DRISI

CALTRANS DIVISION OF RESEARCH, INNOVATION AND SYSTEM INFORMATION

Research Results

Optimizing Fuel Consumption and Pollutant Emissions in Truck Routing with Parking Availability Prediction and Working Hours Constraints

This study addresses a variant of the shortest path and truck driver scheduling problem under parking availability constraints.

Traffic Operations

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WHAT WAS THE NEED?

According to the U.S. Environment Protection Agency (EPA, 2018), the U.S. Transportation sector is responsible for 28% of the US's greenhouse gas emissions, 23% of which are caused by medium- and heavy-duty trucks. This means that 6.4% of all greenhouse gas emissions in the U.S. are generated by trucks. Furthermore, this issue is not particular to the U.S.A. The European Union faces a similar problem, with almost 5% of their CO_2 emissions originating from heavy-duty vehicles (Gregor, 2018). The European Commission proposed, in 2018, targets for the reduction of emissions in new heavy-duty vehicles, showing that there is a growing concern with the topic (Gregor, 2018). Similar measures have already been adopted by the state of California as an effort to improve its fleet's efficiency and curb CO_2 emissions. Although California was able to reach its total emissions reduction targets early by pushing for the usage of renewable energy and greener technologies, the emissions caused by the transportation sector keep rising, and heavy-duty vehicles still count for around 8% of the state's CO_2 emissions (Barboza & Lange, 2018). Considering the continuous growth of the trucking industry, it is clear the importance of developing more efficient ways of using the trucks, trying to reduce their emissions as much as possible.

The problem of trying to minimize the fuel/energy consumption and pollutants emissions in the transportation sector is not new. Several studies have approached this topic both for passenger vehicles and trucks. A survey on 'green' vehicle routing can be found in (Eglese & Bektas, 2014), which gives an overview of the types of models used for fuel consumption and emissions, and of the different variants of the vehicle routing problem

DRISI provides solutions and knowledge that improves California's transportation system which involve environmental factors. Multiple models have been developed to estimate the fuel consumption and pollutants emissions based on different factors and targeting the usage on problems of different scales. Some models consider only the average speed of the car, as the one used in (Van De Hoef et al., 2015), but more precise models may consider the vehicle load (Zhang et al., 2015), road incline, and if the vehicle is accelerating, decelerating, or cruising (Demir et al., 2011). Reference (Demir et al., 2011) presents a comparison of different fuel consumption models. These models are then used to give an environmental aspect to transportation problems. These problems can be divided based on their time-dependency (time-dependent traffic conditions or not), choice of decision variables (route, number of vehicles, travel speed, departure time, etc) and choice of cost function (only environmental factors or multi-objective).

The problem is that most of these fuel/emissions-efficient models do not address important practical constraints of the trucking industry, i.e., working hours or Hours-of-Service (HOS) regulations and parking availability. These factors are particularly important to long-haul truck drivers, which are usually not the focus of these studies. In most cases, the studies focused on the trucking industry which consider working hours regulations and, to a certain extent, parking focus on the monetary costs directly accrued by the trucking company.

A part of this problem which is still overlooked most of the time is the issue of parking availability. Most models assume that any valid parking location will always be free, which is unrealistic as appropriate truck parking is an issue both in the U.S.A. (U.S. Department of Transportation, 2015) and in Europe (SETPOS Consortium, 2009). In (Vital & Ioannou, 2019, 2020), Vital and Ioannou studied the problem of including both parking availability information and HOS regulations in the planning of long-haul transportation, but those studies do not cover fuel consumption and emissions. Several variants of the two sides of this problem, fuel/emissions optimization and scheduling with working hours regulations, have been studied.

WHAT WAS OUR GOAL?

Currently, what we lack is a model that can integrate both sides. A model able to generate solutions with reduced environmental cost, but that are still feasible in practice. In this project, we address this research gap by extending the shortest path and truck driver scheduling problem under parking availability constraints (Vital & Ioannou, 2021a), which focused on the working hours regulations and parking availability constraints, to consider the impact of traffic conditions and different travel speeds in the fuel consumption and pollutants emissions of the trucks, as well as how uncertainties in the parking availability affect the problem's solutions.

