Institution: University of Bath

Unit of Assessment: C17 Business and Management Studies

Title of case study: An open-source solver for vehicle routing problems

Period when the underpinning research was undertaken: 2014–2017

Details of staff conducting the underpinning research from the submitting unit:

Name(s):	Role(s) (e.g. job title):	Period(s) employed by submitting HEI:
Güneş Erdoğan	Professor, previously Reader	October 2014 – present

Period when the claimed impact occurred: 2015–2020

Is this case study continued from a case study submitted in 2014? No

1. Summary of the impact

Research on vehicle routing problems conducted at University of Bath School of Management by Professor Erdoğan has saved companies in excess of USD2,300,000 (August 2019) and contributed to reductions in CO_2 emissions. An open-source tool has been made freely available to help organisations optimise pickup and delivery operations. This innovative tool supports cost efficiencies through the optimisation of routes, and effectiveness through improved on-time delivery. It has been shown that the tool has significantly lowered the costs of the distance traversed for haulage and transport companies. It has been used by organisations around the globe and it has provided significant financial benefits to those adopting it.

2. Underpinning research

Research into the applications of information and communication technology by Erdoğan has offered new opportunities to engage with vehicle routing problems (VRPs) and create efficiencies in the transportation of goods. VRPs are a frequently encountered optimisation challenge in logistics. Engagement with these problems aims to minimise the cost of transportation operations for a fleet of vehicles operating out of a logistics hub. However, the applications of VRP solutions are not limited to logistics. Similar problems arise in other sectors, such as urban transportation, waste collection, and healthcare.

One particular application is the redistribution of bikes in a bike-sharing system. A good redistribution system is essential to ensure that both bikes and empty bike-parking slots are available at bike-sharing stations. Redistribution systems involve vehicles operating out of a central station that pick up and deliver bicycles and then return to the depot. Following his move to University of Bath in 2014, and working with colleagues from Southampton and Paris, Erdoğan's research on VRP solution algorithms resulted in an exact (optimal) algorithm for the management of bicycle-sharing systems (R1) with the practical aims of minimising customer dissatisfaction and improving utilisation of the system. An international team from Brazil, Canada and the UK (Bath) developed a specific type of VRP that solved problems involving up to 60 sharing stations (R2).

The initial development of the prototype VRP Spreadsheet Solver arose out of a collaboration between five UK universities that sought to investigate vehicle and routing benefits for a major UK charity, leading to a beta version (version 0.99) being released in 2013 during the research project. However, since joining the University of Bath in 2014, Erdoğan has significantly expanded the initial Solver's scope and functionality, integrating his new research on bike sharing into the design and operation of the software. This has

centred around the upgrade of the software to solve VRP variants with single-commodity pickups and deliveries, a key feature of shared bicycle systems solutions (R1, R2). This enabled the enhanced VRP Spreadsheet Solver to mature sufficiently to be published (R3) and expanded its functionality so as to broaden the scope of its potential use. Moreover, this additional Bath-developed functionality was critical to the VRP Spreadsheet Solver's subsequent impact regarding oil transportation.

A key benefit from this research was resolution of the challenge of making these algorithms available to transportation managers in the form of a versatile and easy-to-use tool. This is the benefit that the research at the University of Bath has been able to achieve and implement. The VRP Spreadsheet Solver was developed to deliver these algorithms in a form that combines the familiarity of its interface, ease of use, flexibility, and accessibility (R3). It is free to download and is based on Microsoft Excel, which is standard software for small-to-medium-scale quantitative analyses within business and is used in almost every corner of the world, in both academia and industry. Many software packages have built-in functionality for information exchange with Excel, which further eases the integration of the Solver into existing managerial systems. The code for the Solver, developed using Visual Basic for Applications, is open source and can be understood and modified by medium-level programmers. The tool has built-in functions to query a GIS web service, from which distances, driving times, and maps can be retrieved. The VRP Spreadsheet Solver is being used throughout the world to achieve financial, time and resource savings for many small and medium-sized enterprises (S1–S6).

3. References to the research

R1 Erdoğan, G., Battarra, M. & Wolfler Calvo, R. (2015) 'An exact algorithm for the static rebalancing problem arising in bicycle sharing systems'. *European Journal of Operational Research* 245(3), pp. 667–679. DOI: 10.1016/j.ejor.2015.03.043

R2 Bulhões, T., Subramanian, A., Erdoğan, G. & Laporte, G. (2018) 'The static bike relocation problem with multiple vehicles and visits', *European Journal of Operational Research* 264(2), pp. 508–523. DOI: 10.1016/j.ejor.2017.06.028

R3 Erdoğan, G. (2017) 'An Open Source Spreadsheet Solver for Vehicle Routing Problems', *Computers and Operations Research* 84, pp. 62–72. DOI: 10.1016/j.cor.2017.02.022

4. Details of the impact

The VRP Spreadsheet Solver has been used by multiple organisations in diverse sectors across a range of countries. The tool has open access distribution. Several organisations contacted Professor Erdoğan to provide feedback. These included two US companies in the oil industry, an Argentinian company in the agriculture industry, a Finnish company in the tourism sector, and two chains offering chilled food delivery in Taiwan and Turkey. All of these organisations reported significant monetary savings, equalling at least USD2,300,000. Below, we provide further details in relation to three of these companies.

