Green Navigation: A CPS Approach towards Sustainable Transportation

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1 Vision Statement

This white paper advertises the need for cyber-physical solutions that reduce the carbon emissions and energy footprint of the transportation sector by providing computational tools for informing driver decisions. These tools take physical models into account to produce advice that enhances transportation sustainability. According to the US Energy Information Administration [1], in their September 2012 annual energy review [1], the transportation sector currently accounts for one of the largest shares of energy consumption in the nation, among all sectors. Consuming 28% of the total energy, it is responsible for roughly the same amount of energy as that consumed by the entire industrial sector, and significantly outpaces that consumed by the residential and commercial sectors. More importantly, it is responsible for the majority of *fossil* energy consumption, making it a primary source of green house gas (GPG) emissions. According to the US Environmental Protection Agency (EPA)[2], the transportation sector is responsible for roughly 130% of the total emissions of the industrial sector, and 250% of emissions of the commercial and residential sectors combined. More than half of the sector's emissions (as well as 59% of the sector's energy consumption [3]) are attributed to passenger cars and light trucks. They are therefore an obvious target when it comes to attempts for improving the overall energy and environmental sustainability of modern society. A research investment is needed to improve the general understanding of driver-vehicle-infrastructure interactions, and offer computationally-enabled solutions for drivers to reduce their energy cost, emissions, delay, and carbon footprint.

In particular, solutions are needed that offer *individualized* advice to drivers. Currently, vehicular traffic is managed largely in bulk. Traffic lights, route advisories, and other traffic regulators operate in the spirit of *broadcast*, offering the *same feedback* to all. In contrast, with increasing proliferation of computational devices and GPS navigation systems in vehicles with their own networking, storage, and processing capabilities, it becomes possible to customize real-time information that flows back to drivers, thereby allowing individuals to make more informed energy-saving and cost-saving decisions. We envision that such individualization will result in significant total energy and emissions savings.

To assess the social, environmental, and economic impact of the proposed work, it is useful to consult recent transportation statistics. According to the July 2012 edition of the Transportation Energy Data Book [3], produced by Oak Ridge National Laboratory for the U.S. Department of Energy, there is an estimated 230 million light vehicles (passenger cars and light trucks) registered

[1] http://www.eia.gov/aer
[2] http://www.epa.gov/climatechange/ghgemissions/sources.html

in the US. Each of them is driven, on an average, 12000 miles in a year. The average mile-per-gallon (mpg) rating for these vehicles is 20.4 mpg. The potential impact of the proposed research therefore amounts to more than one billion gallons of annual fossil fuel savings *per each 1% reduction in consumption*. A 10% reduction would save enough fuel to offset the entire green house gas emissions of a small nation (such as Sweden).

The idea of large-scale services that offer individualized advice (that balances global optimality and user compliance) may be applicable to other domains. It may constitute a blueprint for offering energy consumption advice in areas that range from residential energy management to data center applications.

Early results show that when a choice of route exists for drivers, it is possible to develop GPS navigation systems that arrive at fuel-optimal routes, thereby reducing vehicular fuel consumption by an average of 14% over the fastest route and 6% over the shortest (averaging a 10% improvement over typically chosen routes) [5]. In a similar study conducted in Lund, Sweden [4], researchers reported that, utilizing traces of trips that exceed 5 minutes, it was shown that 42% of drivers chose routes that are not fuel-optimal. According to their models, changing these routes to fuel-optimal ones would have saved an average of 8.2% in fuel consumption; a number that is remarkably similar to the findings in Urbana from the GreenGPS experiment [5]. While both Urbana and Lund are small college towns with light traffic, the advantage of choosing a well-informed route can be further multiplied in *congested* traffic with better real-time awareness of the degree of congestion, as well as by considering behavioral factors and specifics of individual driving styles. These preliminary findings motivate our proposed work on individualized advisories for greener transportation.

At least three complementary opportunities can be investigated for reducing emissions and energy consumed by considering three scenarios of progressively increasing driver engagement:

- *Same-route optimizations:* Can navigation systems improve fuel consumption and emissions of drivers without altering their route? This problem formulation involves the minimum imposition on the driver who need not change neither trip plans nor path. The answer to the above question is positive. Fuel savings can be achieved by improving performance in congested traffic. Drivers in congested traffic often find themselves engaged in frequent acceleration-deceleration cycles (commonly referred to as stop-and-go traffic). This phenomenon creates extra delay, unnecessary fuel consumption, increased air pollution, excessive driving discomfort, and safety hazards. Despite decades of intensive research in this area, it remains a puzzling phenomenon as no analytical method has been developed to fully explain field observations based on drivers' car-following behavior (typically nonlinear and heterogeneous, and dependent on the driving environment). Navigation services are needed that deliver individualized advice to drivers, generally streamlining traffic even when routes are not changed.

- *Independent route-selection optimizations:* More energy saving opportunities are available when drivers have (and are willing to exploit) a choice of multiple routes to their destinations. In this case, informed route selection can consider (i) roadway infrastructure parameters, (ii) vehicle parameters, (iii) traffic flow parameters, and (iv) human parameters to feed models that predict fuel consumption on different routes. Prior work in the area focused on exploiting shared information only such as traffic speed and congestion levels on different streets [4, 2, 6]. It is interesting to develop prediction models that exploit vehicle-specific and driver-specific information as well. One can then devise a navigation service that predicts fuels consumption, for individual vehicles and drivers on a path, and computes the fuel-optimal and emissions-optimal route for the particular vehicle and driver. Note that, different vehicles might be routed on different paths from the same source to the same destination. For example, a vehicle with a large disparity between highway MPG and city MPG may save more fuel by taking the freeway even when slightly longer, whereas a vehicle with a smaller difference between the two MPG ratings, may be better off going through the city. It is interesting to investigate the benefits of such individualization from a fuel-saving perspective.

- *Global route-selection optimization:* Independently optimizing the route for each driver may be globally suboptimal. However, once a new GPS navigation service reaches sufficiently high market penetration, more opportunities become available for optimization. To illustrate, consider two sets of cars that must choose a route between the same source and destination. Two routes are available, one is four segments long and the other is five segments long. Each segment contributes a unit of gas consumption in light traffic and two units in congested traffic. We shall also assume that either route will get congested if all cars followed it. Hence, if all cars were advised to take the shortest route, it will cost each $2 * 4 = 8$ units of gas, whereas if half of the cars were advised to take the longer "detour", some will spend 4 and some 5, reducing the average to 4.5 units. This oversimplified example illustrates that, by offering individualized advice (e.g., different cars were given different routes for the same source-destination pair), a navigation system with sufficient market penetration can improve both the global consumption and the consumption of each individual vehicle. To ensure fairness, the system must maintain history, and ensure that all vehicles share the global reduction in fuel consumption equitably in the long run (even though some inequity may occur for individual trips). To encourage driver compliance with occasionally suggested (longer) detours, an analytic model should be developed that decides when a detour is appropriate. The model must ensure that drivers who ignore the routing advice will incur bad traffic with a sufficiently higher frequency than if they take the advice. Hence, while some individual route instances may in fact be suboptimal to the driver (in favor of a global optimal), on average the incentive to follow the advice is higher. Reseach is needed on optimization problems that offer global route optimization solutions that reduce both collective and individual fuel consumption and emissions in the presence of sufficient market penetration.

References

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