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THE ROLE OF TRAVEL BEHAVIOUR RESEARCH IN REDUCING THE CARBON FOOTPRINT: A US PERSPECTIVE

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ABSTRACT

While the US makes up only about 5 percent of the world's population, it produces over 20 percent of the world's GHG emissions in the transportation sector, and passenger vehicles, used for the daily travel of households, are the primary source. Technological innovations offer much potential for reducing emissions from passenger vehicles, but consensus is growing that multifaceted changes in human behavior are key to meeting GHG emissions reductions targets. Key behavioral questions include how willing Americans will be to adopt new technologies, in what style they will drive their vehicles, and how much they will drive their vehicles. The goal for travel behavior researchers is to identify the "levers" that can be "pulled" to get people to make the low-GHG choices. In this paper, we provide an overview of progress towards this goal. We first outline the relevant behaviors and present a framework for understanding the contribution of individual behaviors to efforts to reduce GHG emissions. We then review existing knowledge on the factors correlated with these behaviors, and, thirdly, examine evidence on the effectiveness of interventions to reduce GHG emissions and discuss outstanding questions. We conclude with a discussion of research challenges and needs.

1. INTRODUCTION

Fourteen years after the United Nations adopted the Kyoto Protocol, the United States remains absent from the list of signatory states (United Nations, 2011), notably so given its position—second only to China—for the volume of carbon dioxide (CO₂) emissions from fuel combustion (International Energy Agency, 2010). Largely responsible for

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putting the US in this position is the transportation sector: CO₂ emissions from fossil fuel combustion in the transportation sector accounted for 26.4 percent of all GHG emissions in the US in 2007, second only to electricity generation as a source of greenhouse gas (GHG) emissions (US Environmental Protection Agency, 2009). While the US makes up only about 5 percent of the world's population, it produces over 20 percent of the world's GHG emissions (US Environmental Protection Agency, 2006).

The transportation sector is large and diverse, encompassing travel by air, land, and water, and the movement of both passengers and freight. But passenger vehicles, used for the daily travel of households, are the primary source of CO₂ emissions within the transportation sector (US Environmental Protection Agency, 2009). Household travel accounts for over 80 percent of VMT and three-quarters of CO₂ emissions from "on-road sources" in the US (Federal Highway Administration, 2009). In the US, over 88 percent of person miles of travel in 2009 were by passenger vehicle, and the average American household made nearly 6 vehicle trips per day, totaling over 66 vehicle miles of travel.¹ Reducing GHG emissions in the US means doing something to reduce CO₂ emissions from passenger vehicles used for daily travel.

The good news is that many technological innovations with the potential to reduce transportation emissions from passenger vehicles are possible in the near-term. Improvements in efficiencies for heavy- and medium-duty trucks and incremental and "in-use" efficiencies for light-duty vehicles are among the most cost-effective strategies to reduce GHG emissions in the US by 2030; use of biofuels, improved hybrid-electric vehicles, and alternative refrigerants are less cost-effective, though still viable (Lutsey and Sperling, 2009). However, consensus is growing that technological innovations alone will not be enough to reach targeted reductions in GHG emissions: changes in human behavior are also essential (Lutsey and Sperling, 2009; Rajan, 2006). First, the effectiveness of technological innovations in reducing GHG emissions depends on their adoption by consumers, more specifically, their willingness to pay more for higher fuel efficiencies or for alternative vehicle technologies. Second, how individuals drive their chosen vehicles—speeds, acceleration, idling—influences fuel efficiencies and thus GHG emissions. Third, how much individuals drive their vehicles, measured as vehicle-miles-traveled (VMT), determines fuel use and thus GHG emissions. Thus, multifaceted changes in behavior are key to meeting GHG emissions reductions targets.

This presents two challenges for travel behavior researchers. The first challenge is to improve our understanding of the relevant behaviors and the factors that shape them. The second challenge is to develop an understanding of mechanisms for changing these behaviors. These two streams of research are related, in that the first provides the basis for designing "interventions" to achieve the latter—policies or programs that change the factors that influence the relevant behaviors to achieve the desired outcome of a reduction in GHG emissions (Figure 1). Policy makers need researchers to identify for them the "levers" that can be "pulled" to get people to make the low-GHG choices.

In this paper, we aim to provide an overview for researchers of our progress towards this goal. We first outline the relevant behaviors and present a framework for understanding the contribution of individual behavior to efforts to reduce GHG emissions. We then review existing knowledge on the factors correlated with these behaviors, and, thirdly, examine evidence on the effectiveness of interventions to reduce GHG emissions and discuss outstanding questions. We conclude with a discussion of research challenges and needs. We make no pretense of comprehensiveness. Due to a variety of factors—primarily the availability of literature and our own familiarity with key issues—our review addresses passenger travel for daily use (not airline travel) and is largely oriented toward adult travel (as opposed to youth or teenage travel). Instead we aim for this review to provide a fruitful starting point for a discussion of the role of travel behavior researchers in the struggle to slow the current trend towards global climate change.

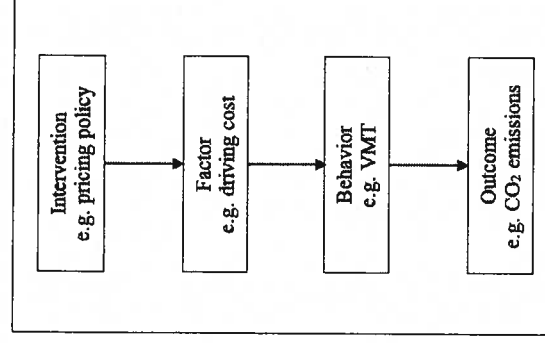


Figure 1. Causal Chain

2. BEHAVIORAL FRAMEWORK

The GHG emissions produced by passenger cars in the US are a function of vehicle miles travelled (VMT) and emissions per mile (Figure 2). The behaviors underlying these components are complex. VMT is the direct result of a series of behavioral choices shaped by the physical environment and policy context over different time frames. The rate of emissions per mile is also fundamentally a function of behavior, both the choice of vehicle type but also the style of driving (e.g., accelerations). In this section we first define each of these behavioral components of GHG emissions in more detail, and then outline a conceptual framework useful to understand these behaviors and ways of changing them.

