Energy and Environmental Impacts of Personal Mobility

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Personal mobility is critical for any progressive society. Being able to travel anywhere anytime with little restrictions provides the conditions for a vibrant economy. However, our mobility is often restricted due to limitations in the transportation infrastructure. In particular, when many people utilize the infrastructure at the same time, congestion invariably occurs. One can look at this as a resource management problem. If resources (i.e., the transportation infrastructure) are limited and demand is high, then congestion will likely occur. Two ways of solving this problem are to provide additional resources and/or limit the amount of demand.

In the United States, our transportation system has primarily been developed around the automobile. The majority of our personal trips are made by driving our cars to various destinations. Statistics show that only a small percentage of our country's travel demand is satisfied by public transit. Instead, we have invested billions of dollars into building a large network of roadways that allow us to drive our automobiles almost anywhere. After a major build-out of roads in the 1950's through the 1990's, it is now significantly more difficult to construct new roadways due to higher population densities and subsequent land-use restrictions. Instead, transportation officials are turning towards Intelligent Transportation Systems (ITS) and other means to improve the capacity of existing roadways through the use of computer, communications, and control technology [1]. By improving overall capacity, congestion on our roadways should be reduced.

Nevertheless, studies have shown the roadway congestion is continually getting worse. For example, the Texas Transportation Institute conducts an Annual Mobility Study that estimates traffic congestion in many large cities and what the impact is on society [2]. It defines congestion as "slow speeds caused by heavy traffic and/or narrow roadways due to construction, incidents, or too few lanes for the demand". Because traffic volumes have increased faster than road capacity, congestion has progressively gotten worse despite the push towards alternative modes, new technologies, innovative land-use patterns, and demand management techniques.

Some of the major concerns of roadway congestion are the impacts on energy and air quality. The TTI Annual Mobility Study estimates that billions of gallons of fuel are wasted every year due to congestion [2]. Also, heavy congestion often leads to greater mobile source emissions. One way to estimate the energy and emissions impacts of congestion is to examine velocity patterns of vehicles operating under different levels of congestion. Roadway congestion is often categorized into different "levels-of-service" or LOS (see [3]). For freeways (i.e., non-interrupted flow), LOS can be represented as a ratio of the traffic flow divided by the roadway capacity. There are several different LOS values that range from the letters "A – F". For these different levels of service, a typical vehicle velocity trajectory will have different characteristics. Examples of these velocity trajectories are shown in Figure 1 (from [4]). Under LOS A, vehicles will typically travel near the highway's free flow speed, with little acceleration/deceleration perturbations. As LOS conditions get progressively worse (i.e., LOS B, C, D, E, and F), vehicles will encounter lower average speeds with a greater number of acceleration/deceleration events.

For each of the representative vehicle velocity trajectories (such as those shown in Figure 1), it is possible to estimate both the fuel consumption and pollutant emissions. For automobiles, we are most often concerned about carbon monoxide (CO), hydrocarbons (HC), oxides of nitrogen (NOx), and particulate matter (PM). Figure 2 shows example automobile fuel consumption and emission rates that correspond to the average speed of the representative velocity trajectories shown in Figure 1. The fuel consumption and emission rates are normalized by distance traveled: grams per unit mile. As would be expected, when speeds are very low, vehicles do not travel very far, therefore the grams/mile emission rate is quite high. In fact, when the car is not moving, we get an infinite distance-normalized emissions rate. On the other hand, when vehicles travel at higher speed, they experience higher engine load requirements and therefore have higher fuel consumption and emission rates. As a result, this type of speed-based emission factor curve has a distinctive parabolic shape, with high emission rates on both ends and a minimum at moderate speeds of around 45 – 50 mph.

