SHIFT (STATE HIGHWAY INDUCED FREQUENCE OF TRAVEL) CALCULATOR

About the methodology

This document outlines key background information, data sources, inputs, and methodological considerations for the SHIFT Calculator. Please reach out to the analysis team with any follow-up questions or requests for data.

Calculator Overview and Purpose

RMI has developed and calibrated the induced travel calculator to evaluate the net impacts of class 1 (interstate) road widenings in US Metropolitan Statistical Areas (MSAs) and of class 2 or 3 roadways in urbanized counties (i.e., counties in MSAs)—including their effect on state-wide vehicle miles traveled (VMT) and their emissions impacts. The calculator builds on analysis and methodology first published by Jamey Volker and Susan Handy at the University of California-Davis to calculate the induced travel impacts of lane mile additions in California metros and counties. It was also recently extended by Joe Cortright to Portland, Oregon.

The calculator will enable users to estimate long-run induced VMT (i.e., steady state in 5 to 10 years) from capacity expansions of large roadways in MSAs or urbanized counties based on existing lane mileage and VMT data. Drawing from the body of literature estimating the relationship between VMT and lane mileage increases on these roads, it applies a ratio of 1.0—meaning a 1% increase in lane mileage yields a 1% increase in VMT—for expansions on interstate highways and a ratio of 0.75 for expansions on other freeways, expressways, and principal arterial roads. This is consistent with literature discussed in greater detail below—the calculator generates an estimate for induced VMT at the appropriate order of magnitude for a given area based on this body of empirical research. Because the calculator uses factors that are drawn from studies that consider the impacts of road widenings over hundreds of observations and many years to calculate net impacts, the calculator is best used to understand order-of-magnitude impacts, rather than precise, project-specific outcomes. As described below, we take steps to underscore the limited precision of the calculations by reporting in intervals, as well as by clearly contextualizing the underlying research and scope of analysis in this document.

The calculator is not intended as a substitute for more granular traffic modeling or simulations, but rather as a tool that can effectively translate well-established induced travel demand literature to an informed understanding of the impacts of road expansions.

Background on Induced Travel

The following background information and explanation on the induced travel phenomena is courtesy of Volker and Handy of the National Center for Sustainable Transportation at UC Davis. **The following passage helps characterize the state of the induced demand literature that underlie this tool.**

> Attempts to address traffic congestion commonly rely on increasing roadway capacity, e.g., by building new roadways or adding lanes to existing facilities. But studies examining that approach indicate it is only a temporary fix. They consistently show that adding roadway capacity in congested areas actually increases network-wide vehicle miles traveled (VMT) by a nearly equivalent proportion within a few years, reducing or negating the initial congestion relief. That increase in VMT is called "induced travel."

The induced travel concept is not new (see the “fundamental law of highway congestion” Anthony Downs suggested in 1962). Indeed, it is explained by the bedrock economic principles of supply and demand: “adding capacity decreases travel time, in effect lowering the ‘price’ of driving; when prices go down, the quantity of driving goes up” (Handy and Boarnet, 2014a).

The magnitude of the induced travel effect is commonly measured as the elasticity of VMT with respect to lane miles:

$$Elasticity = \frac{\%\ Change\ in\ VMT}{\%\ Change\ in\ Lane\ Miles}$$

The greater the elasticity, the greater the increase in VMT from a given increase in roadway capacity. An elasticity of 1.0 indicates that a given percent increase in lane miles will cause the same percent increase in VMT.

Most recent studies have estimated elasticities in the same ballpark, despite using a range of methods to control for other VMT-inducing factors and the bidirectional relationship between VMT and capacity expansion. In general, the studies show that a 10% increase in roadway capacity is likely to increase network-wide VMT by 6-10% (an elasticity of 0.6 to 1.0) in the long run (5 to 10 years), with greater elasticities for expansions of major highways (e.g., interstates) than for capacity increases on other roadways. These longer-term elasticities account for short-run shifts in travel (as people take advantage of the increased capacity and travel speed by driving more), as well as longer-run dispersion of residential and business location and development.

For more information on the induced travel and other impacts of highway expansion, see Handy (2015) and Handy and Boarnet (2014a). For a summary of key studies estimating the elasticity of VMT with respect to lane miles, see Handy and Boarnet (2014b). Please also see the References section below for a list of relevant studies.

