PRIORITIZATION OF TRANSPORTATION PROJECTS FOR ECONOMIC STIMULUS WITH RESPECT TO GREENHOUSE GASES

Final

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June 20, 2009

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State of California
DEPARTMENT OF TRANSPORTATION

Business, Transportation and Housing Agency

Memorandum

Flex your power!
Be energy efficient!

To: Readers of This Report

Date: June 25, 2009

From: JAY NORVELL
Chief, Division of Environmental Analysis

Subject: Prioritization of Transportation Projects for Economic Stimulus with Respect to GHG

The work reflected in this report began in December 2008. The original impetus behind the report was to create, in a short amount of a time, a conceptual framework under which categories of economic stimulus transportation projects could be evaluated for their potential to increase or decrease greenhouse gas emissions. While the economic stimulus projects have been selected and are moving forward, the conceptual framework presented in this report still provides a valuable starting point for the analysis of the greenhouse gas impacts of transportation projects. However, note that this analysis was of generalized groups of projects. It is not intended to substitute for specific project-level analysis or area-wide analyses that integrate land use and transportation, such as required by California's SB 375.

Although this report was funded by the Department of Transportation, the Governor's Office; Business, Transportation and Housing Agency; and the Air Resources Board were also involved in its development.

My thanks to the Dr. Deb Niemeier and the team at U.C. Davis.

Prioritization of Transportation Projects for Economic Stimulus with Respect to Greenhouse Gases (GHGs)

Introduction

The federal government is currently considering a broad range of economic stimulus projects in the transportation sector. According to recent estimates, California may receive approximately $3B to $4B in infrastructure funding, much of it for highway and transit projects. There is little doubt that transportation is integral to the California economy, now the 8^{th} largest in the world [1]. Yet, the transportation sector is also the state's largest source of greenhouse gases (GHG). Between 2002 and 2004 the transport sector annually accounted for approximately 38% of the state's total GHG emissions; the on-road portion alone (as distinguished from aviation, rail and water-borne) represented approximately 36% of total GHG emissions [2]. With AB 32 and Executive Order S-3-05, every sector including transportation must show reduced levels of GHG emissions by 2020 and 2050. In addition, SB 375 requires that regional transportation plans demonstrate consistency with 2020 and 2035 GHG targets.

The purpose of this assessment is to provide a high level framework to aid in the selection of transportation infrastructure improvement projects that can help to reduce GHG emissions and enhance the existing infrastructure through strategic improvements in operations and in preservation and maintenance. Our primary objective in this effort was to develop a consistent and reliable framework to quickly identify and categorize those projects with the greatest potential for a reduction in project level GHG emissions. Admittedly, there are other important factors that play a role in assessing projects, including cost, regional-scale impacts, co-pollutants and operational impacts such as reductions in delay. These factors, while important, were not a primary focus in this study. Finally, although created to address the prioritization of projects in California, the framework is based on widely applicable transportation and GHG-related principles. Planners in the U.S. and other settings should find the framework of value when assessing the GHG implications of transportation projects.

As of 2009, California's transportation and air quality agencies have entered a planning transition period. The transition involves shifting from focusing solely on the traditional "business as usual" (BAU) environmental and mobility challenges to a new era that also encompasses addressing climate change impacts. The findings presented here are best viewed in the context of that transition. Beginning in 2010, California's state and regional agencies will face new climate change planning milestones. Notably, SB 375 mandates that in 2010, the state must establish 2020 and 2035 GHG emissions targets applicable in each region, and that regional transportation plans (RTPs) adopted as of late 2010 must document how these targets will be achieved. Also, under the state's Climate Change Scoping Plan (prepared pursuant to AB 32), GHG regulations are expected to be adopted by 2011 and to take effect beginning 2012. California RTPs approved in late 2010 and beyond will - for the first time - be benchmarked against climate change goals. Some California metropolitan planning organizations (MPOs), such as those in the San Diego and San Francisco Bay Area, have already begun the process of incorporating GHGs into their long-range planning efforts. Their early efforts demonstrate that GHG emission reduction goals will be difficult to achieve, and will likely involve significantly adjusting and re-aligning the mix of transportation projects included in long-term regional plans.

Set against this transition, there is a short-term need to optimize the use of economic stimulus funds to implement important infrastructure improvements. The challenge for state and regional planners is how to prioritize improvements funded through the economic stimulus in a way that complements, rather than complicates, the climate change planning they will have to complete in the near future. In addition, projects funded under the economic stimulus need to work in concert with corridor and regional-level transportation management goals that involve coordinating transit, high-occupancy vehicle, single-occupancy vehicle, and alternative travel modes. The framework presented here is designed to assist in the prioritization of transportation projects with respect to project level GHG emissions during this transition period and provide time for regions to develop sustainability strategies consistent with SB 375.

Currently, most projects aimed at improving operations are evaluated on the basis of their potential effectiveness at reducing forecasted delays, or maintaining travel times in the face of sometimes dramatic increases in VMT. For any given project, once a preferred alternative has been identified, a Build vs. No-Build comparison across a number of different parameters is typically performed (e.g., the project must reduce project level regulated air pollutants). The evaluation of transportation projects with respect to GHG emissions cannot directly rely on this traditional comparison process. A project that reduces or maintains travel times may not reduce VMT (or alternatively GHG emissions) sufficiently enough to maintain progress toward targets defined by AB 32, S-3-05 and SB 375.