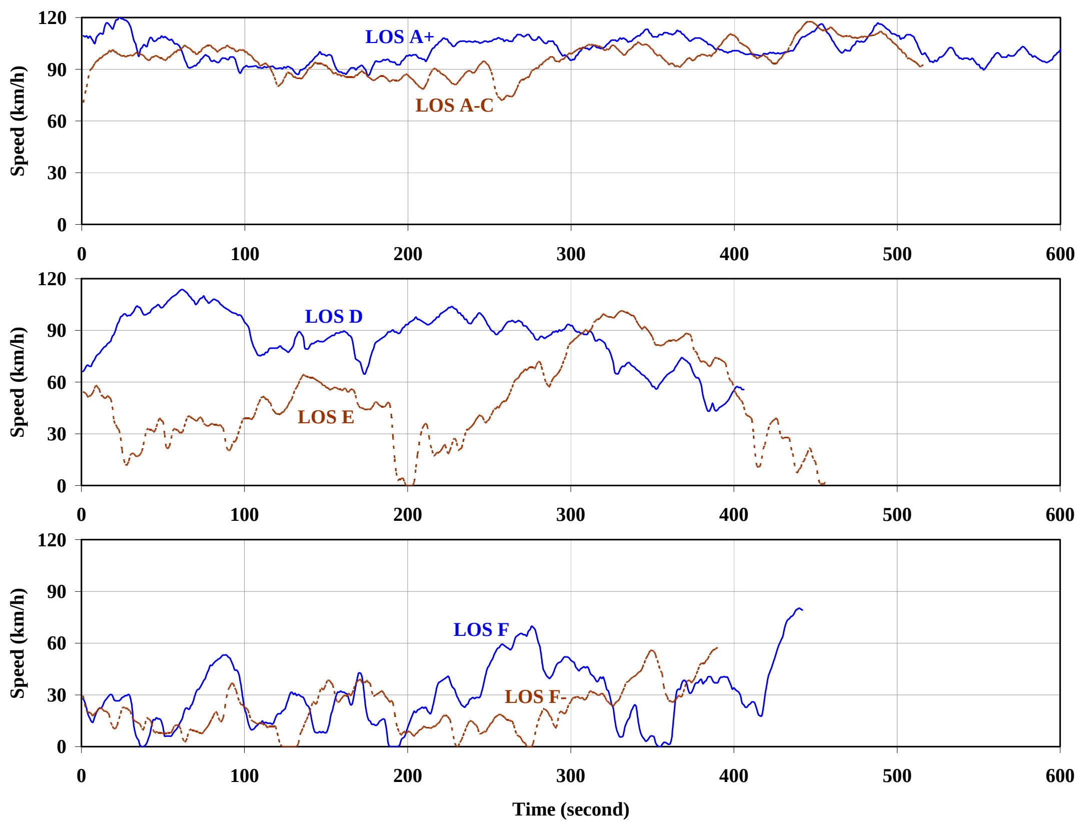

Figure 1. Example vehicle velocity trajectories for different congestion levels-of-service on a freeway (from U.S. EPA facility cycle development, see [4]).