Methods Explanation

Consistent with the methodology of previous induced demand calculators, induced VMT is estimated using the following equation:

$$\Delta \mathbf{VMT} = \mathbf{elasticity} * \frac{\mathbf{VMT}}{\mathbf{lane.mi}} \Delta \mathbf{lane.mi}$$

The calculator uses 2019 lane mileage and VMT data provided to the authors by the Federal Highway Administration (FHWA). The data are aggregated at the county level by roadway facility type. Census delineation files are used to map the county-level data to MSAs and to identify counties that lie in MSAs.

The calculator uses an elasticity of 1.0 for lane additions to class 1 facilities (i.e., interstates) in MSAs. As Volker and Handy have previously explained, the 1.0 elasticity is drawn from Duranton and Turner (2011), and it also reflects several other studies that find convergent estimates of the impact of induced demand.

Volker and Handy's detailed summary of this work is available on the California Induced Travel calculator site. Notably, they highlight that the two-stage least squares regression used by Duranton and Turner (2011) represents an improvement in researchers' ability to address simultaneity bias. This preferred method finds a long-run elasticity of 1.03 for travel on interstate highways in the MSAs studied. Subsequent studies that build on these methods and introduce additional data continue to converge around a central travel demand elasticity of roughly 1.0 for both interstate highways and other major roadways (e.g., state highways and arterials) in urbanized areas. This includes Melo et al. (2012), Graham et al. (2014), Hsu and Zhang (2014), and Hymel (2019). For an extensive and detailed review and discussion of the induced travel literature, including a comparison to analyses undertaken in the context of environmental review processes, please see Volker et al. (2020).

The calculator applies a lower elasticity for lane additions to class 2 or 3 facilities. Instead of 1.0, we apply an elasticity of 0.75 to lane additions to these roads. Research that includes these roads within the scope of analysis find elasticities within a range of about 0.7 to 1.0, while in some cases accounting for a broader set of road types (e.g., Hymel [2019], Cervero and Hansen [2002], Duranton and Turner [2011]). We choose here to explicitly incorporate a lower factor to reflect evidence that the impact of road widenings can vary by road type. There continues to be a range of uncertainty around project-specific outcomes. Overall, research on induced travel demand shows that road networks converge around this dynamic, but as is the case with any measure of central tendency, project-by-project impacts may land higher or lower.

The calculator uses MSAs as the unit of analysis for lane mile additions to class 1 facilities and urbanized counties as the unit of analysis for lane mile additions to class 2 or 3 facilities. We chose these geographies based on the units of analysis used in the empirical research. Like Duranton and Turner (2011), we use MSAs as the unit of analysis for class 1 facilities. The selection of urbanized counties as a unit of analysis for class 2 and 3 facilities derives from Cervero and Hansen (2002). Overall, the calculator accounts for the differing levels of granularity used in the empirical studies reviewed.

Calculation Overview

Further explanation of calculation inputs, guidance on interpretation, and analytical approaches is provided in the detailed bullets below.

Calculation Inputs

- **Timing:** The lag between facility expansion and full induced VMT impacts is expected to be 5 to 10 years.
- **Elasticity:** The calculator utilizes an elasticity of 1.0 to estimate the impacts of lane mile additions to Class 1 facilities and an elasticity of 0.75 for Class 2 or 3 facilities. Note that induced VMT is reported in confidence intervals of +/-20%, reflecting the range of elasticity estimates reported in the literature. As previously noted, research on induced travel demand shows that impacts converge around these elasticities, but as is the case with any measure of central tendency, project-by-project outcomes may land higher or lower. The interval-based reporting is intended to reflect this reality and avoid communicating false precision.
- **User Inputs/Scope:** The calculator can be used to evaluate capacity expansions (lane additions, roadway lengthening, and new facility construction). The calculator may be applied to additions of general purpose, high-occupancy-vehicle (HOV), and high-occupancy toll (HOT) lanes, given that they are understood within the context of the overall precision of the calculator. When it comes to HOV or HOT lanes, the overall impact of induced demand can vary depending on lane configuration and pricing. However, the literature does not provide clear, generalizable estimates to determine by how

much, and analysis of more recent roadway expansions (i.e., studying networks that have incorporated HOT/HOV lane configurations) continues to converge around similar elasticities. As such, the calculator does not reflect incremental differences in impact by lane type. General intuition can be used to help contextualize and interpret results (i.e., logical reasoning infers that the impact of HOV lanes is likely to be slightly lower), and the results are framed in a way that helps communicates this uncertainty. *(Also see discussion of net impacts.)*.