¹ Calculated by the authors using data from the 2009 National Household Travel Survey, accessed using the Online Analysis Tools, Table Designer (website, <http://nhts.ornl.gov/tables09/ae/TableDesigner.aspx>).

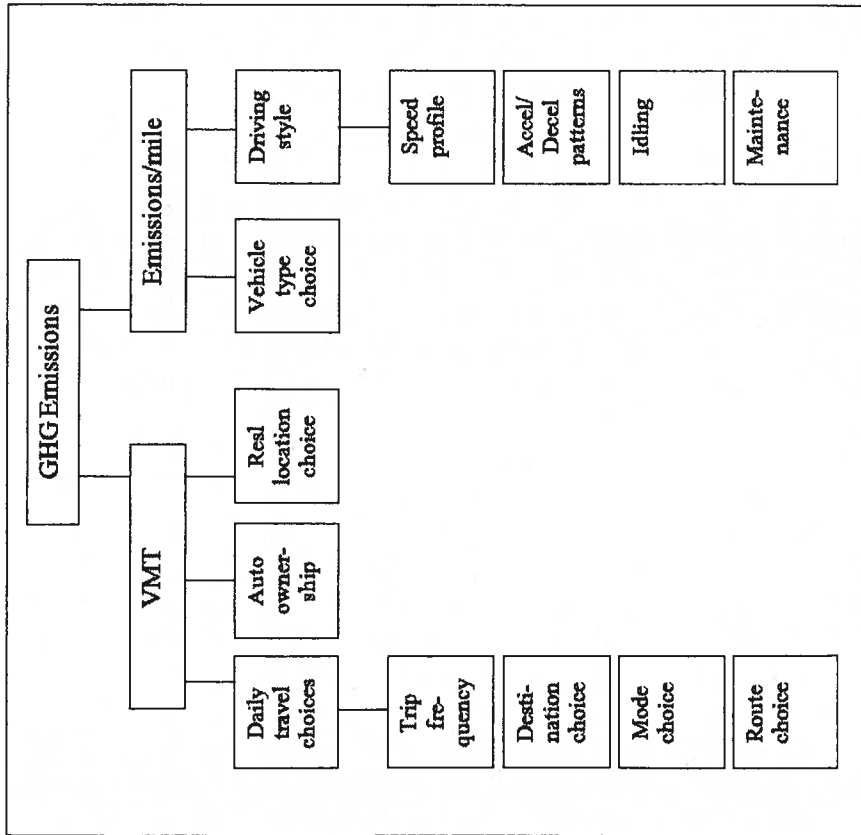


Figure 2. Behavioral Components of GHG Emissions from Daily Travel

1 Behavioral Components

VMT is affected by household and behavioral decisions that play out over different time horizons, including the short-term, mid-term, and long-term (Levinson and Krizek, 2008). Short-term decisions, or daily choices, are typically considered to include the choices of whether or not to make a trip, what destination to go to, what mode of travel to use, and what route to take to get there. The outcome of these decisions is the number of trips per day, the average trip distance, and the share of trips by car, which, when multiplied together, equal total daily VMT. But these daily choices are shaped by longer term choices. To own a car or not is usually considered a mid-term choice—changeable, but not on daily basis. Where to live is considered a long-term choice, though its occurrence varies considerably from individual to individual. It is commonly assumed that the longer-term choices determine the alternatives available for the shorter-term choices, e.g., residential location determines distance to potential destinations, auto ownership influences the possible modes. In reality, the temporal structure among these choices is

not so clear-cut, e.g., auto ownership can precede residential location choice, and work location may necessitate the purchase of a car.

Driving style also has multiple behavioral components. Most important from the standpoint of GHG emissions is the driving cycle for each trip, characterized by the speed of the vehicle at each point of time during the trip. Key components of this profile are idling, acceleration, and cruising speed. Each of these components influences the fuel efficiency of the trip and thus the GHG emissions. To optimize efficiency, and thus minimize emissions, drivers should avoid unnecessary idling, not accelerate too quickly, and cruise at speeds between 25 and 60 miles per hour and ideally at about 50 miles per hour (mph) (US Department of Energy and US Environmental Protection Agency, 2009). Aggressive driving cycles, characterized by fast acceleration and speeding, result in a penalty of 28 to 33 percent in fuel efficiency (Energy and Environmental Analysis, 2001). Decisions about vehicle maintenance also influence emissions. Most notably, engines should be properly tuned and tires properly inflated to minimize emissions. Use of cruise control and overdrive gear technologies also influence fuel efficiency, as does carrying unnecessary weight in the car (US Department of Energy and US Environmental Protection Agency, 2009). Indeed, the obesity epidemic in the US has been blamed for increasing fuel consumption for both passenger vehicles and airlines (suggesting that perhaps weight loss is a solution to climate change as well as health care in the US!).

Choosing a vehicle type is a complex decision that can be defined along several different dimensions. The most basic choice from the standpoint of GHG is the choice of vehicle class, e.g., passenger car versus sport-utility vehicle (SUV) versus light-duty truck (LDT). Finer vehicle class definitions are often used and may be based on function, size, or a combination of both (Choo and Mokhtarian, 2004). The average fuel efficiency for each class of vehicles is significantly different, reflecting the different fuel efficiency standards set by the federal government. Indeed, choice of fuel efficiency is another way to define vehicle type choice, as is emissions rating, e.g., California’s ratings for low-emission vehicles (LEVs), ultra-low-emission vehicles (ULEVs), and super ultra-low-emission vehicles (SULEVs). The choice of conventional versus alternative technology, including electric and hybrid electric vehicles, is yet another important dimension. Related to the choice of technology is the choice of fuel, e.g., gasoline versus diesel versus electricity versus biodiesel, and so on. All of these dimensions of vehicle type choice—vehicle class, fuel efficiency, emissions rating, technology type, and fuel type—affect GHG emissions.