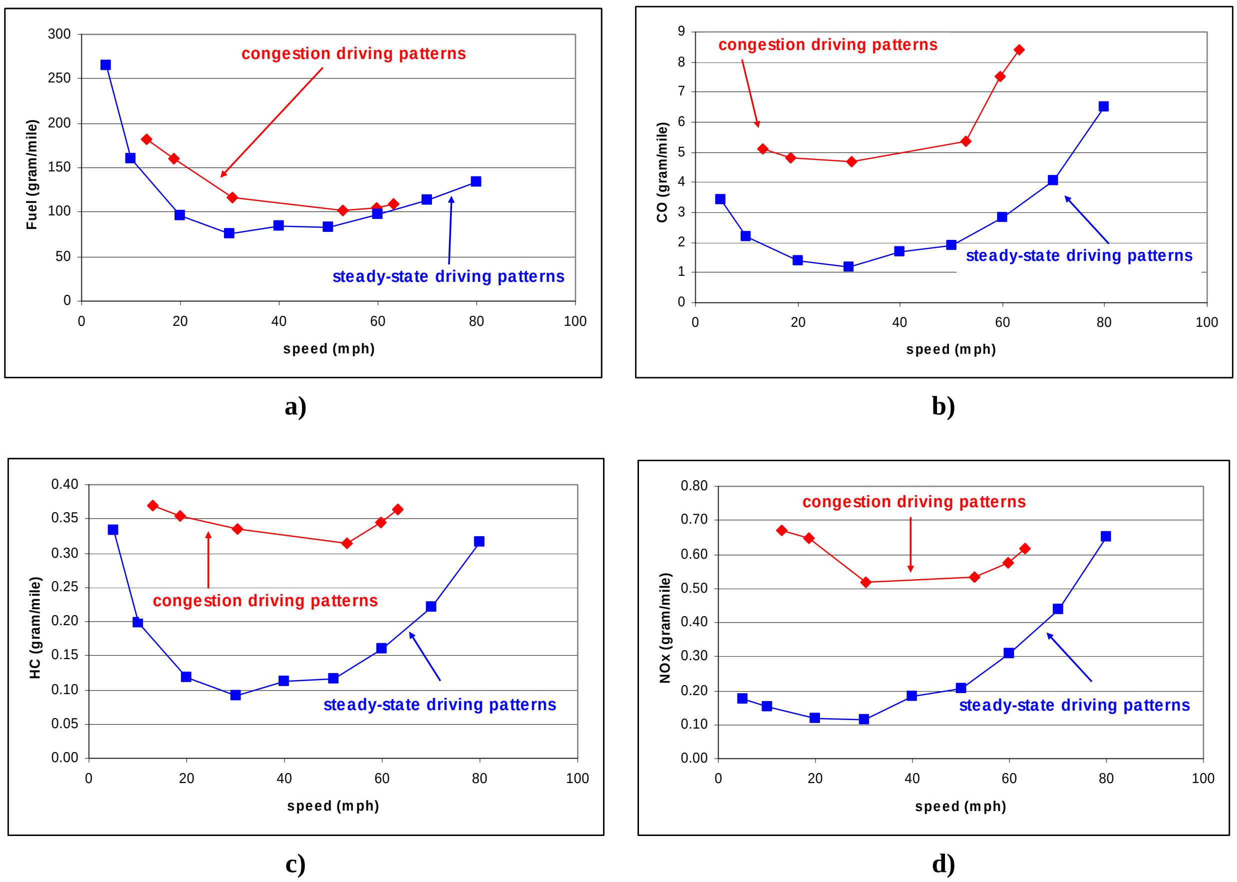

Figure 2. Fuel consumption and emissions versus average speed for a typical passenger vehicle. **a)** fuel consumption; **b)** carbon monoxide; **c)** hydrocarbons; and **d)** oxides of nitrogen.

Also plotted in Figure 2 is a curve of fuel consumption and emissions for a vehicle* traveling at a perfectly constant steady-state speed. It is well known that when vehicles are in traffic there is a lot of “stop-and-go” driving behavior; the accelerations/decelerations associated with this stop-and-go activity lead to higher fuel consumption and emissions. The constant steady-state speed line in Figure 2 illustrates the lower-bound of fuel consumption and emissions for any vehicle traveling at that particular speed.

Several important results can be derived from these plots:

1) In general, anytime congestion brings average vehicle speed below 45 mph (for a freeway scenario), there is a net negative fuel consumption and emissions impact; vehicles are spending more time on the road and as a result fuel economy is worse and total emissions is greater. Therefore in this case, reducing congestion will improve fuel consumption and emissions.

* The vehicle in this case is an average “composite” vehicle representing the 2005 vehicle fleet in Southern California.