Data Overview

- **Source:** The calculator utilizes 2019 lane mileage and VMT provided by FHWA and aggregated at the county level based on its Highway Reporting Monitoring System (HPMS) reporting.
- **Facility Types:** The calculator can be used to estimate induced travel due to road expansions on US roadways with FHWA functional classifications of 1, 2, or 3 (interstates, state highways, and arterials).
- **Geography:** The calculator's use is limited to class 1 roadways in US MSAs or class 2 or 3 roadways in urbanized counties (i.e., counties in MSAs). Note that the data are aggregated using the current HPMS reporting data and mapping conventions/delineations. These differ slightly, based on more recent updates, from the data reporting that fed into past studies of induced demand impacts conducted using pre-2010 data. We do not expect that the relationships identified would fundamentally shift if past studies were re-run today, as indicated by recent studies using data from both periods (e.g., Hymel, 2019).
- **Precision:** Induced VMT is reported annually and in intervals. This reflects the nature of the calculations, which are intended to provide a useful order-of-magnitude estimate based on well-established evidence of expected impacts.

Interpreting Results

- **Travel Substitution:** There is a possibility that some of the increased VMT on the expanded facility is traffic diverted from other types of roads in the network. But, in general, the research shows that "capacity expansion leads to a net increase in VMT, not simply a shifting of VMT from one road to another." (Handy and Boarnet, 2014a.)
- **Net Impacts:** As noted previously, the calculator provides a reasonable estimate for the net impact of capacity expansions; project-specific outcomes may vary in pace and magnitude at the margins, depending on a range of factors, and land either below or above the central elasticity factors by years 5 to 10. For example, a road expansion project to streamline a chokepoint may drive a different outcome than a lane widening project on a typical major road, increasing throughput potentially by even more than we have estimated. In another case, we would expect that the induced demand impact of lane mile additions of toll managed lanes will vary depending on the magnitude of the toll and the balance of lane designations. The calculator's results do not describe differences across these dynamics but address the shared long-run impacts of adding capacity (and subsequently reducing the costs of driving).
- **Local Context:** To that end, local context and project-specific knowledge can help interpret the calculator outcomes and are particularly critical when it comes to designing solutions to highly localized and acute challenges.

Future Adaptation

Note that this calculator itself represents an adaptation of existing methods to new geographies. As noted in previous iterations, continued efforts to build on and extend this work are welcome and highly feasible. The basic construction and general approach of this calculator is essentially identical to prior iterations. However, it pulls from a different collection of US-wide data, builds on prior work with its approach to cumulative emissions, and alters elasticity estimates from the Colorado approach.

Additionally, the calculator's greenhouse gas (GHG) emissions outputs can be applied and interpreted according to the more detailed bullets below.

Cumulative GHG Emissions

The calculator outputs an estimate of the cumulative GHG emissions generated by induced demand through 2050. Cumulative GHG emissions are calculated under two sets of assumptions, both drawn from the US Energy Policy Simulator (EPS), to estimate the impacts under both a case aligned with achieving the US Nationally Determined Commitment (NDC) and a business-as-usual (BAU) case.

- The NDC-aligned case accounts for a set of policies and assumptions that target mitigation investments consistent with a climate-safe future, including 100% electrification of new passenger vehicles by 2035 and rapid renewable power development.
- The BAU scenario reflects projected efficiency and electrification improvements and current policy measures.

The scenario paths for the United States are fit to each state using state-specific data points for start-year values (below). Using generic rates of change represents a simplifying step in the analysis, given that state-specific trajectories toward and contributions to the NDC will vary, depending particularly on the characteristics of energy production in each state. The scenarios offer a generalizable sense of scale and pace that is well within a level of precision suited to the calculator. Like the estimates of induced demand, the estimated emissions are reported in intervals. For example, the cumulative GHG emissions figures are rounded to the nearest hundred thousand metric tons. Additional information on these scenarios and underlying assumptions are easily accessed via detailed EPS documentation.