WHAT DID WE DO?

In this project, we first address a `green' variant of the SPTDSP-PA (shortest path and truck driver scheduling problem with parking availability constraints) (Vital & Ioannou, 2021a). This variant differs mainly by the inclusion of fuel consumption in the objective function, the usage of travel speed as a decision variable (to control fuel consumption), and for considering time-dependent traffic conditions. Then, to make the model more realistic, section Parking Availability Uncertainty extends it to include uncertainty in parking availability. In practice, it is impossible to be certain about the future parking availability of any location during planning. Therefore, we include this uncertainty in the model and study its effect on the solutions depending on the information provided to drivers/planners.
The problem consists of planning the path and schedule for a truck starting at an origin location and visiting an ordered list of clients, where the last client is referred to as the destination. Each client has a fixed non-negative service time, and time-window constraints restricting the vehicle's arrival

time. The schedule must comply with HOS (Hours-of-Service) regulations, which impose restrictions on how long the driver can work or drive without resting, and the minimum duration of rests (rests of different durations satisfy different restrictions). Drivers can rest only at rest areas, but arrival time at rest area nodes is also subject to time-window constraints (representing parking availability). The problem is solved over a simplified road network that includes only the main routes the truck can take between two consecutive client locations, and the rest areas around them.

The vehicle consumes fuel when driving or idling. We consider the consumption model for diesel trucks defined in section Consumption Model. The driving consumption rate is described by a non-linear speed-dependent function, and the idling consumption rate is taken as constant. The average travel speed can be adjusted within the allowed range to control the travel time and energy consumption. We assume that the speed profiles are defined such that all edges satisfy FIFO assumptions when considering only one of the speed limits.

During long trips, HOS regulations require drivers to rest along the way. Rest stops are restricted to rest areas and their minimum durations are defined by the regulation. We do not allow for rests to be taken at client locations. However, note that service times longer than 30min can reset the 8h driving limit constraint despite counting as on-duty time for other constraints. Each parking location has a set of time-windows representing the intervals when parking spaces are expected to be available. These time-windows restrict the vehicle's arrival time. The vehicle is not allowed to arrive early and wait. The regulation sets a minimum duration for the rest stops, but it does not set a maximum duration, so the driver is allowed to extend the stay when convenient. Similarly, each client has a set of time-windows constraints and a service time, which define when the truck can arrive at the client and the duration of stay. However, drivers cannot extend the service time at the client. As rest areas are not required stops, so that rest areas can be bypassed. Clients have mandatory stops, so all considered routes go through the client nodes.

WHAT WAS THE OUTCOME?

The main issues for commercialization are the lack of truck parking availability data, scalability, and the need to study the systemwide effects that would be caused by a large-scale deployment. The current state of the USA's truck parking infrastructure is unfavorable for systems that rely on parking availability information such as the one developed in this project. Due to the limited availability of truck parking data, usage would be limited to regions and routes with facilities able to provide data, or to applications where it is acceptable to use rough estimates based on user experience or surveys. For example, if used to estimate the impact of policy decisions, it might suffice to perform periodic surveys of the parking conditions to determine reasonable simulation parameters. Furthermore, even in the absence of parking data, drivers might appreciate the option of defining time periods when they would rather avoid certain parking facilities based on experience, even if that is not as accurate as data provided by intelligent parking systems. We believe that, currently, the potential for commercialization is low as a standalone system, but parts of it could be gradually integrated into existing routing/scheduling/planning systems for small-scale experimentation. We recommend as a primary direction for future research studying how large-scale usage of this type of planning algorithm would affect truck parking demand, and ways to coordinate decisions to avoid adverse effects.

In this study, we addressed a variant of the shortest path and truck driver scheduling problem under parking availability constraints which focuses on optimizing fuel consumption and emissions by controlling the truck's travel speed and accounting for time-dependent traffic conditions. As it is impossible to be certain about the future parking availability of any location during planning, we also studied the case of stochastic parking availability.

