# Opportunistic Driving: a Critical Design Space for Reducing Fuel Consumption of Timely Long-Haul Truck Transportation


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## ABSTRACT

We study the problem of minimizing fuel consumption of a long-haul truck traveling across national highway under a deadline constraint. We consider a practical setting where the truck traversing a road segment is subject to variable speed ranges due to time-varying traffic conditions. The consideration of variable speed ranges not only differentiates our study from existing ones, but it also allows us to leverage on *opportunistic driving* to improve fuel efficiency. The idea is for the truck to opportunistically wait (e.g., at highway rest areas) for benign traffic conditions, to traverse road segments at favorable speeds for saving fuel. We observe that the traffic condition and thus the speed range are mostly stationary within certain parts of the day, and we term them as *phases*. We then propose an efficient phase-based dual-subgradient heuristic which can optimize opportunistic driving to reduce fuel consumption. Simulations based on real-world traces over the US national highway system show that our heuristic significantly saves fuel as compared to several conceivable baselines, where a large part of the fuel reduction is contributed by opportunistic driving.



## CCS CONCEPTS

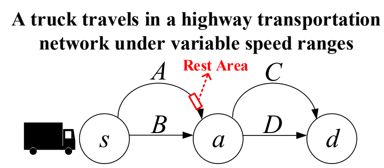
• **Applied computing → Transportation**;

## KEYWORDS

Energy-efficient timely transportation, opportunistic driving

**ACM Reference Format:**

Wenjie Xu, Qingyu Liu, Minghua Chen, and Haibo Zeng. 2019. Opportunistic Driving: a Critical Design Space for Reducing Fuel Consumption of Timely Long-Haul Truck Transportation. In *e-Energy '19: Proceedings of the Tenth ACM International Conference on Future Energy Systems, June 25–28, 2019, Phoenix, AZ, USA.* ACM, New York, NY, USA, 3 pages. https://doi.org/10.1145/3307772.3330163


| Timeline | [0, 1) | [1, 2) | [2, 3) |
|---|---|---|---|
| Feasible Road Speed | $R_1^{lb}$ to $R_1^{ub}$ | $R_2^{lb}$ to $R_2^{ub}$ | $R_1^{lb}$ to $R_1^{ub}$ |

**Figure 1: Opportunistic driving saves fuel. A truck leaves $s$ at time 0, and must arrive at $d$ no later than time $T$. Each road has a length of 50, and requires the driving speed to be subject to both a minimum speed limit $R^{lb}$ and a maximum speed limit $R^{ub}$. If the truck enters the road at a time $t$ where $t \in [0, 1)$ or $t \in [2, 3)$, we have $R^{lb} = R_1^{lb}$, $R^{ub} = R_1^{ub}$; otherwise, we have $R^{lb} = R_2^{lb}$, $R^{ub} = R_2^{ub}$. The truck can wait at the end of road $A$ before entering node $a$; it cannot wait after traversing $B$. The truck fuel consumption rate is $f(r) = 0.01\times(r-50)^2+1$ for each road, where $r$ is the driving speed.**

## 1 INTRODUCTION

In the US, in 2016, the transportation sector accounts for 34.1% of carbon dioxide emissions [5]. Trucks haul 70.6% (up to 10.42 billion tons) of all freight tonnage [3], and account for 24.5% of transportation carbon dioxide emissions [5]. Considering that most (over 60%) US transportation sector carbon dioxide emissions come from petroleum fuels [5], together with an observation that fuel consumption is the largest (26%) trucking operating cost [8], it is critical to reduce fuel consumption to provide both cost-efficient and environment-friendly heavy-duty truck operations.

*Path planning* and *speed planning* are two well-recognized approaches to effectively save fuel. Differences in distances and road conditions can lead to substantially different fuel consumption when driving along different paths. For example, it is reported that one can save 21% fuel by choosing a fuel-efficient path [13]. Meanwhile, driving at an appropriate speed is also critical for saving fuel, considering that normally there is a most fuel-efficient speed for each vehicle. It is around 55mph for many trucks [14], and the fuel economy will degrade if driving below or above this speed.

Note that it is not always possible to drive at the most fuel-efficient speed over the most fuel-efficient path. On one hand, sometimes one must drive faster, because freight delivery is time-sensitive for many transportation services, e.g., logistics with delivery time guarantee [1] and perishable goods delivering [4]. Driving



*e-Energy '19, June 25–28, 2019, Phoenix, AZ, USA*



ACM ISBN 978-1-4503-6671-7/19/06…$15.00
https://doi.org/10.1145/3307772.3330163

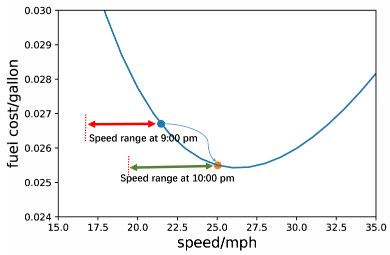



**Figure 2: The fuel-speed function of a truck traversing a road segment in eastern US. Here the most fuel-economic speed is around 26mph. It is substantially below the commonly-known 55mph, as the road segment has a positive grade.**

slower yet at/along a more fuel-efficient speed/path may not ensure a timely delivery. On the other hand, sometimes one must drive slower, because the maximum driving speed on a real-world road depends on the dynamic traffic condition. The dynamic road traffic conditions lead to *variable speed ranges* (VSR) of driving.