Alternatively, maintenance and rehabilitation (M&R) projects are usually triggered by poor pavement condition, primarily roughness; preservation projects are usually aimed at extending the life of currently good pavement. Due to budgetary constraints, many projects are delayed until long after an M&R project is triggered by level of service standards, which makes comparing GHGs for a “project now” versus a “project later” appropriate. Both M&R and preservation activities can reduce GHG emissions relative to delaying a project because smoother pavement can result in ongoing improved vehicle fuel economy for the time period until the pavement becomes rough again. More research is needed to better quantify the fuel economy effects of pavement smoothing. In the near term, however, every project will require the use of a combination of new or recycled materials, construction equipment and will create construction work zone traffic delays, all of which lead to a one-time input of GHG emissions.

While there is strong evidence that increases in operational VMT translate to increases in GHG emissions, there is virtually no research on how to prioritize projects on the basis of potential GHG emissions. This study begins to fill this gap in knowledge by providing a new framework for rapidly identifying those projects with the greatest potential for maintaining progress toward legislatively mandated targets. In the long run, with additional research, this framework can be deployed to assist in the selection of project alternatives and to identify those innovative aspects of transport infrastructure development that will significantly reduce GHG emissions. Under the new framework, six basic projects types are identified: transit, alternative mode enhancements, traffic operations, mixed flow capacity additions, maintenance and preservation, and those projects that are considered GHG-neutral (e.g., landscaping). Each project type is described along with current state of knowledge that might indicate the direction of their potential impact on GHG emissions.

FRAMEWORK SUMMARY

California was the first state to adopt legislation specifically intended to limit greenhouse gas emissions. Passage of the California Global Warming Solutions Act of 2006 (commonly known as AB 32) mandates that the California Air Resources Board (CARB) set a 2020 greenhouse gas target based on 1990 levels, implement and enforce regulations to meet the 2020 limit, and identify and develop greenhouse gas emissions reduction measures (AB 32, 2006). The medium-term targets are coupled with an executive order (S-3-05) mandating a long-term reduction target of 80% of 1990 greenhouse gas emissions by 2050 [3].

AB 32 complements a number of other recent legislative initiatives designed to reduce transportation related emissions. These include AB 1493 (California's Vehicle Global Warming Law, commonly known as the "Pavley Bill") which limits greenhouse gas emissions from vehicles sold in California beginning with model year 2009 [4]; AB 1229 (The Global Warming and Smog Emissions Consumer Labeling Law) which requires new cars sold in California to include vehicle's global warming emissions information in the existing smog index decal (AB 1229, 2005), and Executive Order S-01-07 which requires a low-carbon fuel standard (LCFS) that achieves reductions in all greenhouse gases and is scheduled for implementation by January 1, 2010 [5].

Given California's statutory and regulatory technology mandates, over time the average vehicle will emit fewer GHG pollutants for every mile driven. This means that holding all other factors constant (such as speeds and miles driven), a typical year 2050 vehicle will emit far fewer GHG emissions than its year 2009 counterpart. However, it is important to acknowledge that existing technology mandates will be, on their own, insufficient to achieve GHG reduction goals. Consider an illustration from a recent study that assessed CO_2 emissions in Midwestern U.S. cities and that assumed all light-duty vehicles were hybrid-electrics (HEVs) by 2050. Even with 100% HEVs, year 2050 fleet CO_2 emissions were still marginally above year 2000 fleet emissions, due to 50 years of growth in population and vehicle use [6]

Since the early 1970's, California's population and vehicle miles of travel (VMT) have increased at rapid rates; between 1970 and 1995, population grew by almost 60% and VMT more than doubled [7]. Growth, which has traditionally been coastally-oriented, is now occurring inland with the greatest population growth in the Sacramento, Bakersfield, and the Riverside-San Bernardino areas [8]. Increasing population has been matched by more VMT, increased hours of delay, ever larger shares of urban freeways operating under congested conditions, and critically, significant environmental externalities, including more than 500 tons of criteria pollutants every day [8]. Thus, in spite of all of California's efforts to date, transportation remains one of the fastest-growing sources of greenhouse gases in California. Partially in response to these challenges, the state recently passed SB 375, which has been heralded as a significant step in managing future growth. In the absence of significant technological advancements, the basic transportation and land use infrastructure will remain the most influential factor governing future VMT growth.

PROJECT SELECTION FRAMEWORK

GHG emissions for transportation projects can be divided into those produced during construction and those produced during operations (Figure 1). Construction GHG emissions result from material processing, emissions created by onsite

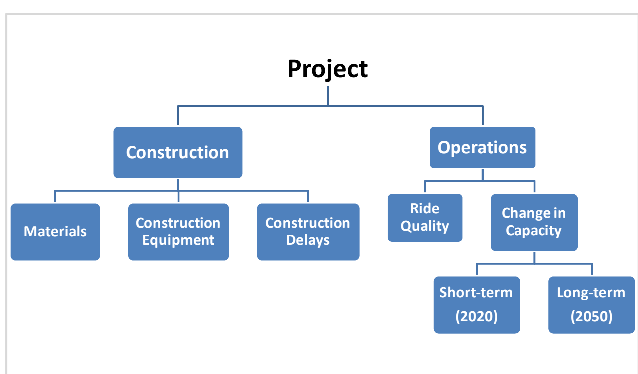

Figure 1. Project elements affecting GHG emissions.

construction equipment, and emissions arising from traffic delays due to construction. These emissions will be produced at different levels throughout the construction phase; their frequency and occurrence can be reduced through innovations in plans and specifications and by implementing better traffic management during construction phases [9, 10].

