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A Multicriteria Analysis for the Green VRP: A Case Discussion for the Distribution Problem of a Spanish Retailer

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Abstract

This research presents the group of green vehicle routing problems with environmental costs translated into money versus production of noise, pollution and fuel consumption. This research is focused on multi-objective green logistics optimization. Optimality criteria are environmental costs: minimization of amount of money paid as externality cost for noise, pollution and costs of fuel versus minimization of noise, pollution and fuel consumption themselves. Some mixed integer programming formulations of multi-criteria vehicle routing problems have been considered. Mathematical models were formulated under assumption of existence of asymmetric distance-based costs and use of homogeneous fleet. The exact solution methods are applied for finding optimal solutions. The software used to solve these models is the CPLEX solver with AMPL programming language. The researchers were able to use real data from a Spanish company of groceries. Problems deal with green logistics for routes crossing the Spanish regions of Navarre, Basque Country and La Rioja. Analyses of obtained results could help logistics managers to lead the initiative in area of green logistics by saving money paid for environmental costs as well as direct cost of fuel and minimization of pollution and noise.

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Keywords: multi-objective optimization; mixed integer programming; green logistics; vehicle routing problems

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1. Introduction

Nowadays there is a tendency in green vehicle routing research to consider methodology and procedures, which will help logistics companies to develop cleaner solutions. The main purposes are not to pollute the environment so much, to emit less harmful substances and to create less noise without causing other types of pollution. All the above environmental friendly issues are strongly related with transportation costs.

This paper considers the group of green vehicle routing problems with environmental costs in monetary terms. Mathematical formulations of optimization models are taking into account the noise production, the pollution caused by carbon dioxide and the fuel consumption as well. This research is focused on multi-criteria green logistics optimization. Optimality criteria are environmental costs defined as minimization of amount of money paid by a transportation company as externality cost for noise, CO₂ emissions, and direct fuel costs used by trucks for delivering goods. Apart from monetary criteria, this work considers environmental criteria like minimization of noise, pollution and amount of consumed fuel. The selected multi-objective green vehicle routing optimization problems are formulated as mixed integer programming procedures. Similarly, these mathematical models were formulated under assumption of existence of asymmetric distance-based costs and use of homogeneous fleet.

For computational experiments the exact solution methods are applied for finding suboptimal solutions. The software used to solve these models is the CPLEX solver with use of AMPL programming language (Fourer et al., 1990). This research has been performed using real data from a Spanish company of groceries called Eroski. This research problem deals with green logistics for routes crossing the Spanish regions of Navarre, Basque Country and La Rioja. The results of the current analysis may be helpful for logistics managers to lead the initiative of constructing routes which have a lower environmental impact.

1.1. Road transportation

Road transportation is not only important for the economic development, but also harmful to the environment because of externalities such as pollution and noise (Koc et al., 2016; Kovacs et al., 2015; Avetisyan et al., 2014; Grafton et al., 2004). For many years, the planning of freight transportation by road mainly focused on cost minimization, but along with the increasing concerns for the environment, logistics managers and freight carriers have started to focus their attention on the formulations of transportation problems that can include environmental aspects of transportation (Absi et al., 2013; Koc et al., 2016; Demir et al., 2014a; Sawik et al., 2015, 2016a, 2016b, 2016c).

1.2. Vehicle Routing Problem

The vehicle Routing Problem (VRP) has been studied since 1959 with the objective to minimize the total distance traveled by all vehicles. There are several variants to the VRP (Toth and Vigo, 2014). These are formulated based on the nature of the transported goods, the quality of service required and the characteristics of the customers and the vehicles. From this basic problem, there were developed other problems such as VRP with time windows (VRPTW), the capacitated VRP (CVRP), the multi-depot VRP (MDVRP), the site-dependent VRP (SDVRP), the open routing problem (OVRP), Cumulative VRP (CumVRP) and finally green vehicle routing problem (GVRP), which considers environmental aspects of transportation (Koc et al., 2016; Demir et al., 2014a, Gaur et al., 2013; Lin et al., 2014, Erdogan et al., 2012; Sawik et al., 2016a, 2016b). There are some other papers that combine variants to the VRP, such as Oberscheider et al., 2013,

in which the problem is formulated as a multi-depot vehicle routing problem with pick-up and delivery and time windows (MDVRPPDTW).