2.2 Conceptual Framework

One way to conceptually organize the many different factors that affect each of these choices is to differentiate between demand-side and supply-side factors. On the demand-side are individuals, living in households, and their assorted needs (or desires) for activities, such as work, shopping, and recreation. Individuals and their households also bring attitudes, preferences, tastes, and lifestyles to the table, along with time and money constraints. Life stage, e.g., young and single or married with kids, together with lifestyle, e.g., home body or outdoorsy type, engender certain patterns of activities, which themselves engender certain needs for travel. Notwithstanding the occasional trip for

pleasure, the demand for travel is largely derived from the demand for activities, as people seek to get from one place to another.

On the supply side are three components essential to this discussion: the land use system, i.e., the spatial distribution of activities; the transportation system, i.e., the facilities and services that link activity locations; and the automobile market, in terms of the types of vehicles available, their features, and their costs. All three components influence behaviors related to both VMT and emissions per mile, more or less directly, as will be discussed below.

The individual choices that influence GHG emissions depend on interactions between demand-side and supply-side factors. According to utility-maximizing theory, individual choices depend on the set of alternatives available and the characteristics of those alternatives, on the supply side, and the importance that individuals give to those characteristics, on the demand side. In theory, an individual chooses the alternative, from the available set, that maximizes his utility, which depends on the characteristics of each alternative and the weight that individual gives to each characteristic. If the low GHG emissions option offers higher utility than the higher emissions options, it will be chosen; if it doesn't, it won't.

Spurring people to choose the low GHG emissions option more often means increasing the utility of this option relative to the others. On the supply side, one approach is to change the characteristics of the choices available, for example, by building a bike lane that improves the safety of bicycling, or by offering a tax break for low emission vehicles. On the demand side, it may be possible to change the importance that individuals give to different characteristics in their decision making, for example, through educational campaigns. Both approaches may be used either to create "carrots" that encourage the low-emissions choice or "sticks" that discourage the high-emissions choice. Another supply-side approach is to change the choices available, for example, by adding rail to the mix of available modes, or by offering an alternative vehicle technology, or, alternatively, to eliminate high-emissions options.

Travel behavior research has traditionally focused on understanding patterns of individual response to the supply side, thereby identifying the most important supply-side characteristics in the decision making process. This makes sense from a policy standpoint, as the supply side is directly and indirectly shaped by public policy through investments and regulation. Correspondingly, transportation planning has traditionally focused on providing a transportation system that performs well on the important characteristics, such as time, cost, or quality. New infrastructure for a particular mode decreases its cost, readily defined to include travel time and convenience, thereby increasing its utility, leading to an increase in its use. Investments in road infrastructure increase driving, while investments in transit or non-motorized infrastructure tends to increase the use of these alternatives to driving. In contrast, auto manufacturers respond to demand, by developing vehicle models that provide for the qualities consumers want, but they also aim to shape it, by changing the relative importance that individuals give to different vehicle characteristics. Demand and supply interact with each other in multiple ways over multiple time frames, and these interactions involve decisions on the part not just of

individuals and households in their roles as consumers, but also of government and private firms (Levinson and Krizek, 2008). Our focus in this paper rests on the behavior of individuals as consumers and the ability of government to shape that behavior, but we wish to stress the importance also of research that aims to understand individual and institutional behavior within government and the car market as well.

There are many ways to organize and structure a discussion on the topic of behavioral contributions to GHG emissions in the realm of daily travel. For example, instead of organizing the relevant behaviors according to their contribution to VMT and to emissions per mile, one might classify them according to technology adoption and technology use. Instead of an economic framework, psychological theories commonly used in health behavior research might provide a way to understand the relevant behaviors. A comprehensive review of evidence on consumer behavior and behavioral change related to sustainability (Jackson, 2005), for example, offers an alternative approach. Thus, our approach is not the only one, nor necessarily the best, but it has proven useful to us in developing this paper.

3. UNDERSTANDING BEHAVIOR

The first step toward bringing about changes in travel behavior that reduce GHG emissions is an understanding of the component behaviors and the factors that influence them—what people do and why they do it. Such an understanding is typically developed through a body of cross-sectional studies that examine statistical associations between various factors and specific behaviors and together build an evidence base for the development of policy interventions. A complete review of all evidence on the factors affecting each behavior and its components is beyond the scope of this paper, but we summarize some of the key factors associated with both VMT and emissions rates and discuss important gaps and limitations. Behavioral studies on VMT vastly outnumber behavioral studies on emissions rates, though gaps in knowledge remain for both.

3.1 VMT

Perhaps the most consistently documented factor associated with VMT is income: within and across nations, higher incomes are associated with more VMT, and increases in income have been shown to be associated with increases in VMT at both aggregate and disaggregate levels (Polzin, 2006). The effect of income on VMT is both direct, by enabling greater trip frequencies and distances, and indirect, by increasing auto ownership. Age, household size and structure, auto and license availability are also important factors (Polzin, 2006).

That land use patterns impact VMT is also now widely accepted, although the magnitude of this impact is still a matter of contention (Ewing, *et al*, 2008; Transportation Research Board, 2009). The research examining relationships between various dimensions of travel behavior and land use characteristics is extensive. Many literature reviews have been published (Badoe and Miller, 2000; Crane, 2000; Ewing and Cervero, 2001) and more

appear each year focusing on different dimensions or policy prescriptions (Geurs and Van Vee, 2004; Saelens and Handy, 2008; Saelens, *et al.*, 2003; Transportation Research Board, 2009; Van Wee, 2002).