GHG emissions associated with normal (post-construction) operations can be divided into those associated with pavement smoothness and those associated with any change in capacity. With respect to pavement smoothness, although additional research is needed, there is some indication that as ride quality improves, fuel economy also improves [11], which in turn would reduce GHG emissions. Changes in capacity can be divided into short-term and long-term outcomes. Projects that tend to yield shorter-term outcomes are those that reduce near-term delay and effectively increase capacity through optimization (e.g., turn lanes, ramps, and signal optimization). These generally reduce short-term GHG emissions by smoothing traffic flow. These short-term GHG reductions, however, will diminish in effectiveness over time as VMT growth overtakes initial congestion-relieving benefits. Projects that tend to yield longer-term outcomes are those that provide substantially increased roadway and destination access by adding new lane miles of capacity or new travel mode options (e.g., HOV lanes, transit improvements, mixed lane additions, new roads). Depending on the type of project these may or may not reduce GHG emissions. Over the life of these longer-term outcomes, GHG emissions will increase to the extent the projects facilitate or accommodate current trends in single occupancy vehicles (SOV) VMT growth. Finally, usually, but not always, operational GHG emissions will dominate construction emissions [12].

To further illustrate these concepts, consider non-capacity increasing projects, for example, pavement rehabilitation and maintenance projects. These projects are not expected to affect long-term VMT. They will generally create additional GHG emissions during construction phases and potentially reduce operational GHG emissions due to improvements in pavement smoothness quality. With innovations such as longer pavement lives (Figure 2), improved traffic management plans, and changes in materials, the GHG emissions produced during construction can be mitigated to some degree by longer intervals between maintenance and rehabilitation events [13, 14]. Further research is needed to quantify emission benefits from construction innovations.

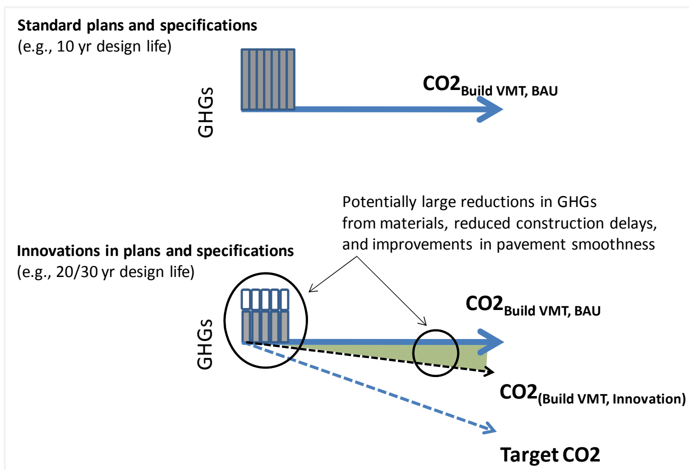

Figure 2. Innovations can reduce one-time and ongoing emissions for maintenance and rehabilitation projects.

Alternatively, projects that increase capacity may or may not affect GHG emissions depending on the type of project. In general, projects that alleviate existing delays may reduce short-term GHG emissions but will likely have very little long-term GHG benefit since they do not decrease VMT in the long run (Figure 3). It is important to note that projects in currently approved RTP's have primarily been selected and designed to address declines in travel mobility measures (e.g., reducing delay) that are projected to result from long-term

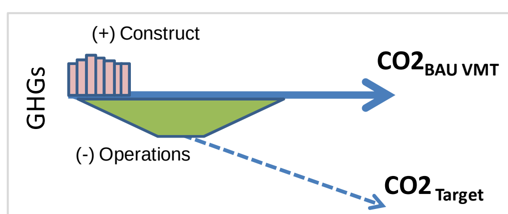

Figure 3. Short-term congestion relief benefits overwhelmed by VMT growth.

population growth. Consequently, those projects that add capacity without reducing real VMT (i.e., resulting in shorter or fewer SOV trips) will not contribute to meeting mid-term and long-term GHG targets. As might be expected, projects such as transit improvements and HOV lanes are more likely to reduce GHG emissions than new roads or mixed flow additions.

Using this conceptual framework, we qualitatively organized typical projects into six primary types (Table 1). *Added capacity projects* include those projects that improve operational efficiency, thus indirectly adding capacity, as well as those projects that directly add capacity through lane or transit/HOV improvements. For added-capacity projects the likelihood of GHG reductions declines and the likelihood of increased GHG emissions rises as mixed flow solutions are implemented. *Non-capacity adding projects* that rehabilitate, maintain, or preserve the condition of pavements generally reduce roughness, and thus may reduce vehicle fuel consumption. If no fuel economy benefits are achieved these projects would still tend to be long term neutral with respect to business-as-usual (BAU) emissions.

Table 1. Project categories and their anticipated long-term relationship to GHG emissions[1]

Added-Capacity Projects	Example Projects (in no particular order)	GHGs
Mixed Flow Capacity Addition	Additional lanes (incl certain types of auxiliary) Tolled roads (mixed use)	↑ Increasing likelihood of GHG increases Increasing likelihood of GHG reductions ↓
Traffic Operations	Operational improvements (ramp metering, signal improvements, turn lanes, auxiliary lanes) Traffic management systems Truck lanes (climbing, separated flow) Elimination of at-grade rail crossings	
Enhancements and Capacity Additions for Alternative Modes	Bike facilities Pedestrian facilities Park& Ride (carpool) Tolled lanes (high occupancy restricted) HOV lane addition/enhancements	
Transit	Rail Bus Ferry Transit infrastructure (stops, waiting areas) Bus rapid transit Park & Ride (transit)	
Non-Capacity Added Projects	**Example Projects (in no particular order)**	**GHGs**
Maintenance, Rehabilitation, Preservation	Pavement preservation Pavement rehabilitation and maintenance Stormwater/drainage	Long-term neutral impacts without innovation
Neutral/Other	Bridge preservation Bridge rehabilitation Bridge replacement Facilities preservation Facilities rehabilitation Facilities replacement Damage restoration Safety improvements Landscaping, Sound Walls	

[1] Project specific details will govern the direction of GHGs. For example, an HOV lane added in a rural area with no enforcement will likely replicate the effect of adding a mixed flow capacity addition.