For many years, the most important requirement has been to minimize the total distance travelled by vehicles or total time taken into the delivery (Juan et al., 2014). Nowadays, fuel consumption, reduction of pollution and noise are an important part of the final objective in VRPs. Bektas & Laporte (2011) present the Pollution-Routing Problem (PRP), an extension of the classical Vehicle Routing Problem (VRP) with a broader and more comprehensive objective function that accounts not just for the travel distance, but also for the amount of greenhouse emissions, fuel, travel times and their costs.

1.3. Algorithms and Multi-Objective Approach

Different algorithms have been considered to solve these types of aforementioned optimization problems (Bektas, 2006; Faulin, 2003). Christofides et al. (1981) formulated optimization problem for transportation, which is referred to as the vehicle routing problem and is a generalization of the multiple travelling salesman problem. An enhancement of the Miller-Tucker-Zemlin model for the asymmetric traveling salesman problem is presented in Sawik (2016d).

Multi-objective models for transportation can be divided into three groups: transportation, traveling salesman and vehicle routing problems (Sawik et al., 2016b). There are several ways to solve multi-objective transportation problems with environmental aspects (Demir et al., 2014a, Jabir et al., 2015; Qu et al., 2016; Sawik et al., 2015, 2016a, 2016b, 2016c).

1.4. Eroski Group

The real input data for computational experiments have been provided by a Spanish supermarket chain. The largest part of Spain's powerful cooperative group Mondragon Corporación Cooperativa is the distribution arm, called Eroski Group (Grupo Eroski, 2016a). The Eroski group is one of the leading chains of the Spanish retailing market. Currently Eroski is Spain's fourth largest supermarket chain (Grupo Eroski, 2016b). It operates more than 800 supermarkets throughout Spain. Under the name Eroski, besides supermarkets, there can also be find petrol stations and travel agencies. The company was founded in 1969 in the regions of Biscay and Guipuzcoa in Spain as a co-operative between ten smaller consumer cooperatives in the region. Its headquarters located in Elorrio, Biscay. The name given, Eroski, is a combination of the Basque words "erosi" (to buy) and "toki" (place), which can be translated as "buying place" (Grupo Eroski, 2016a).

2. Related Work

Recently there have been several publications of G-VRP models, in which authors include differently formulated environmental aspects of transportation. Munoz-Villamizar et al. (2016) assesses the implementation of an electric fleet of vehicles in collaborative urban distribution of goods, in order to reduce environmental impacts while maintaining a level of service. An important review of the environmental impact developed by road transportation and its influences in routes optimization is depicted in Demir et al. (2014a). Interesting theoretical results about relation between transportation costs and optimal transport map can be found in Chen & Figalli (2016). Dominguez et al. (2016) discusses the multi-start algorithm for two-dimensional loading capacitated vehicle routing problem with heterogeneous fleet. In Sawik et al. (2016a) research on G-VRP is focused on the distance travelled and the altitude difference within the obtained optimal route.

2.1. Environmental Monetary Costs

The parallel considerations of environmental monetary costs along with pollution and noise for transportation decision-making problems are really new when we consider all these assumptions in one model, and this new situation is only covered by a small number of papers. The most common costs associated with the problems of goods delivery are those related to driving distances, including: fuel consumption, driving times, maintenance (amortization) of vehicles, or drivers' salaries. Other frequently considered indirect costs or externalities, such as congestion, safety-costs, CO₂ emissions, etc. (Golden et al., 2008; Sbihi & Eglese, 2010). Likewise, it is frequent to find in the vehicle routing literature many different constraints, which naturally appear in real-life distribution processes (Drexler, 2012). Jaillet et al. (2002) present incremental cost approximations for inventory routing problems with one central depot using rolling horizon. Consideration and evaluation of selected economic, social and environmental costs for automobile-oriented transportation system can be found in Garceau et al. (2013). Pazhani et al. (2016) considers the importance of incorporating transportation costs in inventory replenishment and supplier selection decisions. Optimal assignment of the type and number of vehicle to each depot route to minimize the total transportation costs has been carried out by Tari & Hashemi (2016). Wang et al. (2011) propose a multi-objective optimization model that captures the trade-off between the total cost and the environment influence.