This calculation assumes that the lane mile addition input to the calculator is complete by 2023. These calculations incorporate a five-year lag period between installation and induced demand to reflect the initial point at which the full or near-full induced demand effects may be felt.

Cumulative GHG emissions are calculated on both a direct and lifecycle basis, to showcase the additive impact of direct and indirect emissions from induced demand. The direct portion of the cumulative emissions footprint is calculated using scenario-specific trajectories for vehicle electrification, electricity emissions intensity, vehicle efficiency improvements, and travel demand growth from US EPS, paired with state-specific data to set start year values for these metrics. Data sources for start year values are described below:

- **Electricity GHG Intensity:** GHG intensity of electricity end use demand in a given state, including imports, is generally based on a load-weighted average of hourly data downloaded from the National Renewable Energy Laboratory's Cambium database for the "Mid" case. The exceptions are Hawaii, DC, and Alaska, where data is drawn from state energy data system (SEDS) values (and adjusted to reflect transmission and distribution-related energy loss).
- **Average Fuel Economy (*light-duty vehicles [LDV] and heavy-duty vehicles [HDV] with an internal combustion engine [ICE]):*** Fuel economy by vehicle type as reported by the Bureau of

Transportation Statistics (BTS)[i], weighted by FHWA-reported state VMT levels by vehicle on interstates and arterials in urban areas.[ii]

- **Average Fuel Economy (*LDV and HDV Zero-Emission Vehicles [ZEV]*):** ZEV fuel economy as calculated in the US EPS start year. *[does not vary by state]*
- **LDV vs HDV share of VMT:** Distribution of VMT by state and vehicle type on interstates and arterials in urban areas, as reported by FHWA.
- **ZEV share of LDVs and HDVs:** Share of ZEVs as calculated in the US EPS start year. (*Does not vary by state.)*

Beyond the direct emissions impact, which reflects the emissions impacts of gasoline and diesel combustion, the lifecycle emissions calculation also incorporates upstream and manufacturing emissions:

- **Upstream GHG emissions** come from the production of gasoline and diesel, drawn from work done by the California Air Resources Board to utilize the Argonne National Lab's Greenhouse Gases, Regulated Emissions, and Energy Use in Technologies model (i.e., GREET model) and calculate lifecycle fuel emissions intensities.
- **Manufacturing GHG emissions** are associated with light-duty vehicle production, drawn from International Council of Clean Transportation estimates (note that HDV manufacturing emissions are not incorporated).

Note that real-world lifecycle emissions impact will also include the emissions generated by the infrastructure assets themselves, via production of building materials (e.g., concrete manufacturing, asphalt production), construction activities, operation and maintenance of infrastructure assets, and even disposal/end-of-use phase considerations. These may vary considerably with design and material choices; the International Panel on Climate Change (IPCC) finds that in the United States, infrastructure-related emissions for light-duty vehicles range from 17 to 45 gCO_2e per passenger kilometer (~27 to 72 gCO_2e per mile).

Relative to the cumulative transportation emissions generated from induced demand, these impacts would likely lead to a slight increase to our indirect lifecycle emissions estimates. Additional impacts could occur if highway expansion facilitates construction of lower density residential and commercial development than would otherwise have occurred, but we did not quantify this. As such, ours is a conservative estimate.

In addition, emissions estimates are calculated to illustrate the additive emissions impacts of induced demand. They do not incorporate a counterfactual scenario analysis. The emissions impact of congestion pales in comparison to the impact of additional induced travel, especially given that road expansions are not a lasting solution for congestion. Moreover, we expect the emissions impact of congestion to diminish in the coming years as stop-start technology becomes increasingly common in the US vehicle fleet. As such, we find it appropriate to present the added emissions as a stand-alone calculation of impact.

[i] See BTS National Transportation Statistics, tables 4-23, 4-11, 4-13, 4-14, and 4-15.
[ii] See FHWA Highway Statistics 2019 Tables VM-2 and VM-4

Annual Emissions

The calculator also uses an estimate of the annual direct GHG emissions generated by induced demand, which are calculated as a current snapshot (i.e., based on the most recent emissions and efficiency assumptions), to generate annual emissions equivalent units.

