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An open source Spreadsheet Solver for Vehicle Routing Problems

Güneş Erdoğan

School of Management, University of Bath, Bath BA2 7AY, UK

A R T I C L E I N F O

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A B S T R A C T

The Vehicle Routing Problem (VRP) is one of the most frequently encountered optimization problems in logistics, which aims to minimize the cost of transportation operations by a fleet of vehicles operating out of a base. This paper introduces VRP Spreadsheet Solver, an open source Excel based tool for solving many variants of the Vehicle Routing Problem (VRP). Case studies of two real-world applications of the solver from the healthcare and tourism sectors that demonstrate its use are presented. The solution algorithm for the solver, and computational results on benchmark instances from the literature are provided. The solver is found to be capable of solving Capacitated VRP and Distance-Constrained VRP instances with up to 200 customers within 1 h of CPU time.

1. Introduction

The Vehicle Routing Problem (VRP) is one of the most frequently encountered optimization problems in logistics, which aims to minimize the cost of transportation operations by a fleet of vehicles operating out of a base called *depot*. It arises in many industries and contexts at tactical and operational levels. The VRP has been introduced more than 50 years ago by Dantzig and Ramser (1959), and many variants of the VRP that incorporate additional features such as time windows (intervals in which the customers may be visited) and fleet composition (Laporte, 2009) have been studied. Despite its operational nature, the VRP is considered to be in the academic domain of Operations Research rather than Operations Management. This is due to the inherent difficulty of solving a VRP, not only due to the complexity of the associated solution algorithms but also practical considerations regarding the implementation of the solution.

From a practitioner's perspective, there exist a number of barriers to develop an in-house VRP solver. Developing a solution algorithm for VRP is a daunting task, and even if an open-source academic code is to be used as the solution algorithm, most academics develop algorithms in C++ and the resulting codes are not designed for the faint-hearted. The travel distance and duration data have to be repeatedly retrieved from a GIS, due to their dynamic nature, which introduces either a recurring cost of acquisition or the requirement for in-house specialist knowledge. It is not straightforward to manually compute the existing cost of the vehicle routes, much less so to visualize and compare the existing and optimized solutions, which is important to demonstrate the benefit of an optimization tool.

Although there exist many commercial software packages to solve VRPs, any package must be integrated with the existing software infrastructure of the company, and needs to be learned by the planning managers. Most commercial VRP software packages have a black-box component, the algorithm determining the vehicle routes, since the developers will want to protect their intellectual property. Finally, every real-world application of the VRP has specific needs to which the software should be custom-tailored, which requires a constant link with the company that developed it. In case the company ceases to exist, the software faces the risk to become obsolete in a few years.

In this study, we introduce VRP Spreadsheet Solver that overcomes the problems stated above through the familiarity of its interface, ease of use, flexibility, and accessibility. Microsoft Excel is arguably the standard software for small to medium scale quantitative analysis for businesses, and is being used in almost every corner of the world, in both academia and industry alike (Hesse and Scerno, 2009). Many software packages have built-in functionality to exchange information with Excel, which eases the integration of the solver. The code for the solver, developed using Visual Basic for Applications (VBA), is open-source and can be understood and modified by medium-level programmers. VRP Spreadsheet Solver has built-in functions to query a GIS web service, from which the distances, driving times, and maps can be retrieved. The solver is available for download on an academic website at no cost (Erdoğan, 2013), and has been downloaded over 2000 times.

E-mail address: G.Erdogan@bath.ac.uk

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VRP Spreadsheet Solver has been used in practice by multiple organizations in diverse sectors and countries. The organizations that provided feedback include two US companies in the oil industry, an Argentinian company in the agriculture industry, a Finnish company in the tourism sector, and two chains of chilled food delivery in Taiwan and Turkey, all of which report significant savings. We believe that VRP Spreadsheet Solver has the potential to be used throughout the world and achieve savings for many Small and Medium-sized Enterprises (SMEs), and consequently reduce CO_2 emissions. Furthermore, new VRP variants have emerged through our interaction with the users that are relevant to other sectors, and they are our contribution to the literature.

The rest of this paper is organized as follows. In Section 2, we provide a brief list of applications of the VRP. In Section 3, we present two case studies of the application of VRP Spreadsheet Solver, and a resulting new VRP variant. We provide a brief overview of how to use VRP Spreadsheet Solver in Section 4. In Section 5, we present a unified formulation that encompasses all variants of the VRP that VRP Spreadsheet Solver can handle, a metaheuristic optimization algorithm that VRP Spreadsheet Solver utilizes, and the results of VRP Spreadsheet Solver on a number of benchmark instances. Finally, in Section 6, we give our concluding remarks.

