Vehicle routing in networks with time-varying speeds

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Abstract

Vehicles travelling through road networks often find that their speed of travel and hence the times for their journeys vary according to when the journey takes place. This is because traffic congestion limits the speeds of the vehicles according to the road usage. Much of this congestion is predictable because it arises from regular patterns of road usage, though congestion arising from incidents such as accidents will not be. Traffic information giving speeds of vehicles on different road sections at different times of the day is now available for many road networks through the use of roadside or vehicle-based traffic data collection systems. This information can be used to plan individual journeys or routing plans for a fleet of vehicles.

There are different objectives that may be optimized in these vehicle routing models. If the focus is on direct economic cost, this may relate to the cost of fuel and the cost of paying drivers and so may be a function of the distance travelled and the time taken. In addition, there may be interest in reducing environmental costs relating to air pollution in various forms, such as greenhouse gas emissions.

Previous work in this area has used models where the objective has been to minimize the total time required in networks with time varying speeds. Assuming that a vehicle travels at a preferred speed unless it is forced to travel more slowly by the congestion on a road segment at the time of travel, models have been constructed where the first in first out (FIFO) property is maintained and results have been obtained for real road networks (Eglese et al., 2006). In Maden et al. (2010) a case study is presented showing that this approach was able to reduce the amount of CO2 produced compared to conventional models that did not take traffic information into account by about 7%.

In the model presented in this paper, it is now assumed that the speeds of the vehicles on each road segment are decision variables, i.e. the speed may be set to any value that is less than or equal to the maximum speed of the traffic on the road segment at that time. The objective chosen in this case is to minimize the CO2 produced. The production of CO2 per unit distance is normally a U-shaped function of speed, though the precise shape depends on the vehicle characteristics and other factors such as the weight of the load carried. In other words, there is an optimum speed at which the production of CO2 per unit distance is minimized. If there were no congestion, the optimal solution would be to minimize the distance and travel at this optimum speed

on every road segment. However the time-varying speed constraints mean that sometimes it will be necessary to travel below the optimal speed; there may also be occasions where because congestion on the route is expected to increase later, it may be better to travel faster than the optimal speed on the current road segment in order to avoid congestion later. As speeds vary on different road segments at different times, the optimal routes may be different from minimum distance routes.

For single vehicle routes between a given origin and destination, an exact dynamic programming algorithm has been developed. However this is computationally time-consuming and so a heuristic approach has been designed to determine the best route and the best speeds for the vehicle to use on each road segment. The heuristic can also be applied to a single vehicle route where a list of customers must be visited in a given order and time window constraints apply to the arrival time at each customer.

A Vehicle Routing Problem is then considered where a set of customers require delivery of goods to them from a central depot using a homogeneous set of vehicles with limited capacity. The customers may have time window constraints for the deliveries. The depot and customers are located on a road network where the maximum vehicle speeds for each road segment at different times of the day are given. The objective is to determine the routes and vehicle speeds on each road segment for each vehicle to satisfy the customer demands and to minimize the total CO2 emissions. To solve the problem, the heuristic algorithm is embedded into a column generation based tabu search algorithm, which takes advantage of the power of branch-and-price to generate new sequences of customers with negative reduced cost. The approach is based on that in Prescott-Gagnon et al. (2009).

Results are given to show the effectiveness of this approach on examples including those based on real road networks using observed traffic information.

References

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