1) ***Twin Eagle*** operates within the petroleum industry. It provides a set of services ranging from leasing pipelines for fuel oil to natural gas extraction, refinement, and transportation. The company owns a fleet of 150 tanker trucks that operates in multiple regions of the US. Its main use of *VRP Spreadsheet Solver* was the planning of the routes of tanker trucks that transport oil between wells. The trucks are subject to strict rules regarding driving time and working time, in addition to capacity constraints. Due to the scale of the fleet and the frequency of the operations, even small improvements result in large monetary savings. The Senior Financial Analyst at the company stated: "*Utilizing the optimization program, I have proven that there are additional cost savings that can be achieved through routing improvements. With operations at such a large scale, even modest percentage reduction in miles would contribute significantly to the*

business". The company has reported annual savings from June 2016 of approximately USD500,000 (June 2016) and overall savings to date of USD2,000,000 (June 2020) (S1).

2) ***Matkapojat*** is a travel agency that operates in Helsinki, Finland, and sells travel packages. Its main product is a Helsinki-to-Tallinn (Estonia) travel package, including pickup from customers' homes, ferry crossing to Tallinn, day trips in Tallinn, and the journey back. It operates a fleet of buses, which are transferred from Helsinki to Tallinn to be used for the day trips, and are then transferred back. The demand is volatile and requires last-minute planning for maximum efficiency. The pickup times for customers are subject to strict time constraints. The company has offices throughout Finland, from which the buses originate and to which the buses return. Starting from 27 August 2015, the company reported estimated savings of between 2.5% and 5% in the expenses incurred by charter buses, corresponding to between EUR30,000 and EUR60,000 per year. This equates to total savings of between EUR150,000 and EUR300,000 during the 5 years of the REF2021 time window. The Product Coordinator described the added benefits of the Solver: "*Thanks to the time window options and manual solution sheet, the timetables and routes can be simulated in advance before opening the route and the possibility for better customer satisfaction is higher*" (S2).

3) ***Sinon Corporation*** is a Taiwan-based company that provides solutions to the agriculture, food distribution and technology sectors. The company used *VRP Spreadsheet Solver* to better plan the distribution of food from its warehouses to it supermarkets. It owns 45 supermarkets throughout Central Taiwan, served by 15 trucks of various sizes. The company modified the Solver to better suit its purposes, reporting that: "*Since you wrote your VRP Solver in Excel VBA, its interface is familiar enough for non-programmers to use and change. We let real users modify your program to: work offline, split large orders, match truck types to stores, add multiple runs, simulate 'what-ifs' using historical data, and generate reports".* The Senior Manager stated that since February 2015 the company has, through use of the Solver, achieved cost savings of 9% and distance savings of 20% in a quarter, for non-perishable food products. It also described estimated cost savings of 15–20% and distance savings of 30% for perishable products (S3).

Two more testimonial letters have been provided, by the Facilities Engineer at Chesapeake Energy and the Distribution Coordinator at Danone, operating in the US and Argentina, respectively. Chesapeake reports a "*significant decrease in miles driven ... saving roughly USD25,000 annually*" since February 2016 (S4). The Distribution Coordinator for Danone Argentina described how, since June 2017, its team "*generates more than 150 routes daily all over the country with an annual budget of USD30,000,000, so delivering a 1% decrease (in routing costs) generates great savings*" (S5). Together for the tool as whole, we have documented evidence of significant financial benefits, as well as material reductions of CO_2 emissions.

We have gathered Google Analytics data from the hosting page to evidence the Solver's reach (S6). This shows that approximately 25,000 people have viewed the Solver over a period of 40 months to the end of December 2020, from 136 different countries. The tutorial video for the tool on YouTube has been watched over 70,000 times. The largest numbers of Solver page visits originate from the United States, India, Turkey, Brazil, United Kingdom, Colombia, Germany, Thailand, Canada, and Indonesia, which demonstrates the commonality of the challenge of VRPs throughout the world.

5. Sources to corroborate the impact

S1 Testimonial letter from the Senior Financial Analyst at Twin Eagle (a company in the energy sector in the US), dated 1 June 2016 (http://www.twineagle.com/).

S2	Testimonial letter from the Product Coordinator at Matkapojat (a tourism company based in Finland), dated 27 August 2017 (https://www.matkapojat.fi/).
S3	Testimonial letter from the Senior Manager at Sinon Corporation (Taiwan-based corporation operator of a chain of supermarkets), dated 23 February 2015 (http://www.sinon.com/).
S4	Testimonial letter from the Facilities Engineer at Chesapeake Energy (a company in the energy sector in the US), dated 24 February 2016 (http://www.chk.com/).
S5	Testimonial letter from the Distribution Coordinator at Danone Argentina (food sector corporation), dated 12 June 2017 (http://corporate.danone.com.ar/).
S6	Google Analytics page on the number of views and locations of visitors to the download page for the open-source VRP Spreadsheet Solver between 1 August 2017 and 31 December 2020.