2. Applications of the VRP

With the progress of computer hardware and optimization software, better algorithms and implementations for the VRP emerge every year. The computational reach of exact algorithms for the VRP is limited to 200 customers for the most studied basic variants of the VRP, e.g. the column-and-cut generation algorithm of Baldacci et al. (2011), and decreases significantly for more realistic variants that include features such as a heterogeneous fleet or distance constraints. On the other hand, state-of-the-art metaheuristic algorithms e.g. Adaptive Large Neighborhood Search (Pisinger and Ropke, 2007), Iterated Local Search (Subramanian et al., 2010), and Unified Hybrid Genetic Search (Vidal et al., 2014) can handle much larger instances and detailed operational constraints but cannot offer a mathematical guarantee of performance.

As stated in the introduction, many commercial and free solvers exist for the VRP. A recent survey (Partyka and Hall, 2014), based on the answers to a questionnaire by 15 software vendors, have provided a number of characteristics of available VRP software packages. More recent surveys (Bräysy and Hasle, 2014; Wang et al., 2015) list a number of commercial and free VRP software packages, the latter including VRP Spreadsheet Solver, and provide features required of VRP software packages. We refer the interested reader to the comprehensive book of Toth and Vigo (2014) for critical reviews of many variants of the VRP and the associated solution algorithms.

In the rest of this section, we provide a brief list of applications of the VRP. The list is by no means complete, but is provided to give an impression of the generality of VRP and the diversity of the industries and contexts it arises in. The most straightforward applications of the VRP are found in the logistics sector. Companies in the small package shipping industry, for example, aim to minimize the routing cost while keeping the routes of the drivers as consistent as possible (Groër et al., 2009). A decision support tool utilized by Toyota for selecting third party logistics service providers based on optimized vehicle routes is presented in Schittekat and Sörensen (2009). The problem of a large Benelux logistics service provider that aims to minimize the total transportation cost in a multi-depot system, which consists of the speed-related, distance-related, and vehicle-related costs of transportation is analyzed in Demir et al. (2014).

Some examples of the VRPs arising in urban transportation are the efficient routing of the school buses (Bektaş and Elmastaş, 2007), and the design of tourist tours for visiting multiple points of interest in a city (Gavalas et al., 2014). The joint problem of bin allocation and vehicle routing to optimize solid waste collection is studied in Hemmelmayr et al. (2014). There is also a growing body of literature on optimizing the rebalancing operations for shared bicycle systems that aim to minimize the total cost and maximize the user satisfaction (Forma et al., 2015).

The importance of the use of VRP models in humanitarian logistics have been underlined in the survey by Van Wassenhove (2006). Optimizing post-disaster relief operations by minimizing estimated total travel time of vehicles is studied in Özdamar and Demir (2012). The problem of finding the optimal routes for teams that survey a disaster area to assess damage and relief needs is analyzed in Huang et al. (2013). Planning of fuel distribution operations in the case of a domestic disaster is studied in Nerg and Stuckenschneider (2014), where the authors use VRP Spreadsheet Solver to optimize the routes.

With the increasing emphasis on climate change and environmental concerns, a venue of research within the VRP has emerged in the past decade, named as Green Vehicle Routing Problems (G-VRP). The objective function of these problems focus on minimizing CO_2 emissions, noise pollution, and accidents, as stated in the recent survey on G-VRP (Eglese and Bektaş, 2014). The problem of minimizing the risk of running out of fuel, which is prominent in the route planning for Alternative Fuel Vehicles, is studied by Erdoğan and Miller-Hooks (2012). The problem of determining the optimal size and mix of a vehicle fleet of electric vehicles is analyzed by Hiermann et al. (2016).

Applications of the VRP are not limited to companies with a sole focus on logistics. Indeed, variants of VRP may arise in any context where a pickup or delivery service is performed. Specifically, examples from the healthcare sector include routing of nurses for home health care (Mankowska et al., 2014) and the transportation of blood donations to storage centers (Şahinyazan et al., 2015; Yi, 2003), and the delivery services for biological samples collected from patients to testing laboratories (Andrade-Pineda et al., 2013).

3. Case studies

VRP Spreadsheet Solver can solve more than 64 variants of the VRP, based on features related to selective visits to customers, simultaneous pickups and deliveries, time windows, fleet composition, distance constraint, and the final destination of the vehicles. Some of these variants are relevant in practice but have not been formally studied. VRP Spreadsheet Solver can hence provide a starting point and a benchmark result for future studies on such problems. In the rest of the section we go over two case studies in which VRP Spreadsheet Solver was used, and a new VRP variant that we introduce as a result.

3.1. Healthcare sector

A non-profit organization based in Istanbul, Turkey provides a set of healthcare services at home, including visits by medical doctors and nurses providing physiotherapy and psychotherapy, as well as logistic services such as patient transport, domestic cleaning, and personal hygiene. The services are performed at no cost and are provided for the poor, elderly, and disabled citizens. The number of registered patients is over 3000, and an average of 1000 patients in separate locations are served each day. The organization operates out of three bases and owns a fleet of 90 vehicles, each of which can by driven by the health specialists and contains a small medical inventory.