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Improving efficient resource usage and reducing carbon dioxide emissions by optimizing fleet management for winter services

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ABSTRACT

Heavy duty vehicles (HDVs), such as those used for winter services (e.g. snow plowing), are responsible for around 25% of CO_2 emissions caused by road transportation, which is also a challenge of energy resources. In this paper an optimization approach developed for the fleet management of winter services is presented, which was also evaluated in city of Maribor, Slovenia. The algorithm used is based on a mathematical graph theory, specifically on a solution to the Chinese postman problem, using two types of optimization: 1) optimization of the entire plan of the winter service and 2) optimization of the completed part of the planned service.

The winter service includes plowing and a salting process that requires refilling the salt reservoirs on the vehicles. In our real-world case only one base was available for refilling the salt reservoirs, so two additional optimization approaches were evaluated: a) optimization of the traversals of plans starting form a single base and b) using proposed three additional recharge bases distributed across the city and recharging at the closest base when needed. The results of the optimization suggested a reduction of route length by 28.3% when executing the entire plan. When considering a redistribution of the salting material at three other locations, our estimation has showed that additional savings up to 9.8% could be achieved regarding to the selection of those locations. Less routes traveled consequently leads to a reduction of resource usage (diesel) and lower CO_2 emissions. When executing 15 plans in a single winter service campaign, 210 L less diesel was used, resulting in 1.362 t less CO_2 emissions per campaign, representing a reduction of 30%.

Our model was initially based on real-life snow plowing processes and their statistics; where possible we used real-life data to configure the model, such as the salting material, loading times, the quantity of salting material distributed per km, the characteristics of the plowing vehicle, etc. Due to the heavy conditions during the execution of planned winter services, plans sometimes had to be readjusted on the go. Combining optimization with custom software for real-time execution, planning and service monitoring, assisted from the cloud, provided even more deterministic cost and environmental management, and gave further opportunity for optimization processes.

1. Introduction

Fossil fuel consumption by road transportation vehicles contribute approximately 20% of the EU's carbon dioxide (CO_2) emissions that is the main greenhouse gas (GHG) (COM, 2014). These emissions are 25% higher than in 1990 and transport is the only major sector in the EU where GHG emissions are still rising (EPURE, 2016). Heavy duty vehicles (HDVs) (e.g. winter service vehicles) are responsible in total for about a quarter of CO_2 emissions in the EU (COM, 2014).

The challenge of reducing CO_2 emissions from HDVs in EU was not tackled adequately before 2014. CO_2 emissions from such vehicles were not measured and not reported before Heavy-Duty Vehicles (HDV) Strategy under EU legislation was published in May 2014 (COM, 2014). The short-term action of this strategy is to certify, report, and monitor HDVs emissions in order to step closer

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towards curbing them. The EU Commission has already developed a computer simulation tool, the Vehicle Energy Consumption Calculation Tool (VECTO), to measure CO_2 emissions from new vehicles (Savvidis, 2014).

Providing winter services (snow removal, road salting, and road maintenance) relies heavily on HDVs and causes many negative impacts related to the resource utilization and environment, as a consequence of un-optimized use of HDVs (e.g., overly long routes, too much of salting material on-board, inefficient use of energy resources, and hence more CO_2 emission). It is also a complex logistic challenge due to the combinatorial complexity of winter service processes and the difficult weather conditions, in which the service is usually carried out. In order to reduce resource usage and environmental impacts, as well as to provide a higher quality service, winter services must be improved considerably beyond their current state. Thus, optimizing winter road services offers significant opportunities to realize savings, improving mobility in the urban area as well as social and environmental conditions (Kinable et al., 2016).

Optimizing winter services represents important challenges in operations research. This research area deals with the application of advanced analytical methods in order to make better decisions and improve services and processes. Basic work in this field has been carried out by Cambell and Langevin (1995), who described urban snow removal and disposal operations, assigning snow removal sectors to snow disposal sites. The authors formulated a snow disposal assignment as a multi-resource generalized assignment problem, developing a two-phase heuristic solution (Cambell and Langevin, 1995). An overview of the challenges with the winter road maintenance and proposed solutions is available in the series of papers published by Perrier et al., which was used as a reference when designing our model. The first paper of a four-part survey introduces system design problems for a winter road maintenance (Perrier et al., 2006a), the second part provides a survey of optimization models for the systems' design (Perrier et al., 2006b), a third part is focusing on a review of optimization models and solution algorithms for the routing of vehicles and spreading operation (Perrier et al., 2007a), where the fourth one introduces vehicle routing problems for plowing and snow disposal operations (Perrier et al., 2007b).