2.2. Noise, Pollution and Fuel Consumption

Methodology for calculation of noise in transportation models is not obvious at first sight. First of all, noise itself has different impacts on environment comparing with pollutions. It appears only for short period of time along with moving truck. However, it is possible to measure and consider it in optimization models for transportation. According to research carried out by different scientists, heavy goods vehicles generate noise between 88 and 92 dB, and light goods vehicles between 79 and 81 dB (Cirovic et al., 2014; Murphy & Poist, 2003). Aforementioned noise classification of vehicles has been used especially by researchers from Japan, Great Britain and Serbia.

Pollution and fuel consumption are considered very popular for the green transportation literature (Úbeda et al., 2011; Suzuki, 2011; Lin et al., 2014; Demir et al., 2014b). Some publications consider these environmental aspects for sea (Lättiä et al., 2013) or air transport (Chao, 2014).

3. Computational Experiments

The computational experiments were performed using the AMPL programming language and the CPLEX 11.0. solver with the default setting, on a MacBookAir laptop with Intel Core i7 processor running at 1.7GHz and with 8GB RAM.

3.1. Mathematical models

Several green vehicle routing multi-objective optimization models have been considered. The optimality criteria are:

- minimization of environmental cost:
 - amount of money paid as externality cost for noise,
 - amount of money paid as externality cost for pollution.

Additional optimality criteria are:

- minimization of total distance
- minimization of amount of money paid as direct costs of fuel,

- minimization of noise,
- minimization of pollution, defined as amount of CO₂ emissions,
- minimization of fuel consumption.

All considered models have linear objectives and constraints. According to types of decision variables optimization models have mixed integer programming formulations. The appropriate group of constraints is associated with the set of objectives.

Constraints for all multi-criteria objectives are formulated as follows:

- to ensure that all the vehicles begin and end their routes at the depot,
- to guarantee that each node, except the depot, is visited by a single vehicle,
- to assure that each node, except the depot, is linked only with a pair of nodes, one preceding it and the other following it.
- to guarantee that no vehicle can be overloaded,
- no vehicle exceeds the maximum allowable driving time per day,
- to avoid subtours with the use of the Miller-Tucker-Zemlin formulations.

The exact approach is applied for finding optimal solutions with use of CPLEX solver. These green vehicle routing mathematical models were formulated under assumption of existence of asymmetric distance-based costs and the use of homogeneous fleet.

3.2. Theoretical background of both the problem formulation and the method employed for solution

Multi-objective G-VRP optimization models are formulated by mixed integer programming. Weighted-Sum method is applied for obtaining suboptimal Pareto solutions. For finding optimal solutions exact method is used with Branch-and-Bound algorithm. Considered multi-criteria G-VRP optimization models consist Miller-Tucker-Zemlin formulation for elimination of subtours from obtained solutions.

3.3. Real input data

This research has been focused on different points of Navarra, Basque Country and La Rioja, where Eroski Group has its mains points of sale in that region. The depot of this area is located in Elorrio, Biscay. It is the warehouse of the goods that need to be transported. It means that Elorrio, the depot, is the first node taken by the trucks before the transportation to 27 other destinations, most of them in Navarra. The delivery points are different villages in Navarra, La Rioja and Basque Country, where Eroski Group owns different supermarkets and where the transportation has to be done. The list of locations of the delivery points is presented in Table 1.

Table 1. Locations of the delivery points.

Navarra	Pamplona	Tudela	San Adrián	Lodosa	Rada	Irurzun
	Carcastillo	Sangüesa	Estella	Berriozar	Tafalla	Beriain
	Villava	Burlada	Orkoyen	Artajona	Cizur	Alsasua
La Rioja	Logroño	Calahorra	Autol			

Basque Country	Vitoria	San Sebastián	Araia	Alegria	Salvatierra	Sta. Cruz de Campezo
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It is important to consider the distribution of these points in a geographic map in order to know which ones are the best to be connected.