When studying the trade-offs between prioritizing emissions reduction or trip duration, we found that although focusing on emissions reduction can increase trip duration significantly, this impact is greatly reduced when considering scenarios with limited parking availability. We also present a cost lower bound that combines HOS requirements with information on optimal speeds for particular cost functions and can be used to significantly speed-up problem solution in deterministic scenarios, both static and time dependent.

The resource-constrained shortest path formulation was further extended to model drivers possible recourse actions when unable to find parking and the ensuing costs. We used this formulation to study how the solutions are affected by the level of information provided to drivers. We found that ignoring uncertainty in parking availability results in inconsistent performance even when restricting parking to periods when probability of finding parking is high. Furthermore, results might not reflect the intent of the cost function used, e.g., minimizing illegal parking events and/or the priority assigned to emissions reduction. Giving drivers full information about the probability of finding parking at any time/location significantly improves performance and reduces illegal parking-related risks, but also substantially increase problem complexity and computation time. Using full information regarding parking availability but restricting the parking times to high availability time-windows can reduce complexity while maintaining consistent, although reduced, performance.

WHAT IS THE BENEFIT?

As this project addresses the issue of emissions reduction, we want this to be reflected in our objective function. We take as objective function a linear combination of trip duration and fuel consumption. The trip duration term accounts for driver wages and operational costs (excluding fuel), whereas the fuel term accounts for fuel and emissions costs. The emissions costs can be seen both as carbon pricing, or simply the level of importance attached to reducing emissions as opposed to reducing trip duration. This cost function considers both time and fuel.

LEARN MORE

Final Report: https://escholarship.org/uc/item/8rw99523

IMAGES

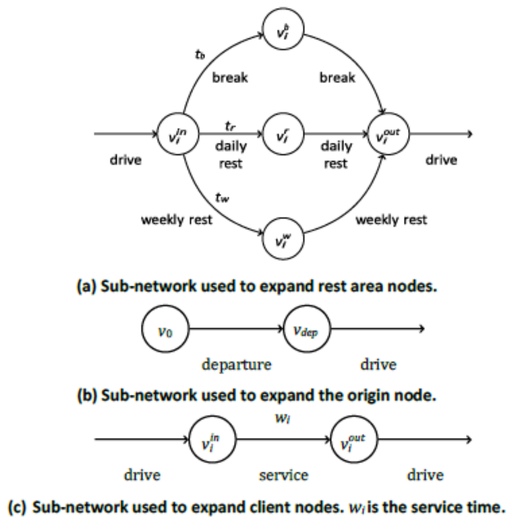

Image 1: Sub-networks used to model non-driving activities.

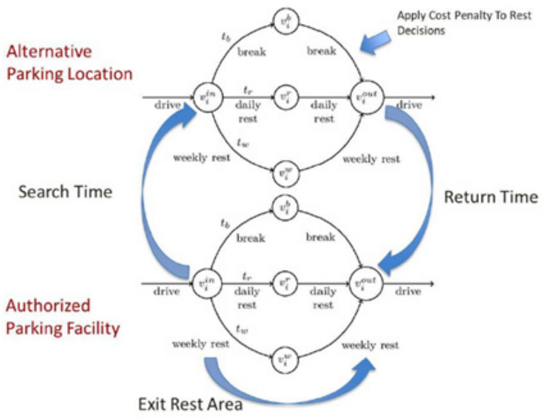

Image 2: Subgraph representing the actions that can be taken at rest areas after inclusion of recourse actions and alternative parking locations.

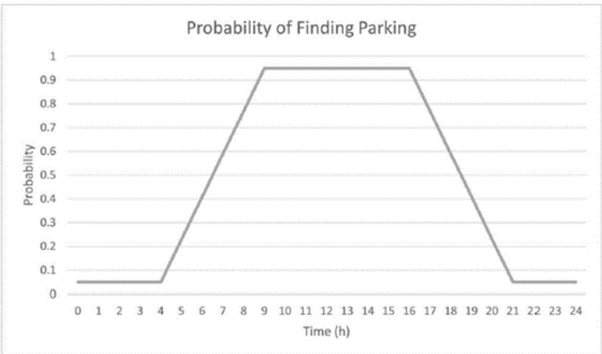

Image 3: Function used to define the probability of finding parking at a given rest area and time.