The importance of land use characteristics relative to socio-demographic characteristics varies for different dimensions of travel behavior, as follows (adapted from Ewing andervero, 2001): (1) trip frequencies are primarily a function of the socioeconomic characteristics of travelers and secondarily a function of the built environment, (2) trip lengths are primarily a function of the built environment and secondarily a function of socioeconomic characteristics, (3) mode choices depend on both socioeconomic characteristics and characteristics of the built environment, though probably more the former, and (4) characteristics of the built environment are much more significant predictors of VMT—an outcome of the combination of trip lengths, trip frequencies, and mode split.

But there remains considerable room for a deeper understanding of how land use directly and indirectly influences VMT and its component behaviors. One set of questions involves potentially conflicting impacts on different components. For example, residents in higher density neighborhoods may drive fewer miles than their lower density counterparts but may make more overall vehicle trips. Another set of questions involves the effects of land use on short-term, mid-term, and long-term choices. In particular, some have hypothesized that the primary effect of land use on travel behavior occurs through residential location choice, when households “self-select” into the type of neighborhood that supports their preferred way of traveling (Cao, *et al.*, 2009). Yet another set of questions has to do with conflicting effects of land use on VMT and behaviors related to emissions per mile. For example, higher density environment might lead to fewer and shorter driving trips, but also slower speeds and more acceleration and deceleration that increase emissions per mile.

What is the outlook for getting Americans to drive less? On the positive side, VMT in the US began to plateau in 2004 and actually dropped in 2007; given current economic conditions and volatile gas prices, this trend is expected to continue (Puentes and Tomer, 2008). On the other hand, countless studies suggest that getting people to drive less is an uphill battle. Consider that some people, at times, derive positive utility from driving itself (Ory and Mokhtarian, 2005; Redmond and Mokhtarian, 2001), and a significant share of individuals admit that they drive more than they need to (Handy, *et al.*, 2005). For example, specific behaviors that contribute to longer driving distances include seeking parking spaces close to the front door of the destination (Shoup, 2005) or elderly drivers making a series of right turns to avoid a single left turn (Ball, *et al.*, 1998). One study found that one-third of participants deviated more than 10 percent from the route with the minimum travel time (Parkany, *et al.*, 2006). The habit of driving may be strong, the motivation to reduce driving low (Eriksson, *et al.*, 2008), and psychological resistance high (Tertoolen, *et al.*, 1998). As discussed in Section 4, efforts to overcome these hurdles have met with mixed success.

3.2 Emissions Rate

The rate of emissions per mile of driving is determined both by the vehicle technology and the style in which the vehicle is driven. The latter is clearly a question of behavior, but so is the former, in that the technology of the vehicles in use depends on the types of vehicles that individuals choose to buy.

Studies show that vehicle type choice depends on demographic characteristics such as age, income, gender, and household size; however, attitude, personality, and lifestyle factors matter too (Choo and Mokhtarian, 2004). In the US, the design of the neighborhood seems to affect vehicle ownership as well as vehicle type choice, with suburban residents favoring SUVs and pick-up trucks (Cao, *et al.*, 2006). Fuel economy is apparently not factored into decisions about vehicle type in a systematic way, though it has symbolic value for drivers who wish to project an image of resource conservation or thrift (Turrentine and Kurani, 2007).

Driving style is garnering increased attention as an important factor in GHG emissions, particularly with the advent of hybrid vehicles and the practice of “hypermiling,” in which drivers attempt to adjust their driving to maximize average fuel efficiency, as discussed below. Speed is a key component of driving style, and one of the key factors associated with speed is age, with younger drivers driving at higher speeds than older drivers (Waselewski, 1984). Other relevant aspects of driving style include acceleration and deceleration behavior as well as idling behavior, estimated by one study to account for 1.6 percent of CO₂ emissions in the US (Carrico, *et al.*, 2009). In addition to socio-demographic and attitudinal factors, characteristics of the built environment may also affect these behaviors. For example, arterials with traffic signals are likely to produce more acceleration, deceleration, and idling than freeways, while drive-in facilities (e.g., fast food restaurants, banks) likely reduce vehicle starts but increase idling time.

It is important to recognize the potential connections between vehicle type choice, driving style, and VMT, both in the aggregate and at the individual level. One example is what is called the “rebound effect.” As fuel efficiencies increase, VMT also increases, resulting in a 20 percent “take back” of potential energy savings (Greene, *et al.*, 1999; Small and Van Dender, 2007); decreases in fuel prices may have a similar effect (Small and Van Dender, 2007). Another example of offsetting effects involves the use of technological innovation to enable larger, heavier vehicles and better acceleration performance rather than improved fuel efficiencies (Lutsey and Sperling, 2005). Increases in VMT produce compounding effects if they result in increases in stop-and-go traffic, which means slower speeds, more acceleration and deceleration, and more idling, all resulting in increases in GHG emissions on top of the increase from increased VMT.

4. CHANGING BEHAVIOR

If the goal is to reduce GHG emissions, what policies and programs can be used to change these key contributing behaviors? In this section, we discuss policy interventions

signed to reduce VMT, encourage low-emissions driving styles, or promote the purchase of low-emission vehicles. Ideally, the effectiveness of such interventions is evaluated through before-and-after studies with treatment and control groups that isolate the effect of the intervention from other forces. Unfortunately, for most of the promising interventions, few such studies exist. As a result, many questions remain about their true potential. Here we review existing evidence on the effects of a range of interventions and discuss some of the outstanding research questions.