- **The annual direct emissions snapshot** is calculated based on the LDV vs HDV VMT mix on urban interstates and arterials in the given state, average current US vehicle stock fuel efficiency, and Environmental Protection Agency's (EPA) reported energy and emissions intensity factors for gasoline and diesel
- **Annual emissions equivalent units** (i.e., equivalence in terms of gallons of gasoline consumed) are calculated from the snapshot using factors documented via EPA's GHG Equivalencies Calculator. Equivalencies are calculated using US-based factors, rather than on a state-specific basis. The factors are available here.

References

Cervero, R., and Hansen. (2002). "Induced Travel Demand and Induced Road Investment: A Simultaneous Equation Analysis." *Journal of Transport Economics and Policy*, 36(3), 469-490. Available at: https://www.ingentaconnect.com/content/lse/jtep/2002/00000036/00000003/art00005.

Downs, A. (1962). "The Law of Peak-Hour Expressway Congestion." *Traffic Quarterly*, 16(3), 393-409. Available at: https://trid.trb.org/view/694596.

Duranton, G., and Turner, M. A. (2011). "The Fundamental Law of Road Congestions: Evidence from US Cities." *American Economic Review*, 101(6), 2616-2652. doi: 10.1257/aer.101.6.2616. Available at: https://www.aeaweb.org/articles?id=10.1257/aer.101.6.2616.

Graham, D. J., McCoy, E. J, and Stephens, D. A. (2014). "Quantifying Causal Effects of Road Network Capacity Expansions on Traffic Volumes and Density via a Mixed Model Propensity Score Estimator." *Journal of the American Statistical Association*, 109(508), 1440-1449. doi:10.1080/01621459.2014.956871. Available at: https://www.tandfonline.com/doi/abs/10.1080/01621459.2014.956871.

Handy, S., and Boarnet, M. G. (2014a). *Impact of Highway Capacity and Induced Travel on Passenger Vehicle Use and Greenhouse Gas Emissions: Policy Brief*. Prepared for the California Air Resources Board. Retrieved from: https://ww2.arb.ca.gov/sites/default/files/2020-06/Impact_of_Highway_Capacity_and_Induced_Travel_on_Passenger_Vehicle_Use_and_Greenhouse_Gas_Emissions_Policy_Brief.pdf.

Handy, S., and Boarnet, M. G. (2014b). *Impact of Highway Capacity and Induced Travel on Passenger Vehicle Use and Greenhouse Gas Emissions: Technical Background Document*. Prepared for the California Air Resources Board. Retrieved from: https://ww2.arb.ca.gov/sites/default/files/2020-06/Impact_of_Highway_Capacity_and_Induced_Travel_on_Passenger_Vehicle_Use_and_Greenhouse_Gas_Emissions_Technical_Background_Document.pdf.

Handy, S. (2015). *Increasing Highway Capacity Unlikely to Relieve Traffic Congestion: Policy Brief*. Prepared for the National Center for Sustainable Transportation. Retrieved from: https://escholarship.org/uc/item/58x8436d.

Hsu, W., and Zhang, H. (2014). "The Fundamental Law of Highway Congestion Revisited: Evidence from National Expressways in Japan." *Journal of Urban Economics*, 81: 65-76. doi:10.1016/j.jue.2014.02.002. Available at: https://www.sciencedirect.com/science/article/pii/S0094119014000126?via%3Dihub.

Hymel, K. M. (2019). "If You Build It, They Will Drive: Measuring Induced Demand for Vehicle Travel in Urban Areas." *Transport Policy*, 76: 57-66. doi:10.1016/j.tranpol.2018.12.006. Available at: https://www.sciencedirect.com/science/article/abs/pii/S0967070X18301720.

Melo, P. C., Graham, D. J., and Canavan, S. (2012). "Effects of Road Investments on Economic Output and Induced Travel Demand: Evidence from Urbanized Areas in the United States." *Transportation Research Record: Journal of the Transportation Research Board*, 2297: 163-171. doi:10.3141/2297-20. Available at: https://journals.sagepub.com/doi/10.3141/2297-20.

Volker, J. M. B., Lee, A. E., and Handy, S. (2020). "Induced Vehicle Travel in the Environmental Review Process." *Transportation Research Record: Journal of the Transportation Research Board* (in press). doi:10.1177/0361198120923365. Available at: https://sci-hub.se/10.1177/0361198120923365.