It is important to recognize that in order for an assessment to be made regarding the likelihood of GHG reductions, a baseline must be established for comparison. In the short time available to construct this conceptual framework, we made a number of simplifying assumptions. We assumed that baseline conditions for *added capacity projects* are no-build conditions; that is, the no-build condition reflects forecasted growth and anticipated increases in VMT, absent meeting targets such as those that will soon be established under SB 375. Projects in which GHGs are identified as likely to be reduced are, in the short-term, those that improve traffic flow and reduce stop-and-go driving without substantially increasing VMT, and in the long-term those that reduce VMT from forecasted no-build conditions (i.e., at project completion, result in shorter or fewer single-occupancy vehicle trips). For *non-capacity adding projects*, baseline conditions are defined by business-as-usual maintenance and rehabilitation intervals and practices. These projects are not expected to change long-term VMT growth projections and thus are designated neutral for long-term GHG emissions, or as providing long-term GHG reduction by reducing pavement roughness and thus improving fuel economy. Although this is not strictly the case (e.g., projects will produce construction emissions), we assume that these projects will not, on average, increase yearly operational GHG emissions. In the short-term, for example, during construction, additional GHG emissions will be produced although there are innovations that can impact the magnitude and anticipated duration of these emissions.

OTHER IMPORTANT CONCEPTS TO CONSIDER WHEN REVIEWING PROJECTS

Vehicle Emissions and Speeds

Traditional transportation-related air quality assessments focus on several principles, some of which remain applicable in the GHG context. A key concept is the relationship, for a given point in time, between vehicle emissions and travel speeds. In general, stop-and-go traffic produces high emission rates for virtually all vehicle types and traditional urban-scale pollutants such as hydrocarbons (HC), carbon monoxide (CO), and oxides of nitrogen (NOx). Per-vehicle emissions of urban-scale pollutants decline as traffic flow improves until, at very high speeds (e.g., 60+ mph), emission rates increase again. Vehicular CO_2 emissions follow a similar pattern [15]. Road congestion that significantly reduces speeds or increases engine loads will also increase emissions. A key disconnect between traditional urban-scale pollutants and CO_2, however, lies in the understanding that although emissions of traditional pollutants of interest (HC, CO, and NOx) have declined substantially in recent decades as vehicle technology has improved, CO_2 emissions are governed by fuel economy, which has remained static over time. Thus, holding fuel consumption per mile driven as a constant, any increase in VMT results in increased CO_2.

There also exists another important disconnect between traditional transportation-air quality pollutants and GHGs. In the traditional view, emission reduction goals have been oriented toward single points in time connected to federal Clean Air Act deadlines to attain National Ambient Air Quality Standards (NAAQS). Thus, for example, HC, CO or NOx emissions could remain high until the deadline year, as long as reductions were achieved by the deadline. In the GHG context, emissions have cumulative negative impacts. Thus, climate change policy goals are oriented toward achieving sustained progress toward lowered emissions over time, consistent with 2020, 2035, and 2050 emission targets. Actions that accelerate GHG reductions have value over those that achieve similar reductions but at a later date. Therefore, there is an ongoing need to assess the opportunity to implement innovative construction and operational practices that can advance GHG emission reductions.

Vehicle Emissions and Road Conditions

There are three contemporary U.S. studies that examine the relationship between pavement roughness and fuel economy, one based on Florida DOT data from a single instrumented light duty van [16], one based on WesTrack test track data for heavy duty trucks [17], and unpublished NCAT test track data that is reported in other publications [11, 16, 18]. None of these studies can be considered conclusive because of small datasets that do not satisfy the criteria for statistical significance, and results that are limited to the specific vehicles classes included in each respective study. However, they all conclude that increased roughness decreases fuel economy of passenger vehicles, light duty vehicles, or trucks. The three sources of data, all reported in [11, 18] indicate that for a 10% decrease in roughness, fuel economy may improve anywhere from 1.3% to 10%. All of them lack the depth and breadth of data to define an empirical relationship between roughness and fuel economy, but all support the fact that decreased roughness improves fuel economy.

The relationship between roughness and fuel economy has important implications for pavement management and construction practices (scheduling and selection of rehabilitation and maintenance, smoothness specifications). The relationship suggests that any policy, management, or technology innovations that decrease the roughness of roads, particularly those with high AADT and high roughness, could result in significant GHG emissions savings when aggregated over time and the entire fleet of vehicles traversing a pavement. Policy and management strategies could include simply overlaying or grinding high roughness roads sooner rather than later, preserving pavements already in good condition, or introducing innovations in technology to achieve these outcomes. This is a critical avenue of research, since previous research efforts have not collected sufficient data to establish consensus on the specific relationship between roughness and fuel economy for different types of vehicles.