1 VMT Reduction Strategies

Strategies to reduce VMT broadly fall into two camps: “sticks” that discourage auto use; and “carrots” that encourage choices that reduce auto travel. We discuss five categories of policy levers—pricing, parking, land use, non-motorized infrastructure, and voluntary travel behavior change—that use carrots and/or sticks to change behavior.

Pricing

Because travel choices are sensitive to cost, pricing is believed to be one of the most effective strategies for reducing VMT. One justification for increasing the price of driving is that drivers do not directly pay for the full cost of infrastructure for automobiles. For example, although gas taxes are used to fund much of the cost of transportation infrastructure in the US, sales and property taxes are also commonly used, especially for local roads (Pew Charitable Trusts, 2009). Another justification for increasing the price of driving is that drivers do not pay for the many other costs of driving, including non-monetary externalities like air pollution or climate change; pricing can be used to “internalize” the costs of driving—to make drivers account for the full costs of driving when making their travel choices. In general, pricing can be used to raise revenues, discourage driving, or both; in an ideal case it balances the benefits of the use of infrastructure with the costs incurred by that use (Parry and Bento, 2002).

Pricing comes in many different forms, and some have been studied more than others. The most widely used form of pricing is the gas tax. In the US, some have argued that increases in gas taxes are seen as an equitable and cost efficient strategy for achieving a more balanced transportation system (Wachs, 2003). But the idea is not politically popular, and in times of economic recession, decision makers are reluctant to suggest increases in the federal gas tax. Interestingly, it is relatively unclear how effective an increase in the gas tax would be at reducing VMT. Studies show that in the US, gasoline demand is relatively inelastic with respect to gas price and that elasticities have been declining (Espey, 1998; Goodwin, 1992; Hughes, *et al*, 2008). It is likely that a substantial increase in the gas tax—to levels common in countries in the European Union—would be necessary to bring about even a moderate decrease in VMT in the US.

Value pricing, sometimes called congestion charging, congestion pricing, or value pricing, is another form of pricing. There are several variables that can be manipulated: where (what facilities are covered), when (what time periods are covered), and how much (what level the toll is set). London’s well known congestion pricing scheme was part of a larger transport strategy designed from the outset to tackle four key transport priorities:

reduce congestion; improve bus services; improve journey time reliability for the remaining road-users; and make the distribution of goods and services more reliable, sustainable and efficient. Studies show that the policy has succeeded in reducing vehicle travel into central London with a concomitant decrease in CO₂ emissions (Beevers and Carslaw, 2005; Santos and Shaffer, 2004). In the US, a similar form of congestion pricing has been considered (but not yet adopted) for Manhattan and San Francisco, where bridges and/or tunnels provide limited access points and natural sites for imposing fees.

Facility-specific tolls are commonplace in many metropolitan areas in the US. The tolls are most often implemented to pay for the facility and rarely used for modifying behavior. However, by varying the tolls according to the time of day (or level of demand), such facility-specific tolls could achieve, at least locally, some of the benefits of congestion pricing. Several different behavioral outcomes may result: no change in driving with no reduction in GHGs, a shift in driving trips away from the peak that might lead to increased fuel efficiencies and a decrease in GHGs, a shift from driving to transit or non-motorized modes with a direct reduction in VMT, a shift in routes that could increase VMT but might also change fuel efficiencies, in either direction. Toll revenues could also eliminate trips altogether, with a corresponding elimination of some VMT. If toll revenues are used to improve transit service or other driving alternatives, further reductions in VMT might result.

A variant on the facility-specific toll is the HOT (high occupancy toll) lane. HOT lanes are lanes designated for use by high-occupancy vehicles that may be used by single-occupant vehicles if a toll is paid. In general, they are parallel to “free” lanes, and so the solo drivers choose to pay the toll in order to avoid congestion occurring on non-HOT lanes (Brownstone and Small, 2005; Small and Yan, 2001). This approach is often called “value pricing” in the US and has not yet been the subject of rigorous evaluation (Munnich and Loveland, 2005). If these facilities improve traffic flow and thus impact driving style, the effect on GHG emissions might be positive; if they enhance the utility of driving, they might increase VMT and GHG emissions. As with other pricing strategies, the implications for GHG emissions depends on both direct and indirect effects on multiple behavioral components.

Parking

Parking policy represents a more specialized, but clearly separate, form of general auto pricing. Sometimes considered the transportation planner’s “secret weapon,” parking pricing strategies have been shown to have a considerable impact on auto use. For example, in the US, it is estimated that 99 percent of all car trips begin and end at a parking space that is free to the driver (Shoup, 2005). Free and abundant parking makes driving more attractive, while vast parking areas are also a deterrent to walking. Well-documented cases show that when the marginal cost of parking is internalized to the users, higher rates of non-auto use result (Shoup, 2005). In addition, one study found that the perception of parking difficulty had the strongest association of all factors with weekly travel walking (Rodriguez, *et al*, 2010), suggesting that limits on the amount of parking could also prove effective at reducing driving.

The most comprehensive tome on parking policy (Shoup, 2005) suggests two broad strategies to affect the demand for parking and, subsequently, the demand for auto travel. First, communities should charge fair-market prices for curb parking and remove all off-street parking requirements for land development. Second, communities should unbundle the charge for parking from charges for the other uses of land. For example, apartment owners could be required to pay an additional fee for a parking space instead of automatically renting a parking space with the apartment. The relative impact that each of these broad-brushed strategies would have on VMT, controlling for the myriad other factors that affect VMT, remains a question. A comprehensive review of parking policies suggests that greater attention should be given to analyzing the accessibility impacts that different parking restraint measures have on travelers of all modes (Marsden, 2006).