A report regarding optimization of winter service activities in specific cases has been published by Diwakar et al. (2010). The authors were developing efficient algorithms for the estimation of workforce requirements and determining optimal workforce deployment strategies, collecting weather data and extracted parameters relevant to determine plow speed and sand/salt consumption. Another study was carried out by Jang et al. (2011), where a systematic, heuristic-based optimization approach was used to integrate winter road maintenance planning decisions, resulting in optimal truck allocation and route decision policies. Salazar-Aguilar et al. (2012) focused in synchronized arc routing problem for snow plowing operations, where two or more lines were simultaneously plowed, while Monroy et al. (2013) investigated the periodic capacitated arc routing with irregular services. Another interesting study was carried out by Usman et al. (2012), researching the link between winter road collision occurrence, weather, road surface conditions, traffic exposure and temporal trends, allowing the quantification of safety effects of various road winter maintenance activities. Kinable et al. (2016) developed and analyzed the performance of three different optimizations (mixed-integrated programming, constraint programming, and constructive heuristic procedure), representing their strengths and weaknesses. Liu et al. (2014) used capacitated arc routing problem to minimize the distances I the snow plowing of the city of Edmonton. Colicchia et al. (2013) linked environmental concerns with logistics in an empirical study on the adoption of environmental initiatives in contact with the logistics industry. Trani et al. (2016) considered the environmental impacts of HDVs used during earthworks, and presented a quantitative method to predict fuel consumption before the construction phase.

The literature review indicated several studies, formulations and solutions of the approaches towards optimizing winter services. Formulations and solutions are very diverse, because each urban area considered within the studies has its unique environmental conditions and operational constrains (Liu et al., 2014). However, the authors pointing out that their proposed models could be improved, for example, Hajibabai and Ouyang (2016) suggesting improvements of their stochastic dynamic fleet management model with life traffic information and on-line data to approve the realism of their model; Liu et al. (2014) suggesting the expansion of the study, considering more operational constrains, such as route priorities. The studies carried out, considering winter road services, are also limited in terms of emphasizing a link between optimized route management and resource usage. As indicated, winter service processes operated by HDVs cause substantial environmental impacts through inefficient resource usage and CO_2 emissions.

Inspired by the above mentioned challenges, the objective of this paper was to provide a feasible real-time solution for a winter service at the city level, where optimization model considers also route priorities, unexpected events, resource usage, and environmental impacts. Vehicle routing problems related to spreading operations are generally defined as arc routing problems, where arcs represent roads in the observed road network. The optimization algorithm, based on a graph theory was designed – following the framework of the Chinese postman problem (Kwan, 1962) – that searches for the optimal (a minimum cost) tour that traverses every city road (arc) and visits each road only once. Where this is not possible, some of the roads have to be traversed multiple times; the algorithm then finds the roads in the network with the minimal total length that have to be traversed more than once in order to visit all city roads in a closed path. The driven repletion of road segments by HDVs was minimized, positively effecting resource usage, including the salting process. The performance of the proposed model and solution were applied over real data in the city of Maribor, Slovenia, including hypothetical scenario of adding additional salt recharging bases within the service area. The numerical results confirmed that the proposed model can solve the problem effectively, resulting in shorter tours, without skipping the roads, less fuel consumption, optimal salting, consequently decreasing environmental impacts and fixed costs. Furthermore, the model assures the flexibility in terms of further modifications, large scale adaptations, and responses (re-routing) in unexpected events, emergencies, blocked roads, etc. Important is the usage of results, providing a real-time feedback, especially useful in the emergencies and interruption scenarios. The proposed model serves in a decision-making processes of a complex urban winter services and logistic systems.

2. A winter service in Maribor, Slovenia

Maribor is an urban settlement, geographically positioned in the North-East part of Slovenia and has around 100,000 inhabitants. The climate is generally cold with an average annual temperature of 9.5 °C and a precipitation 986 mm. The snowfall during the winter season from November till March is on average around 45–50 mm/month (Climate data, 2015).

The municipal utility company that manages winter road services in Maribor owns 15 HDVs for snow plowing and salting roads in the urban area. The winter service process is organized by a