Project Details Will Govern GHG Emissions in Specific Situations

The material presented in the following sections generally characterizes expected emission impacts associated with projects from each of the Table 1 categories. However, it is important to emphasize that GHG emissions will vary from project to project, even among similar project types. For example, investment in transit infrastructure along a high-density corridor with extensive transit service will yield different outcomes than the same transit infrastructure investment in a low-density suburban area with more limited transit service, the former providing greater potential for GHG reductions. Caltrans is exploring a number of different options for improving traffic flow while managing future VMT growth. One of these strategies includes corridor management techniques developed through system management elements of the Mobility Pyramid. Corridor mobility strategies are being examined for the 26 most highly congested corridors in California. More corridor level research is needed in the identification of appropriate delay mitigation strategies, the ways in which partnerships can be formed and managed, and the selection of performance measures to ensure that mobility increasing approaches help to meet state climate goals. In short, there are numerous project possibilities within each of the six category types profiled here and, for any given project, there are geographic, travel activity, and demographic variables that will influence outcomes. The analysis framework and background material provided here provides a broad template for project assessment; detailed assessments will refine the level of GHG reductions that can be derived from each individual project.

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ACKNOWLEDGMENTS

The research team received important technical support as well as written and verbal comments from representatives of the California Department of Transportation (Caltrans); the California Air Resources Board (CARB); the California Business, Transportation and Housing Agency (BTH); and the Office of California Governor Arnold Schwarzenegger (Governor's Office). The authors thank the following:

Kome Ajise (Caltrans)
Gregg Albright (BTH)
Jim Andrews (Caltrans)
Tracy Arnold (Governor's Office)
Jim Bourgart (BTH)
Mike Brady (Caltrans)
Cynthia Bryant (Governor's Office)
Sarah Chesebro (Caltrans)
Pete Conn (Caltrans)
Ken DeCrescenzo (Caltrans)
Kelly Dunlap (Caltrans)
Ranny Eckstrom (Caltrans)
Anthony Eggert (CARB)
Bill Farnbach (Caltrans)
Doug Ito (CARB)
Kurt Karperos (CARB)
Doug MacIvor (Caltrans)
Mahmoud Mahdavi (Caltrans)
Susan Massey (Caltrans)
Scott McGowen (Caltrans)
Reza Navai (Caltrans)
Jay Norvell (Caltrans)
Vahid Nowshiravan (Caltrans)
Justin Paddock (CARB)
Tom Pile (Caltrans)
Jamesine Rogers (CARB)
Bruce Rymer (Caltrans)
Earl Seaberg (Caltrans)
Julia Vojtech (Caltrans)
Jeff Weir (CARB)

PROJECT CATEGORY DESCRIPTIONS

Guide to Project Category Rating Grids

The category descriptions that follow include a rating grid to view anticipated GHG and capacity impacts (Figure 4). A marker identifies impacts for each category. The marker shading illustrates a qualitative estimate of the range of GHG impacts. Marker size indicates the spread of anticipated impacts across the rating grid. The grid has four quadrants – the bottom two represent projects expected to reduce GHG emissions. The right two quadrants represent projects expected to increase travel capacity. Regardless of a project's capacity rating, projects in the bottom half of the grid are preferable from a climate change perspective. Forecasted impacts assume 2050 conditions relative to a 2004 baseline.

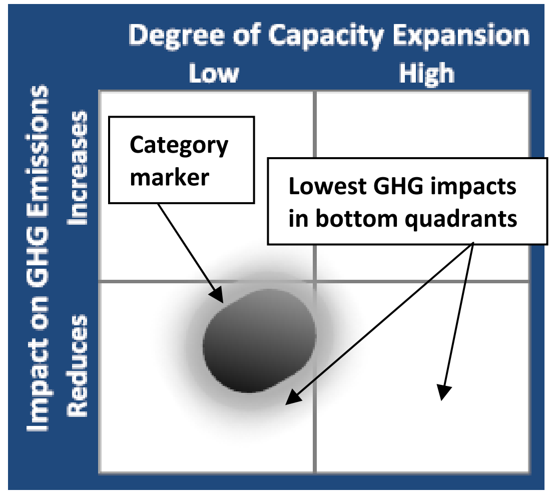


Figure 4. Example category rating grid.

Transit Projects

OVERVIEW: Transit project types include rail, bus, and ferry transit service improvement projects. In addition, transit improvements such as transit station or stop infrastructure are also included.

GHGS: Transit service improvements provide an alternative to single occupant vehicles (SOVs). Transit fleets are moving toward lower-emitting fuel types and better emission control technologies (1); in areas such as San Francisco, large fractions of the transit fleet are hybrid or electrically powered (2). When both transit occupancy and the time price of auto use is sufficiently high enough (3), mode shifts, from SOV to transit, can alleviate congestion on mixed flow roads and reduce GHG emissions from on-road vehicles. When combined with higher land use density and adequate support infrastructure, transit improvements provide the means to support greater contiguous infill development and encourage reduced vehicle use for both work (4) and non-work trips (3). Transit service also provides critical travel options for those who cannot access or adequately operate SOVs.

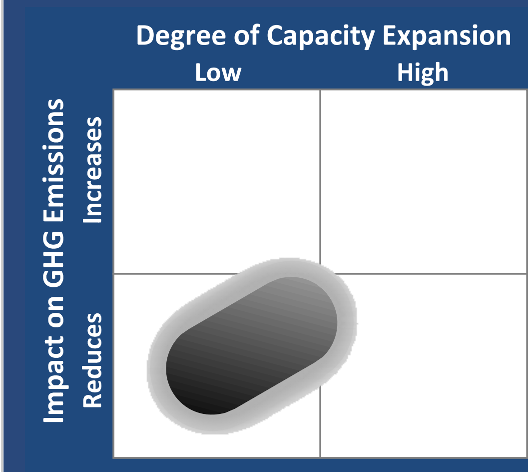
BAU 2006-2030 trends include 66% VMT growth and 60% vehicle fuel consumption growth, with most miles driven occurring on the state highway system (5). A single bus or other transit vehicle emits more GHG emissions per mile than a single light-duty automobile. However, transit service, when utilized, optimizes use of the existing infrastructure by moving more passengers per unit of roadway than SOVs, thus reducing overall GHG emissions. Increased use of transit can occur with relaxation of design features such as parking standards (3) and increased service frequency (6).