Land use

The impact of land use patterns on VMT is the subject of much current debate in the US, driven in large part by climate change policy in California that is pushing land use policies as a strategy for local governments to reduce GHG emissions. Proposed strategies generally fall within the strategies that fall under the label of "smart growth" and affiliated terminology) and include policies that encourage higher density, mixed-use land development with provisions for transit and non-motorized modes, combined with policies that promote infill development over "greenfield" development and aim to slow sprawl while preserving agricultural land and open space. Consensus seems to be emerging that this strategy will help to reduce VMT, though to what degree remains hotly debated (as previously mentioned).

A major report published by the Transportation Research Board in 2009 examines evidence on the extent to which developing more compactly would reduce VMT and make alternative modes more feasible (Transportation Research Board, 2009). The report raises out reliable trends from the research and offers several scenarios with varying assumptions, leading to the conclusion that doubling residential density across a metropolitan area might lower household VMT by 5 to 12 percent, and perhaps by as much as 25 percent, if coupled with higher employment concentrations, significant public transit improvements, mixed uses, and other supportive demand management measures. For obvious practical reasons, such a strategy has not been evaluated in a before-and-after study. While it is feasible to evaluate the impact of small changes in the built environment, it is not clear whether such studies would provide a reasonable basis for predicting the effects of a comprehensive, region-wide approach. Instead, policy makers are looking to large-scale travel demand forecasting models to estimate the effects of such an approach on VMT.

Non-motorized infrastructure

Starting in 1991, bicycle and pedestrian infrastructure became eligible for federal funding for the first time in the US. As a result, over \$2 billion in federal funding was invested in sidewalks, bicycle lanes, trails, and other projects designed to promote walking and bicycling over a 13 year period. In theory, these facilities increase the utility of non-motorized modes relative to driving and should lead to a shift in modes and thus a decline

in VMT. While studies show a strong association between the availability of such facilities and levels of walking and bicycling, few studies have examined changes in walking and bicycling in response to the construction of new facilities. One study looking at the association between investments in such facilities and changes in non-motorized travel for metropolitan regions found a measurable effect, despite significant limitations in the data (Handy, *et al.*, 2009). One reason these investments might have a limited impact on VMT is that many of them are geared more towards recreational walking and bicycling than for transportation. In addition, substitution is an important question: encouraging more walking and bicycling might increase walking and bicycling without a one-for-one substitution for driving trips (Krizek, *et al.*, 2010).

If there is any consensus on the effectiveness of investments in bicycle and pedestrian infrastructure, it rests in the realization that substantial increases in the use of non-motorized modes (and possibly decreased VMT) result from an integrated package of many different, complementary interventions; these include infrastructure provision and pro-bicycling and walking programs, as well as supportive land use planning and restrictions on car use. A recent review of 139 studies focused on cycling, supplemented with six case studies, came to this conclusion (Pucher, *et al.*, 2010) as did a comprehensive review of over 300 studies addressing walking and cycling infrastructure, policies, programs (Krizek, *et al.*, 2009b). Notwithstanding the consensus on integrated policies, additional behavioral research is needed to understand the impact of specific policies and the degree to which non-motorized use substitutes for vehicular use.

Voluntary travel behavior change

Social-marketing strategies for reducing VMT come in many different forms, ranging from formal to informal, personalized journey planning to blanket promotional material. In general, these programs focus on the concept of voluntary travel behavior change (TBC), in which people choose to change their travel behavior of their own free will, without outside coercion or regulation. Some programs work with individuals or households to understand their personal travel needs and help them understand how to use other travel options. These programs go by various names such as travel blending, travel smart, or personalized travel planning. The central premise underlying these programs is that some households could derive personal benefits from driving less, if only they knew how. Early studies showed that such programs could produce a measurable and lasting reduction in VMT, but recent assessments have called these results into question and have examined the many methodological challenges inherent in evaluating these programs (Bonsall, 2009; Chatterjee, 2009; Seethaler and Rose, 2009).

The public health field has produced many studies of interventions to increase walking. These studies are not usually focused on walking for transport, and so are not directly relevant to the VMT discussion, but they are suggestive of the potential of such interventions to change travel behavior. The limited research conducted on school-based programs has found some positive results, though methodological and other factors certainly diminish some of these findings (Staunton, *et al.*, 2003). Research on adults is more mixed. The programs studied are typically designed by the researchers for a specific set of participants and use informational materials, phone calls, and in-person meetings to

encourage increased walking. Some find modest but significant behavior changes through follow-up periods are typically months rather than years (Ball, *et al.*, 2005). Unfortunately, the ability to draw strong causal inferences from the available research evidence is limited by the fact that the bulk of the evaluation studies use weak quasi-experimental designs or are victim of reporting bias (Möser and Bamberg, 2008). More research is needed to determine how useful “soft” programs are in the long term, particularly in efforts to reduce VMT instead of increasing use of alternative modes.

2 Vehicle Type

Consumers are bombarded with car ads, usually selling lifestyle and image more than transportation. That vast sums spent by auto manufacturers on such advertising are clear testament to their success in influencing consumer choice. When aimed at the environmental benefits of the vehicle, such ads presumably help to nudge consumers towards more environmentally beneficial types of vehicles, those with high fuel efficiencies or hybrid technology. Few public programs have targeted vehicle type choice, however, and these have focused on financial incentives.

In the US, accelerated vehicle retirement programs, also known as car “scrappage” programs, were first implemented in California in the early 1990s to provide financial incentives to owners of high emitting vehicles to voluntarily “retire” them (California Air Resources Board, 2009). One study of two California scrappage programs concludes that they most likely reduce emissions somewhat, but that the benefits fall short of expectations for a variety of reasons: the scrapped vehicles are usually driven fewer miles than other vehicles of the same model year, some of the vehicles would have been scrapped anyway without the program, and replacement vehicles are usually older than the fleet average (Dill, 2004). Interest in such programs as a strategy for reducing emissions of pollutants in the US seems to have waned, and they are not being pushed as GHG emissions reduction strategy.