2) On the flip side, if congestion brings average speed down from a freeflow speed of around 65 mph to a slower 45 - 50 mph, then congestion is actually *helping improve* fuel consumption and emissions. If relieving the congestion such that the average traffic speed increases back to the freeflow state, fuel consumption and emissions will go up.

3) If the real-world stop-and-go velocity pattern of vehicles were somehow smoothed out where average speed was preserved, then significant fuel consumption and emissions savings could be achieved.

Similar analysis can be performed for roadway travel on arterials and residential roads (i.e., interrupted flow patterns). The analysis is a bit more complicated, but any measure to keep traffic flowing smoothly for longer periods of time will improve overall fuel economy and emissions (e.g., traffic operational improvement measures such as traffic signal synchronization). It is also important to note that these fuel/emissions congestion effects are much more pronounced with heavy-duty trucks since they tend to have much lower power-to-weight ratios.

In terms of addressing congestion and improving mobility and accessibility, there are three general areas that can be addressed:

1) ***Manage Supply***—additional resources and capacity can be provided to the transportation infrastructure. Examples include building additional roads and lanes to increase roadway capacity; building more bike and walkways to promote these alternative modes; improving transit facilities and services as well as better intermodal facilities and services so people will use transit more often; improve overall system operations (e.g., quickly respond to roadway incidents); implement intelligent transportation system techniques to improve travel efficiency.

2) ***Manage Demand***—implement pricing mechanisms to limit use of resources; provide a much greater range of alternative modes of transportation; allow for alternative work locations and work schedules; and have employers provide travel support programs.

3) ***Manage Land-Use***—implement better urban design; provide for mixed use development of land; increase both housing and industrial density; allow for innovative planning and zoning; and implement some type of growth management.

It is important that these different areas should be addressed together, rather than separately. For example, if you only increase supply, this will likely induce additional demand. On the other hand, providing demand management without increasing supply could limit economic growth.

Within these general areas, there are several specific programs that can reduce congestion and also have a positive energy and emissions impact. This list is not exhaustive but it provides examples of what is being done today and into the future:

Intelligent Speed Adaptation (ISA)—an on-board ISA system monitors the location and speed of vehicles, compares it to a defined set speed, and takes corrective action such as advising the driver and/or governing the top speed of the vehicle. ISA is an active research field in Europe where it is currently being evaluated for improving safety, reducing congestion, and lessening environmental impacts [5].

Carsharing**—**the basic premise of carsharing is to move away from individual vehicle ownership exclusively; instead, a fleet of vehicles can be shared throughout the day by different users to provide a new mobility option. This improves overall transportation efficiency by reducing the number of vehicle required to meet total travel demand (see, e.g., [6]).

Enhanced Transit**—**transit is seldom used in the U.S. since it is typically inflexible and unreliable. New enhanced transit systems are now becoming more available such as Bus Rapid Transit (BRT) and other systems that provide intermodal linkages of standard transit routes [7].

Smart Parking**—**significant fuel consumption and emissions savings can be achieved through the use of advanced technologies to help direct drivers efficiently to available parking spaces at transit stations (and other activity locations), encouraging transit ridership, lessening driver frustration, and reducing congestion on highways and arterial streets [8].

Transit-Oriented Developments**—**TODs promote transit use through the integration of multiple transit options in high-density developments consisting of residential, commercial, and retail entities. TODs have been demonstrated to increase transit usage, elevate the pedestrian mode, and reduce private vehicle use [9].

Innovative Transportation Modes**—**In addition to the automobile, new modes can be used to satisfy travel demand, such as the Segway human transporter, electric bicycles, and neighborhood electric vehicles.

In summary, roadway congestion and associated environmental impacts will continue to get worse unless a number of alternatives take place. This paper shows that some amount of congestion can have a positive impact on fuel consumption and vehicle emissions; however severe congestion can have the opposite effect. There are a number of new transportation innovations that can be implemented to improve our overall personal mobility with minimal energy and environmental impacts.

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