CAVEATS: There is an inverse relationship between the GHG reduction benefits of increased transit use, and the degree to which SOVs emit GHG emissions. As fuel economy improves over time, the GHG reduction benefits of switching to transit will decrease; however, transit use should provide net GHG reductions given foreseeable fleet fuel economy. Transit infrastructure is essential to achieving a more sustainable transportation system, yet because of its two way interaction with urban form, additional factors that influence demand (e.g., fare level, service level, car ownership, vehicle quality and population change) will also play a role in transit's effectiveness at reducing VMT (7).

INNOVATIONS:

- Better use of land use regulations (9); e.g., see SANDAG material at: www.sandiego.gov/environmental-services/sustainable/pdf/sandag.pdf.
- Increasing the cost of auto use will translate to a positive interaction with transit. Pricing could be used to discourage SOVs and encourage and fund transit (8).

TRANSIT IMPROVEMENT PROJECTS



Shading is a qualitative estimate of the range of GHG impacts.

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Traffic Operations

OVERVIEW: The types of projects included in this project category are directed at serious traffic congestion. Project examples include signal optimization, added turn lanes, truck or climbing lanes, traffic management systems, and eliminating at-grade rail crossings.

GHGS: Improving traffic operations by targeting highly congested locations can result in short-term GHG emission reductions. The relationship between emissions and speed is well established: at lower and higher speeds, and during accelerations, GHG emissions will increase. By alleviating stop and go patterns due to, for example, intersection bottlenecks or ramp congestion, traffic will flow more smoothly. These improvements do not generally provide long-term increased capacity and thus, result in GHG reductions that are relatively short-term.

The relationship between speed and CO_2 emissions is parabolic for conventional vehicles, with the lower emissions being produced between about 30mph and 60mph (1,2). This same principle generally holds for other pollutants and flow improvements have long been recognized as providing shorter term emission reductions (NRC, NCHRP); e.g., transportation conformity exempts traffic signal synchronization (5). Thus, congestion mitigation strategies should focus on very highly congested locations (e.g., freeway ramps), with the intent of increasing average travel speeds. In addition, strategies that smooth traffic and reduce stop and go traffic will also contribute to GHG reductions. With these types of improvements, GHG reductions on the order of 7-12% have been realized (1). Data show HEV fuel economy drops with aggressive driving, although city vs. highway fuel economy results are mixed (7).

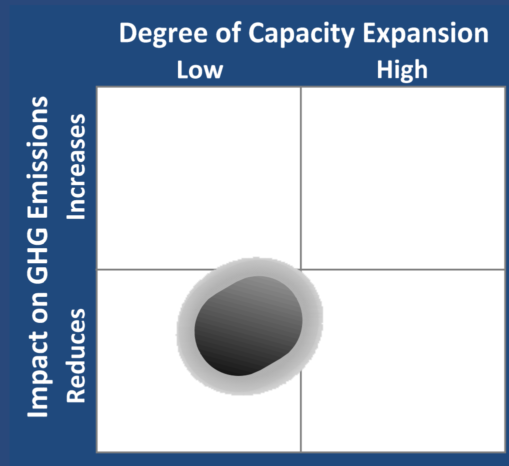
Truck climbing lanes are another strategy for reducing mainline freeway congestion. For example, in general, there are congestion (as well as safety) related benefits from separating trucks from passenger vehicles (5, 6); the likelihood of CO_2 emissions reductions from these types of improvements will increase if average speeds on combined facilities frequently drop below about 25 mph.

CAVEATS: As vehicle fleets become cleaner over time, the GHG reductions from improving highly congested conditions may diminish. GHG reductions will also decline over time as VMT increases and congestion levels rise. GHG emissions benefits from separating truck and passenger vehicles are highly dependent on the level of congestion and the proportions of each type of vehicle (6).

INNOVATIONS:

- Traffic mitigation strategies used in concert have produced much higher reductions in GHGs than individual strategies (e.g., improving signal timing while also adding a turn-lane)

TRAFFIC OPERATIONS PROJECTS



Shading is a qualitative estimate of the range of GHG impacts.

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Alternative Mode Projects

OVERVIEW: This category of project types includes facilities that promote the use of transit and travel modes other than single occupant vehicles (SOVs). Example projects include bicycle and pedestrian facilities, carpool park-and-ride lots, and HOV lanes.