Towards the end of the past decade, the Car Allowance Rebate Program (affectionately referred to as “cash for clunkers”) adopted as a part of the US economic stimulus package, gave consumers a voucher for \$3500 or \$4500 for trading in older vehicles for newer vehicles with higher fuel economy, with the amount depending on the difference in fuel economy. The US Department of Transportation reports that fuel efficiency for trade-in vehicles averaged 15.8 mpg compared to 24.9 mpg for the vehicles that replaced them, a 8 percent improvement for nearly 700,000 vehicles (US Department of Transportation, 2009). One analysis shows that the program increased the average fuel economy of all vehicles purchased during the period by 0.6–0.7 mpg (Sivak and Schoettle, 2009). The program was, of course, very expensive and has not been continued.

Non-financial incentives might also be effective. In 2005, California implemented a Clean Air Vehicle Sticker program that allows certain hybrid vehicles and vehicles that meet the state’s super ultra-low vehicle (SULEV) emissions standards to use high-occupancy lanes throughout the state (Department of Motor Vehicles, 2009). Vehicle owners must apply for a sticker, and the state puts a cap on the total number of stickers. Although the program has not been rigorously studied as of yet, anecdotal evidence

suggests that the time savings of acquiring a Clean Air Sticker increased the demand for hybrid and SULEV vehicles but also that used vehicles with stickers are selling at a substantial premium. Capping the number of stickers is critical to the success of the program, however, because HOV lanes would not provide a time savings if used by too many vehicles. It is also not clear that it makes sense to encourage low-emitting vehicles to travel at free-flow speeds when high-emissions vehicles are stuck in traffic.

4.3 Driving Style

Driving style may be altered through several different types of programs: education, feedback, regulation, enforcement, and physical controls. Each of these types of programs may target speeds or other aspects of driving. Evidence on the effectiveness of these programs in improving fuel efficiency and reducing GHG emissions is varied, as most of the research focuses on safety effects.

Educational programs might aim to increase knowledge of the implications of speed, acceleration/deceleration, and idling on greenhouse gas emissions, as well as vehicle maintenance issues such as tire pressure and engine tuning (Van Mierlo, *et al.*, 2004). While educational campaigns have been widely used to promote traffic safety, their application to “eco-driving” has been limited, at least in the US. A recent study that looked at motivations and beliefs underlying idling recommends a large-scale public information campaign that targets outdated beliefs about proper idling behavior (Carrico, *et al.*, 2009). At least two such interventions have had measured success. A campaign to reduce idling in school parking lots achieved a 34 percent decline in the number of vehicles idling and a reduction in average idling time from 3.7 to 2.5 minutes (McKenzie-Mohr Associates, 2003). A similar campaign, also in Canada, reduced mean idling time from 8 to 3.5 minutes (Lura Consulting, 2002) and led to the adoption of an anti-idling ordinance. In the US, anti-idling laws have been adopted for trucks and school buses, but not for private vehicles. The US Department of Energy and the Environmental Protection Agency maintain a website with tips for drivers on how to improve their gas mileage (US Department of Energy and US Environmental Protection Agency, 2009).

Feedback interventions depend on technology to provide drivers with real-time information about their driving, particularly fuel efficiency and greenhouse gas emissions. The practice of “hypermiling,” in which hybrid vehicle owners aim to maximize their fuel efficiency by altering their driving style in response to real-time fuel efficiency information provided on their dashboards, has garnered media attention in the US, spawned national competitions, and earned an entry in the New Oxford American Dictionary. But evidence on the effectiveness of such interventions for the general driving public is scant. Emerging research at UC Davis is exploring the degree to which real-time efficiency information affects driver behavior, which driver characteristics moderate this effect, and the effect of alternative formats for presenting efficiency information.

Speed limits are perhaps the most pervasive form of regulation of driving style as it affects GHG emissions, though their effectiveness at reducing speeds is debatable. In theory, lowering speed limits could reduce average driving speed, even though most

drivers do not fully comply with the limits. For example, in the US, it is commonly assumed that one is protected from speeding tickets if driving no more than 5 mph over the speed limit, hence traffic tends to move at 60 mph in 55 mph zones, 70 mph in 65 mph zones, and so on. When a federal speed limit of 55 mph was imposed in the US in 1974, the proportion of vehicles speeding dropped, and average speeds dropped from 65 mph to 57.6 mph on rural Interstates and from 57.0 to 53.1 mph on urban interstates (Wilson, *et al.*, 2006), though many newspaper articles reported low compliance. Lowering speed limits again would likely result in a decline in speeds if coupled with an effective enforcement program (Friedman, *et al.*, 2009); the presence of other motivations for reducing speed, such as high gas prices, would also likely help. There is an extensive literature on the effectiveness of speed limit enforcement strategies, though these are oriented toward safety rather than fuel efficiency concerns. One review of studies of speed enforcement detection devices, including speed cameras and radar and laser devices, concludes that these devices can produce a 1 to 15 percent reduction in average speed and a 14 to 65 percent reduction in the share of drivers speeding (Wilson, *et al.*, 2006).

Speeds are perhaps most effectively controlled through physical design. Traffic calming strategies, mostly aimed at reducing speeds in residential areas, would not help from the standpoint of GHG, as they reduce speeds below optimal fuel efficiency levels. But design strategies that keep traffic moving at speeds within the desirable range would. A classic example is the conversion of signalized intersections to roundabouts that require all drivers to slow but not to stop. However, a recent study found that a high-speed roundabout was not necessarily an improvement over stop signs and traffic signals with respect to fuel efficiency and emissions, particularly at high traffic volumes that produce average delays greater than those at stop signs and signals (Ahn, *et al.*, 2009).

