variants of these problems. In addition, it takes into consideration many industrial aspects, such as the ones described above. For example, it allows a heterogeneous fleet, multiple time windows, alternative service locations, variable service times, and travel times that vary according to road network topology and information available from GIS. The algorithmic approach in SPIDER is a unified approach to all problem types and instances. This technique has advantages in terms of simplifying the code and its maintenance, but may sometimes suffer in terms of computation time, since some operations will still be performed for problem instances that may not need them. The SPIDER VRP solver is basically a meta-heuristic approach that integrates several features from successful academic research in the VRP field. The algorithm consists of three main components: Construction of Initial Solutions, Tour Depletion and Iterative Improvement. These are briefly explained below:

Construction of Initial Solutions: The construction phase is based on extensions of classical construction heuristics, like the Clarke and Wright savings heuristic [9], Solomon's I1 insertion [10], and the regret-based insertion [11]. In addition, an instance analysis is performed in order to determine if the instance has a heterogeneous fleet, in which case a special construction heuristic called SPIDER constructor is used to build the initial solution.

Tour Depletion: This phase is intended for reducing the number of routes in the initial solution, but is also used as a local search operator during the iterative improvement phase. Each route is depleted in turn, and an attempt is made to insert all its requests into other routes. If the attempt was successful, the new solution is accepted. The routes that have been changed by this operation may also be optimized using 2-Opt or 3-Opt improvement heuristics of [12].

Iterative Improvement: The iterative improvement phase is based on Variable Neighbourhood Descend (VND) [13], using a number of well-known operators within each route and in-between routes. For example, 2-Opt, 3-Opt, Or-Opt, EXCHANGE, and CROSS (see [14] for more details about some of these operators). However, these heuristics have been extended to accommodate SPIDER's rich VRP model, which allows heterogeneous fleets and multiple time windows. In addition, several neighbourhood filters have been applied to speed up the optimization, for example by analysing the current solution and exploring promising moves only. When the VND reaches a local minimum, a diversification mechanism is applied using Large Neighbourhood Search (LNS) [15]. The overall process is a hybrid of VND and Iterated Local Search (ILS).

To evaluate its performance, SPIDER was tested on published benchmark data availale from the literature and compared favourably with state-of-the-art solution methods [7].

5. Future Trends

Scientific research in transportation optimization is an indispensable part of any commercial software tool, and there is, and will continue to be, a great demand for innovations in research methodologies. Researchers in this field, however, should also be aware of new demands in the industrial sector and try to develop richer models in their research. Issues like heterogeneous fleets, multiple tours, split deliveries, variable service times, soft time windows, special vehicle equipment or driver certificates, dynamic route planning, and many other real-life requirements and constraints should motivate researchers to invest more effort in developing efficient solution techniques that comply with today's ever changing domain of industrial vehicle routing. The complexity of these models, nevertheless, means that solving the problem to optimality is not an option in most practical situations. In fact, heuristics, meta-heuristics and hybrid approaches dominate scientific research in this field.

There is a trend in today's research towards optimization tools that integrate the whole supply chain rather than individual components. In addition, current concerns over global warming have increased the demand towards rewarding lower carbon emissions and green logistics. More robust planning in dynamic and stochastic situations is also gaining more attention every day. Decision support tools that enable the service provider to choose between more than one good solution are also gaining more popularity in the current research environment.

Another important factor that needs urgent attention is the development of better benchmark test cases. Most of the benchmark cases available to the research community for the VRP and its related variants are created randomly. In addition, they are often overly simplified and do not reflect real-world cases. Using such test cases increases the risk of over fitting, i.e., a great effort may be invested in developing solution methods that produce good results on published benchmark instances only. Applying these methods on a larger scale, though, may reveal their shortcomings. The research in [2] identifies several features that test cases for the vehicle routing research should have. These are: 1) they should be based on real-world data; 2) they should be as rich as possible, i.e., contain sufficient details; 3) they should have a common format (e.g. XML); 4) solutions (and not just their objective functions) should be published; and 5) test cases and their solutions should be published in the Web.

Finally, researchers in the field should pay more attention to Cloud-based systems. In the near future, interconnected Cloud-based systems will prevail, since the Cloud will make the services available without needing to install new software or acquire an expensive infrastructure. Thus, “route optimization as a service” will become more relevant with Cloud Computing [16].

6. Summary and Conclusions

This paper reviewed some industrial aspects of vehicle routing that are currently under consideration by the research community to meet the increase in demand for more efficient transportation. The current trend is towards rich VRP models that can be used in commercial decision support tools, in order to achieve better customer service, cost reduction, and efficient resource management in transportation systems. Yet, although scientific research is a major and important component of a complete real-life applicable solution to routing and scheduling problems, there is often a considerable distance between theoretical research and practical applicability. Integrating theoretical scientific research within a commercially applicable tool is usually done by consulting companies, routing software vendors, contract research organizations, and large research laboratories or institutions. In addition, it often requires the cooperation of a number of experts in different fields and possibly several years of development effort. These institutions, however, do not work in isolation from academic research. They monitor research carried out by the scientific community and incorporate state-of-the-art techniques in their products. Assessing the quality of the different scientific approaches is mostly done by comparing their performance against published test cases available for researchers in the academic field. Hence, the focus of researchers in Computer Science and Operations Research should be on developing competitive and robust solution methodologies that can be later integrated within a larger framework for applicability in real-life situations.

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