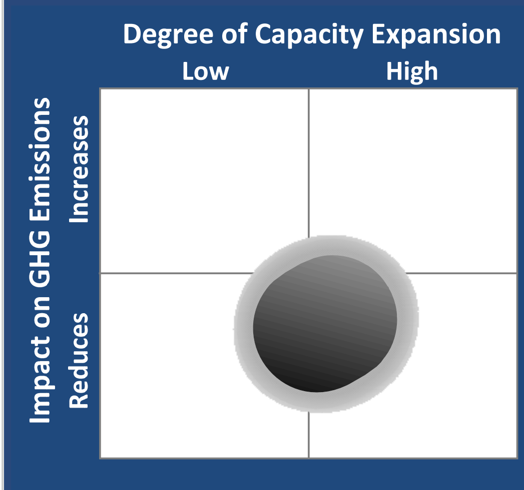
GHGS: Infrastructure supporting alternative travel modes is assumed to reduce GHG emissions in both the short and long term. Historically, geographic development patterns and demographic shifts have led to increased travel activity, the geographic dispersal of travel origins and destinations, and increased SOV use (1). The BAU forecasts for 2020 and beyond include a continuation of past trends (5) and suggest further reliance on SOVs. Mode shift projects reduce GHG emissions by alleviating congestion in mixed flow lanes (6) and reducing per vehicle GHG emission rates (7); reducing per passenger emission rates by reducing vehicle use (8); and, when paired with complementary land use, encourages transit, pedestrian, and bicycle use (2). In addition, system continuity can play an important role. For example, uninterrupted HOV lane systems will produce lower emissions than systems with HOV lane gaps. Support facilities such as park and ride lots facilitate mode shifts away from SOV use, thus reducing GHG emissions. In the Bay Area, for example, surveys showed near-freeway park-and-ride lot users were evenly divided between carpool and transit users (8). Although there is wide variability among park-and-ride lot conditions and accompanying transit resources, generally, 40-60% of park-and-ride lot users previously drove alone (9).

CAVEATS: HOV lane effectiveness depends on many factors, including congestion levels and speeds of adjacent general purpose lanes (3). In addition, effectiveness increases as the number of carpools and buses increase and with elements such as HOV bypass ramps. Alternative mode use (e.g., bicycling and walking) is linked to urban form, residential location choice (4). Park-and-ride lot utilization varies by site characteristics and transit proximity (9). Overall, the effectiveness of any given alternative mode project will be highly dependent upon site-specific considerations, and design features must be optimized to ensure mode switch from SOV.

INNOVATIONS: Caltrans has supported mode choice options at the corridor level, through corridor system management plans, and the regional level (e.g., the Blueprinting process). While these efforts continue, further opportunities include:

- Improving HOV lane system connectivity, as illustrated by the Highway 101 HOV lane "gap closure" project in the Bay Area.
- Implementing HOT/HOV metering and bypass ramps.
- Supporting carpool and van pool sponsored programs.
- See also, Sacramento's Bikeway & Pedestrian Master Plans: http://www.cityofsacramento.org/transportation/engineering/

ALTERNATIVE MODE PROJECTS



Shading is a qualitative estimate of the range of GHG impacts.

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Mixed Flow Capacity Addition

Overview: This project category includes the building of additional roadway capacity. Example projects include new mixed flow or managed lanes, new bridges, new major arterials and other capacity enhancements targeted to single occupant vehicles (SOVs).

GHGs: SOV capacity enhancements are assumed to result in increased travel activity and GHG emissions, based on the linkages among added capacity, travel behavior, and factors affecting on-road GHG emissions (speeds, trips, and VMT). Planners emphasized the need to better understand these linkages following passage of the 1990 Clean Air Act Amendments and implementation of transportation conformity (1, 2). A substantial literature has now investigated how added capacity affects traffic activity (e.g., 3, 4, 5, 7, 8).

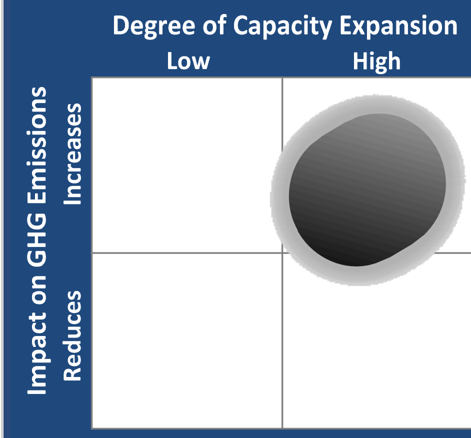
The literature separates short and long-term impacts, and identifies factors that influence how new capacity alters travel speeds, trip generation, mode choice, travel distance, and time-of-day travel choices. The National Research Council (4) found major highway capacity additions increase emissions over the long run, particularly in growing, less developed areas where capacity increases attract further development. NRC noted that in developed areas, traffic flow improvements such as left turn lanes and signal timing may reduce emissions without risking related traffic growth. More recent literature reviews also document a positive correlation between increased lane-miles of capacity and increased daily VMT (6); California-based analyses corroborate this link (8). Increased travel activity contradicts the AB 32 Scoping Plan, which envisions that by year 2030, control strategies will achieve an eight percent reduction in per-capita VMT from BAU conditions.

Caveats: Increased travel due to capacity increases may be partially offset when implemented as part of a package of improvements designed to reach regional GHG emission goals. For example, capacity increases implemented with peak-hour pricing may manage demand that would otherwise lead to increased activity.

Innovations:

- Increasing auto use cost will help to manage travel demand. Pricing also generates revenue to provide complementary transit services.
- California implements pricing (tolling) on new capacity; e.g., SR 91 in Orange County and San Diego's I-15 managed lanes (completion 2012 — http://sdapa.org/download/I-15_Managed_Lanes.pdf).

MIXED FLOW CAPACITY PROJECTS



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Maintenance and Rehabilitation Projects

OVERVIEW: Maintenance and rehabilitation (M&R) activities restore smoothness to rough pavements and extend the life of the investments made in existing pavement layers. These activities include re-surfacing with overlays, grinding of existing surfaces to restore smoothness, improvement of drainage and other activities that smooth the surfaces and preserve the lives of the pavement structures.