3.4. Central Processor Unit (CPU)

The computational experiments for the considered different sets of multi-objective green vehicle routing problems with the Miller-Tucker-Zemlin subtour elimination constraints was capable of finding optimal solutions in most cases for used input data within 7200 CPU seconds.

3.5. Size of the problem

The size of the considered optimization problems is shown in Table 2.

Table 2. Size of the problem.

10460	variables
8645	binary variables
1815	linear variables
27784	constraints

The number of variables and constraints varies depending on the specific restrictions and the number of trucks. The Table 2 presents the maximum values among the considered problems sizes.

3.6. Obtained results for different objectives

The results obtained for different objectives have been compared and presented in Table 3.

Table 3. Comparison of selected results.

Objective function	Distance [km]	Driving Time [hours]	Altitude difference [m]	Fuel consumption per truck [l/100 km]	Carbon emission per truck [kg CO ₂ /km]	Noise per truck [dB]	Total amount of goods [pallets]	Total fuel consumption for all trucks [l/100 km]	Total carbon emission for all trucks [kg CO ₂ /km]	GAP/CPU [%/sec]
Total distance	9303.70	168.94	0.00	28.21	73.62	87400	3189	262435.43	684952.08	6.71%
Fuel consumption	16460.20	299.13	9.00	28.21	73.62	87400	3189	464303.42	1211824.13	6.07%
Carbon emissions	16687.90	303.25	27.00	28.21	73.62	87400	3189	470726.30	1228587.74	6921.609
Noise	17078.00	310.37	-9.00	28.21	73.62	87400	3189	481730.10	1257307.47	5.56%

Cost of fuel	14814.18	269.22	6.00	33.85	66.26	87400	3189	557164.10	1090641.72	7011.096
Externality costs of CO ₂ emissions	15019.11	272.92	18.00	33.85	66.26	87400	3189	564871.55	1105728.97	7041.448
Externality costs of noise	15370.20	279.33	6.00	33.85	66.26	87400	3189	578076.12	1131576.73	7102.517

Table 3 shows the relationship between different formulated environmental criteria. The results shown in Table 3 are presented in increasing order according to distance and driving time requirements. Similarly, total emissions for externality costs objective are presented using the same metrics (so that they can be properly compared). Obtained values for different objectives have been presented. Altitude difference column shows the difference in altitude between depot and all delivery points within chosen optimal route. Obtained values presented in Table 3 are in most cases for up to 95 trucks used for delivery. In last column Table 3 shows CPU seconds for proven optimal solution or GAP between best approximation and obtained feasible solution within 7200 CPU seconds. Chosen delivery networks order is different according to considered environmental criteria. It is possible to slightly control and limit the carbon emissions, and noise.

4. Conclusions and Future Work

In this paper, we have discussed some green vehicle routing problems with environmental costs considering pollution and noise as transportation externalities. The optimality criteria to be considered in suitable multicriteria models were connected to environmental costs: minimization of amount of money paid as externality cost for noise, pollution and costs of fuel versus minimization of noise, pollution and fuel consumption themselves. Thus, some mixed integer programming formulations of multi-criteria vehicle routing problems have been considered. Some mathematical models were formulated under the assumption of existence of asymmetric distance-based costs and use of homogeneous fleet. The exact solution methods were applied in order to find optimal solutions. The software used to solve these models was the CPLEX solver with AMPL programming language.

Obtained results shows, that it is possible to slightly control and limit the carbon emissions, and noise. There is a relation between obtained distances, driving times and altitude differences within obtained solutions versus obtained values of environmental objectives. This relation proves the need for consideration of all these aspects of transportation together in multicriteria models.

The researchers were able to use real data from a Spanish company of groceries called Eroski. The solved problems deal with green logistics for routes crossing the Spanish regions of Navarre, Basque Country and La Rioja. The analyses of obtained results could help logistics managers to lead the initiative in area of green logistics by saving money paid for environmental monetary costs presented as penalties to local authorities as well as direct cost of fuel and minimization of pollution and noise. Regarding future work, we are currently working in an extended version of this problem, which includes heterogeneous fleet and combination of vehicle routing and portfolio problem.

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