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The Hybrid Vehicle Routing Problem

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ABSTRACT

In this paper the Hybrid Vehicle Routing Problem (HVRP) is introduced and formalized. This problem is an extension of the classical VRP in which vehicles can work both electrically and with traditional fuel. The vehicle may change propulsion mode at any point of time. The unitary travel cost is much lower for distances covered in the electric mode. An electric battery has a limited capacity and may be recharged at a recharging station (RS). A limited number of RS are available. Once a battery has been completely discharged, the vehicle automatically shifts to traditional fuel propulsion mode. Furthermore, a maximum route duration is imposed according to contracts regulations established with the driver. In this paper, a Mixed Integer Linear Programming formulation is presented and a Large Neighborhood Search based Matheuristic is proposed. The algorithm starts from a feasible solution and consists into destroying, at each iteration, a small number of routes, letting unvaried the other ones, and reconstructing a new feasible solution running the model on only the subset of customers involved in the destroyed routes. This procedure allows to completely explore a large neighborhood within very short computational time. Computational tests that show the performance of the matheuristic are presented. The method has also been tested on a simplified version of the HVRP already presented in the literature, the Green Vehicle Routing Problem (GVRP), and competitive results have been obtained.

1. Introduction

In the last few years, the greenhouse effect has become a hot political topic worldwide. The European Commission has recently affirmed that the one-fifth of the EU's total emissions of CO_2 is due to road transport (Demir et al., 2014). Moreover, it has also remarked that, in the last two decades, emissions sensibly decreased in other sectors while they strongly increased in the transport one. Several governments across the world have adopted measures and regulations to reduce emissions due to vehicles emission. Such political decisions have had an important effect on the logistics industry. Many logistics companies have adopted *Green Logistics* projects, to reduce CO_2 emissions. A reduction in pollution can be obtained in two different ways: through a better exploitation of current resources, and by using new, environmental friendly technologies. The first step in this process is to make a better use of available resources. This could be obtained by applying more efficient and sophisticated routing planning optimization methods and adopting smart distribution systems (Mancini, 2013b,a), which would help to decrease the traveling distance of vehicles and hence emissions. However, this generally results in a decline of emissions of only a few percent and the emission level of trucks and vans remains high. To strongly reduce emissions is necessary to exploit environmental friend technologies. One of the most adopted in logistics, specially in last-mile logistics, is the introduction of Electric Vehicles (EVs) in the delivery cargo fleet. This kind of vehicles, commonly adopted for urban

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transport in many large cities across the world (Lajunen, 2014), are becoming more and more popular for last mile deliveries. EVs are not only much more cleaner respect to the conventional vehicles, but also more energy efficient. In fact, the energy source for EVs are renewable sources, such as solar and wind, and therefore, more sustainable. Additionally, EVs are good for the Electric Grid for two reasons. First, they may balance the excess supply of energy by renewable resources, such as wind, during night time, because most EVs are recharged at night. Second, in a smart grid, EVs can act as a power source during daytime peak hours, in which more power is requested (Kempton and Letendre, 1997). A Vehicle to Grid (V2G) system allows the charged EV batteries to give back their energy to the grid. A study on the impact of electric vehicles on smart grids have been proposed in Waraich et al. (2013). However, due to their limited range, they require frequent visits to recharging stations along their route. In fact, latest technologies allows for maximum 100 miles of autonomy, while standard daily routes are generally much longer, as stated in the study proposed by Pearre et al. (2011). Furthermore, long recharging times are requested for a fully complete recharge and the impact of these times on route planning can be extremely significant, especially when tight delivery time windows and service times are considered. A solution to overcome this issue is represented by the battery swapping strategy, according to which, is possible to reduce recharging times by replacing the vehicles batteries with fully charged ones (Yang and Sun, 2015). Although this approach is much faster, it is expensive because the number of battery to be purchased by the fleet holder is much higher than the number of vehicles, and a planning of fully charged battery repositioning at recharging stations must be carried out, with additional operative costs. Recharging times may be reduced introducing fast recharging technologies (Felipe et al., 2014), but these new technologies are very expensive. Another way to reduce loss of time, due to deviations from the original route path to visit recharging stations, is to optimize their location and improve their dissemination along the road network. Many studies have been conducted on optimal recharging stations location, among which (He et al., 2015; Tu et al., 2016; Jung et al., 2014). This approach may be adopted for public transport problems, in which the municipality cover the set up costs for new recharging infrastructures, but cannot be applied by private companies.

For all the above discussed reasons, the management of battery recharging is still an open issue and the diffusion of electric vehicles is still slowed by their limited autonomy. This limitation could be overcome using hybrid vehicles, which can work both with traditional fuel and electric propulsion. The electric battery could be exploited on short routes (which can be performed without recharging the battery) or in zones in which recharging stations may be easily reached, while traditional fuel propulsion could be used in cases in which a visit to a recharging station implies a long deviation, or when the electric battery would allow almost the whole route to be covered. In fact, in such cases, it would be more advantageous to cover a few kilometers with a traditional fuel engine than to plan a battery recharging stop. The use of hybrid vehicles could constitute a fair compromise between economic interest and environmental issues.

The main contribution of this paper is twofold. First, a new, and more realistic, extension of the Green VRP, the Hybrid VRP, has been introduced, in which vehicles may use both electric and traditional propulsion, and a mathematical formulation has been presented. Second, an efficient Large Neighborhood Search Matheuristic (MH) is proposed. To validate the efficiency and the effectiveness of the proposed approach it has been tested also on the Green VRP for which several heuristics have been presented in literature. Results obtained with MH are competitive with the best methods in literature.

The paper is organized as follows. In Section 2 a literature review is reported. Section 3 deals with the problem description, while the mathematical formulation of the problem is given in Section 4. The Matheuristic is presented in Section 5, while computational results are reported in Section 6. Finally, Section 7 is devoted to conclusions and future developments.

2. Literature review

In the last few years, increasing attention has been paid to Green Logistics, which involves the integration of environmental aspects in logistics. Many papers concerning Operations Research applications to Green Logistics have been proposed in the literature. A wide set of issues has been addressed, such as intermodal transportation, mode choice models, fleet choice and exploitation, smart distribution systems and fuel choice. For a complete survey on this subject, the readers may refer to Dekker et al. (2012).

One emerging research area concerns pollution emission minimization. In Bektaş and Laporte (2011), the authors introduced the Pollution-Routing Problem (PRP), an extension of the classical Vehicle Routing Problem with Time Windows, which consists in routing a number of vehicles to serve a set of customers, and determining their speed on each route segment in order to minimize a function that includes fuel, emission and driving costs. The same problem has been addressed in Demir et al. (2012) where an Adaptive Large Neighborhood Search based heuristics approach is proposed. A time-dependent version of the PRP has been addressed in Franceschetti et al. (2013), while (Demir et al., 2014) introduced the bi-level pollution routing problem.

In the nineties and the first decade of the 21st century, refineries focused on removing lead additives from gasoline, in order to preserve air quality. Biofuels based on organic waste can easily be mixed with standard gasoline. However, this technology involves the necessity of adapting engines, which can be quite rather expensive. Electric vehicles are environmentally friendly, since their engines emit almost no emissions. However, due to their limited autonomy, they are more popular for the movements of in-city goods than for medium-long range freight transport. In order to compensate for their short range, a dense power re-supply network would need to be set-up, possibly in conjunction with the possibility of changing batteries. Unfortunately, the present re-supply network is still very limited. Several works, related to power recharging and to location optimization of supply stations, have been conducted (Nicholas et al., 2004; Kuby and Lim, 2005, 2007; Upchurch et al.,