Expanding road capacity is sometimes proposed as a strategy for improving fuel efficiencies and thus reducing emissions, under the rationale that expanded capacity will improve traffic flow and reduce stop-and-go traffic. However, many studies have now documented the existence of an "induced demand" effect in response to new capacity (Cervero, 2002; Handy, 2005; Hansen, 1995; Lee, *et al.*, 1999). By improving traffic flow, added capacity increases the utility of driving relative to other modes, leading to an increase in VMT. In addition, added capacity improves accessibility to destinations served by the facility, leading to increases in development in those areas, thereby increasing demand. The net result may be more vehicles travelling in stop-and-go traffic as bad as it was before the capacity expansion. Research has reliably documented that road improvements prompt increases in vehicle travel; what amount and in what contexts remain outstanding questions.

5. CONCLUSIONS

Travel behavior researchers have an important role to play in efforts to reduce GHG emissions and avert global climate change. Policy makers often seek a solid research base for estimating GHG emissions from daily travel when constructing their GHG inventories

(Ramaswami, *et al.*, 2008), and for identifying and prioritizing policy interventions that will reduce GHG emissions to meet established targets. Although the substantial body of travel behavior research that has accumulated over several decades provides an important starting point for climate change efforts, much more work is needed.

The research base is most solid with respect to the behaviors that contribute to VMT, especially daily travel choices about trip frequency, destination, mode, and route. Research on mid-term choices about auto ownership and longer-term choices about residential location choice is also robust, and studies increasingly account for the interactions between these choices. Travel behavior researchers have shown less interest in behaviors affecting emissions per mile, namely vehicle type choice and driving style. Driving style may seem to be largely an unconscious behavior, yet anecdotal evidence suggests that increasing the consciousness of drivers as to the effects of their choices about driving can have significant impacts. Teenage travel, in terms of accelerations and decelerations, is largely an unstudied issue. In addition, the interactions between VMT, vehicle type, and driving style have mostly been ignored yet potentially pose significant challenges for efforts to reduce GHG emissions. For example, land use policies that reduce VMT might also engender driving styles that reduce fuel efficiencies and increase GHG emissions. Understanding such trade-offs is critical to developing effective policies.

Further work is needed to improve our basic understanding of all of these behaviors and the myriad factors that influence them. On this point, psychological theories could provide important new insights. It is important to consider how individual preferences relating to these concepts are developed and the time horizons in which they are most vulnerable or open to change. Reducing VMT, shifting to low-emission vehicles, and changing driving styles means breaking deeply entrenched habits, and furthermore, the habit forming (and habit breaking) literature could be helpful in identifying new categories of causal factors and developing methods for measuring them (Eriksson, *et al.*, 2008). It is important to refine research approaches to capture taste heterogeneity and identify market segments. Qualitative methods have an important role to play in deepening our understanding of these highly nuanced behaviors (Clifton and Handy, 2003).

Policy makers especially need a stronger evidence base on the effectiveness of potential policy interventions. Rigorous evaluations of interventions such as personalized trip planning or investments in bicycle lanes are difficult to carry out for a host of reasons (Chatterjee, 2009; Krizek, *et al.*, 2009a; Stopher, *et al.*, 2009). But such studies are arguably the most important type of research for policy makers as they provide concrete evidence of the effect of specific policies and programs that can be cited as a justification for more wide-spread implementation. Researchers must work with the public agencies who are implementing the strategies to ensure they are evaluated using rigorous research methods.

Reducing GHG emissions to targeted levels will require many different approaches, several involving technical advances. But it is clear that behavior changes are a critical ingredient to this effort (Rajan, 2006). As the US Secretary of Transportation has himself emphasized, "We must implement policies and programs that reduce vehicle miles driven"

(LaHood, 2009). But changing behaviour is in many ways more complex than changing technology, and indeed the effectiveness of the latter depends also on the former. Our aim herein is to provide an overview for researchers of progress toward the goal of identifying policy "levers" that can be "pulled" to bring about changes in travel behavior that will reduce GHG emissions. Although the evidence base establishes the potential of a wide variety of strategies to reduce GHG emissions from daily travel, many questions remain about the magnitude of their effects alone or in combination in different social, economic, and physical contexts. The imperatives of climate change translate into both an obligation and an opportunity for travel behavior researchers.

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4

A FRAMEWORK FOR SUSTAINABLE TRANSPORT DEVELOPMENT

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ABSTRACT

With increasing attention on climate changes and their impacts on sustainability, which is caused by the emission of greenhouse gases into the atmosphere, more research is being conducted looking at environmental issues and the impact of emissions on local and global air quality. Upon the principle of "the polluter pays", or that those who are causing environmental harm by producing or utilising energy shall bear the cost of its remedy, investigations of transport policies which are specifically intended to reduce emissions and improve air quality are needed. Road use pricing for example, has become a popular policy for managing the demand for travel. The execution of the theoretical principles of congestion charging into practice is complex and will hardly, if ever, be met in reality. The idea has always been to charge vehicles where the extent of the charge should reflect negative externalities they impose on others and on the system, thus helping to reduce negative externalities of traffic. In theory that should include congestion, air quality, etc. However in practice congestion has been the only factor considered as the basis for any charging scheme and to a much lesser extent, if any, on air quality improvement. The purpose of this paper therefore is to present a framework for sustainable transport development which explicitly distinguishes the environment and air quality. Firstly, it is essential to use targets setting as the mechanism for devising transport policies. Secondly, to investigate policies and measures which explicitly identify environmental impacts and the set targets. Thirdly, when monitoring and modelling impacts of such policies on the environment one has to be at least aware of the modelling approach, assumptions and influence of these assumptions on the estimate of the impacts of the policies on emissions. More investigations into emission factors which reflect actual driving behaviour and local driving conditions are needed. Critical to achievement of sustainability is the principle of integration; at the level of setting targets and objectives, at the level of setting policies and measures and at the level of monitoring the impacts of such policies.