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Refueling-station location problem under uncertainty

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ABSTRACT

In this paper, we introduce a two-stage stochastic refueling station location model, where the first stage locates permanent stations and the second locates portable stations. The portable alternative fuel stations are an innovative feature in transportation network. The models are applied to an intercity network for Arizona. Computational results show that the permanent stations locate in and around heavily populated nodes. In addition, the results obtained for the portable stations can be utilized to set up permanent stations when the investor intends to increase the number of such stations. The computational results of the exact and greedy approach are reported.

1. Introduction

The fossil fuels cause air pollution, reduction in natural resources, greenhouse effects and global warming. The transportation sector is a major source of greenhouse gas emissions. Policies to raise the use of clean and renewable energy are a part of government's efforts to protect the environment. One way is to use alternative energy sources like hydrogen, ethanol, electricity, bio-fuels and natural gas to power vehicles (Wang, 2008; Shukla et al., 2011). However, there are several major challenges to overcome before alternative-fuel vehicles (AFV) will be adopted on a mass scale. The absence of refueling infrastructure is one of the major obstacles to the adoption of AFVs. Since infrastructure development is expensive, there is a need to direct investments towards the establishment of refueling facilities, which face maximum traffic flow in the transportation network. Facility location decisions (number and locations of the stations) are a critical element in strategic planning for a wide range of private and public firms. In the related literature, several models have been developed to determine optimal locations of refueling stations. Often models of refueling station location are considered the traffic flow as an origin–destination (OD) matrix, in which each element of matrix represents the number of travelers moving from the origin to the destination on the shortest path. The stations are located in transportation network to refuel these flows on round-trips as much as possible.

The possible success of AFV solutions depends on the ability of the refueling service provider to deploy a cost-effective infrastructure network with comprehensive coverage. Unfortunately, due to the need to deploy an infrastructure network before delivering the vehicles, service provider has to make strategic network design decisions before observing the actual demand. At this point, factors affecting demand for refueling services, such as the AFV adoption rate and the driving patterns of AFV users, are not precisely known. Since the adoption rate of alternative fueling vehicles, and thus refueling demand, is still unknown, the service provider must make deployment plans with incomplete information on hand (Mak et al., 2013).

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Therefore, it is necessary to consider uncertainty of traffic flow in transportation network. The uncertainty is commonly understood as the factors related to imperfect knowledge of the system under concern.

To the best of our knowledge, papers on refueling-station location problem often have located stations under the assumptions of determined demands and uniform candidate facilities. In these papers, the flow on each OD round-trip are known to the decision makers and fixed through the entire time period and each event. However, in reality, the traffic flows on the paths and it is usually hard to predict and have a large degree of temporal variation and continuously changing. In the context of traffic flow, the issue of uncertainty is more complicated, because even for a uniform freeway traffic system, the understanding of its behavior seems to be still incomplete (Li et al., 2012).

The decision maker may face various sources of uncertainties resulting from measurement errors, fluctuation due to special events, an accident, flood, earthquake, abnormal weather conditions, consumer behaviors and complexities of modeling the battery in the vehicle and/or other factors. Another type of uncertainty pertains to the dynamics of traffic. When capacity of refueling station is reached, drivers may reroute to take another path. This dynamics results in the redistribution of traffic flows and consequently the re-establishment of traffic equilibrium on the network. These uncertainties, if not accounted for, could cause a driver to take a route that would require more energy than that available in the battery, resulting in the driver being unable to reach his or her destination (Fontana, 2013). In addition, if a refueling facility is barely capable of handling the average refueling demands over the course of a day or a week, these variations of traffic flow may affect the covering of flow during other occasions. This means that, with choosing locations to build fuel stations in one occasion, it is not possible to cover the maximum flow in special occasions with the same number of stations.

In this work, we consider the uncertain traffic flow in transportation network. The quantities of traffic flow can, in principle, be represented by random variables, but we assume that all random variables are determined by some state of nature. Accordingly, we assume that a number of scenarios can be considered that represent uncertain parameters. A scenario represents a potential realization of important parameters of the problem. To take into account the traffic flow uncertainty, the scenarios are considered as a set of time intervals. These time intervals could be different in terms of traffic flow. The quantity of traffic flow in each interval is not known and is uncertain, but it could be estimated and determined based on events that occur in each scenario. For example, suppose all scenarios start from the New Year's Day holidays. In the first scenario, the traffic flow of the 1st interval rises because of holiday plus good weather, while in the second scenario the traffic flow of the 1st interval experiences less increase because of holidays plus bad weather. So, as much as possible, a reasonable arrangement of refueling stations is needed to cover the traffic flow on roads under different scenarios.

In a deterministic framework, the refueling stations are considered as permanent stations. The permanent stations are fixed and unchanged in every occasion. In the face of uncertainty, the permanent stations are not able to provide maximum cover under different scenarios. To overcome this shortcoming, it is necessary to locate stations in terms of permanent and portable ones, that the later can be moved to different places under different scenarios and make a better coverage on traffic flow. Portable stations are a very useful option in dealing with traffic uncertainty.

The portable stations are one of the beneficial refueling stations in transportation network, which have unique specifications. In providing the economic and environmental benefits of using alternative fuel quickly, the portable station can be deployed and operated in days rather than months in order to keep up with the growing demands for alternative fuel. A portable station may even be deployed within several hours and also occupies a small space and is easy to transport by road or ship-all the equipment is located in a shipping container. The portable stations can deploy for different alternative fuel. In a temporary or emergency situation that interrupts the ability to fuel a dedicated CNG vehicles fleet, a portable CNG station can be deployed (Fig. 1). In places not serviced by natural gas distribution network, CNG can be transported in a bulky trailer (HelloTrade). Another type of portable stations is portable hydrogen transport units (Fig. 2). Mobile station designs can either contain only high pressure hydrogen storage for a limited number of fills, or can include a high speed compressor for multiple high pressures fueling using a medium-pressure hydrogen source (Powertech). In addition for Electric vehicle, mobiles charging stations have been recently introduced. Vehicles with limited electrical power could drive around the city or in their neighborhood to offer emergency services to some electric vehicles that broke down due to running out of power

Fig. 1. The floating gas station.