GHGS: Every activity requires an initial investment of fuel, equipment, and frequently materials that results in GHG emissions. Sources of GHGs for these projects are the following: material production and delivery, equipment operation, work zone traffic congestion (1), and decreased fuel economy due to high pavement roughness (2, 3, 4). However, this initial increase of GHG may be off-set by reductions in vehicle fuel use that occur because of smoother pavement. For pavements with high traffic volumes the off-set over the life of the pavement can be much larger than the initial increase in GHG from construction. M&R activities that produce smoother pavement for improved fuel economy include overlays, grinding or reconstruction; and extending current good pavement condition through preservation activities or drainage improvements. Opportunities for further reducing GHG emissions include improved designs, materials and construction/traffic handling practices; and increased use of recycling of existing pavement materials and in-place recycling techniques. The long-term effect of these activities is often a reduction in GHGs by either improving pavement roughness, which improves fuel economy or by using longer lived pavements which increase the number of years between M&R activities.

While current state standards for pavement roughness, as measured by the International Roughness Index or IRI (224 in/mi for asphalt, 213 for concrete) (5, 6), are significantly rougher than Federal standards (6), due to historical funding constraints there remains a significant portion of highway miles that have not achieved even state standards.

CAVEATS: There is strong evidence of adverse effects of high pavement roughness on fuel economy, yet the precise relationship is unknown. Overlays on roads with low roughness may provide negligible fuel economy benefits, but preserve the existing good condition, and overlays on low volume roads may result in a net increase in GHG emissions since the fuel economy benefits may be insufficient to off-set the material and construction related GHG emissions.

INNOVATIONS:

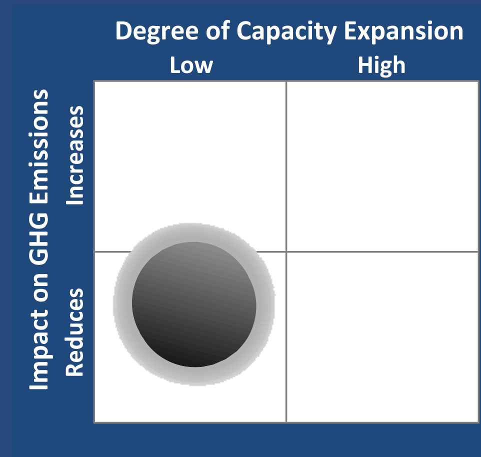
Strategies that reduce IRI and extend pavement life

- Incentivizing very low IRI at construction (e.g. AZ, FL and VA practices). Lower initial IRI correlates with lower future IRI, providing potential fuel economy benefits over a long time horizon
- Longer life designs and enhanced material durability
- Lower-carbon material substitution (e.g. fly ash in concrete, rubber in asphalt, recycled materials)

Construction and traffic management to reduce GHG emissions

- Continuous closures instead of night-time work where feasible, improved traffic management plans to reduce work zone traffic delay

M&R PROJECTS



Shading is a qualitative estimate of the range of GHG impacts.

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Other/Neutral Projects

OVERVIEW: This designation refers to projects that pose minimal to no likely change in GHG emissions relative to business-as-usual (BAU), or whose greenhouse gas emissions are not directly linked to pavements and highway use. These projects could, through innovative practices, yield net decreases in relative GHG emissions. This category includes bridge work, facilities, safety, landscaping, sound walls and stormwater.

GHGS: Bridges and overpasses can be divided into their constituent parts: the substructure, superstructure, and deck. Since the deck provides the driving surface, the recommendations that apply to pavement systems apply to decks as well. The primary methods for reducing long term GHG emissions would focus on extending deck life, and maintaining a smoother riding surface. Because of the short distance, pavement smoothness is likely less important than extending deck life, which would reduce the need for new material investment and reduce workzone congestion, both of which may reduce construction related GHG emissions compared to BAU (1).

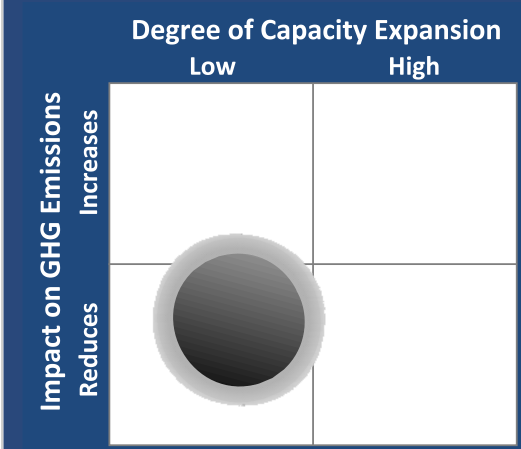
Preservation, rehabilitation, and construction of facilities will all result in initial material GHG emissions compared with no action. However measures to reduce operational energy requirements, e.g. heating, cooling, and lighting, integration of renewable energy technologies such as photovoltaics, and a reduced need for vehicle use, would all likely lead to life cycle reductions in GHG emissions for these projects due to GHG savings during operation (2, 3, 4, 5).

Landscaping and stormwater management activities are likely to contribute negligible amounts of emissions and can be considered neutral activities or provide very slow carbon absorption. Any soil disturbance should be kept to a minimum to minimize the release of carbon trapped in the soil (6). Landscaping should minimize maintenance, fertilizer, and water use, which all have GHG consequences.

INNOVATIONS:

- Elimination of bridge deck failure modes will extend bridge deck life; use of concrete with increased amounts of alternative cementitious materials, where safe.
- Siting and design of facilities to maximize use of transportation other than motor vehicles. Use of concrete with increased amounts of alternative cementitious materials, where safe.
- Building-integrated photovoltaics and passive solar designs could further reduce dependency on carbon-intensive electricity and heat sources.
- Use of low-maintenance, low-water landscaping, such as use of native plants. Minimal soil disturbance when installing landscaping.

OTHER/NEUTRAL PROJECTS



Shading is a qualitative estimate of the range of GHG impacts.

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