In conclusion, it is necessary to optimize path planning and speed planning to save fuel for truck operators. However, in order to achieve the minimal fuel consumption, we note that only optimizing path planning and speed planning is not sufficient. In this paper, we argue that *opportunistic driving* is another critical design space for saving fuel under the setting of variable speed ranges, and it has been ignored by almost all related studies, e.g., [6, 7, 9–12], because they all assume fixed speed ranges.

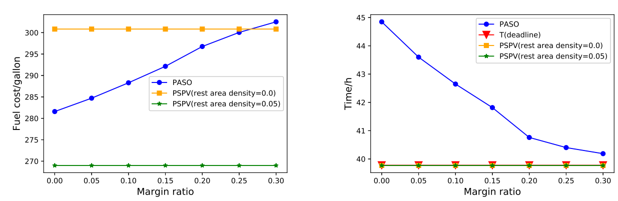
## 2 A NEW DESIGN SPACE FOR SAVING FUEL

We remark that the time-dependent VSR poses a new design of *opportunistic driving* for saving fuel for truck operators. The idea is that it can be more fuel economic for a truck driver to wait at certain highway rest areas for an appropriate length of time, such that he/she can avoid the traffic rush hour and hence travel to the destination at favorable speeds for saving fuel. Consider an illustrative example shown in Fig. 1, where we assume $R_1^{lb} = 30$, $R_1^{ub} = 50$, $R_2^{lb} = 30$, $R_2^{ub} = 40$, and $T = 3$. Without waiting, the optimal solution is a path of $(B, D)$ with speed $\{r_B = 50, r_D = 40\}$, leading to a total fuel consumption of 3.5. Now if one is allowed to wait strategically after passing the road $A$, then the optimal solution will be a path of $(A, D)$ with speed $\{r_A = r_D = 50\}$, and wait for one unit of time after passing $A$ before entering $D$, leading to a total fuel consumption of 2. We also justify our observation using real-world data. We utilize the fuel consumption model used by [6, 7, 11] that is a function of driving speed. We select a road segment in eastern US, and collect the road speed data using HERE map [2]. Fig. 2 shows that at 9pm, the range of the truck driving speed corresponds to a less fuel-efficient part of the fuel-speed function. As a comparison, after one hour at 10pm, traffic condition improves and the speed range becomes more fuel-efficient, allowing the truck to run faster and in the mean time reduce fuel consumption.

## 3 OUR RESULTS

We consider a national highway network modeled as a directed graph, with each edge representing a road segment and each node representing a point connecting different road segments. Each edge has a fuel consumption function, and a time-dependent minimum driving speed limit (resp. maximum driving speed limit). We study the problem of minimizing fuel consumption for the truck to travel from a source node to a destination node across the highway network, with a deadline constraint. Our design space includes path planning, speed planning, and opportunistic driving. We observe that (i) traffic condition remains stationary for certain parts of a day, with a length of several hours for each part; (ii) traffic speed changes roughly synchronously. Thus we define **phase** as a time interval with static traffic conditions and hence fixed speed ranges. We then build a phase expanded network. We use dual sub-gradient algorithm to solve our path planning, speed planning and opportunistic driving planning problem in the phase expanded network.

We use real-world traces to evaluate our heuristic. We compare our heuristic with a conceivable approach generalized from the state-of-the-art assuming fixed speed ranges, i.e., the algorithm from [6]. In order to strictly meet the deadline constraint under variable speed ranges, the conceivable approach which assumes fixed speed ranges takes a prescaled smaller deadline as input. We consider a safety margin defined as $\alpha = \frac{\text{original deadline}-\text{prescaled deadline}}{\text{original deadline}}$.




(a) Fuel consumption results. (b) Travel time results.

**Figure 3: Simulation results of our heuristic PSPV and the baseline PASO, where $\rho$ is the density of rest area.**

We give the simulated fuel consumption results (resp. travel time results) with different $\alpha$ in Fig. 3(a) (resp. Fig. 3(b)). For the conceivable approach, as $\alpha$ becomes larger, fuel consumption increases while travel time decreases. It is clear that a trade-off between energy-efficiency and travel-time-efficiency exists when tuning $\alpha$. Note that when we increase $\alpha$, the conceivable approach obtains a fuel consumption which surpasses our heuristic before its travel time is within the deadline. In comparison, our heuristic always generate energy-efficient solutions meeting the deadline. Moreover, comparing results of $\rho = 0.0$ with those of $\rho = 0.05$, we observe that the fuel consumption of our heuristic reduces by 10% if we allow truck to wait at highway rest areas.

## 4 CONCLUSION

We consider a timely long-haul truck transportation problem subject to variable speed ranges. We note that opportunistic driving is a critical design space for saving fuel, and it differentiates our study from existing ones that are under fixed speed ranges. We design an efficient sub-gradient heuristic. Simulations show that our heuristic significantly saves fuel than conceivable baselines, where a large part of the saving is contributed by opportunistic driving.

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