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Leaving level-of-service behind: The implications of a shift to VMT impact metrics

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ABSTRACT

Concern about climate change has led to policies in California that aim to decrease greenhouse gas (GHG) emissions from transportation. Although these policies mostly promote technological innovations, some policies aim to reduce GHG emissions by reducing the amount of driving, measured in vehicle miles traveled (VMT), through land use and transportation planning. The focus on VMT reduction represents a dramatic shift for the land use and transportation planning fields, which have traditionally prioritized auto mobility by reducing vehicle delay, measured as level of service (LOS). California has taken the bold step to replace LOS with VMT as the metric of transportation impact in the environmental review process for land use and transportation plans and projects under the California Environmental Quality Act (CEQA). This study compares these two metrics – VMT and LOS – and their implications for a sample of land use projects located in Davis, California. We compare the LOS impacts analyzed in the environmental impact reports for the projects to forecasted VMT impacts that we quantify using several available VMT estimation models. Our analysis of LOS mitigation shows how the CEQA process per se impacts the built environment, often in ways that increase vehicle capacity and thus VMT. We find that a switch to VMT metrics may lead to streamlining for projects that reduce travel demand because of their location or design, whereas LOS metrics have led communities to build expensive, capacity-increasing mitigation measures to ease vehicle delay. Finally, we show that the vehicle capacity constructed to mitigate LOS may contravene the goals and aspirations of many communities in California, as well as the state's goals for GHG reductions, and is unlikely to solve the congestion problem caused by misplaced land use development.

1. Introduction

Several states across the U.S. have enacted policies to reduce greenhouse gas (GHG) emissions, including policies aimed at reducing emissions from transportation. Many of these policies promote technological innovations, but some state and local policies also aim to reduce GHG emissions from transportation by reducing the amount of driving, measured in vehicle miles traveled (VMT), through land use and transportation planning. Most notably, California Assembly Bill 32 of 2006 led to the creation of a statewide target to reduce GHG emissions, a cap-and-trade market for GHG emissions, and engendered a series of policies and funding programs to help the state achieve its goals through efficient land use and transportation. In 2008, California Senate Bill 375 established targets for reducing GHG emissions from transportation, in part by reducing VMT through coordinated land use and transportation planning at the regional level. Metropolitan Planning Organizations (MPOs) in California must demonstrate that their federally-required regional transportation plans and state-required Sustainable Communities Strategies will meet regional targets for VMT and GHG reductions. Because cities and counties hold authority to make land use decisions, the state enacted grant programs that encourage local implementation of the regional transportation plans and Sustainable Communities Strategies.

Other western states soon followed California in enacting policies to reduce VMT and increase multi-modal accessibility. Washington enacted House Bill 2815 in 2008 that aimed to reduce statewide passenger VMT, and Oregon's House Bill 2001 (signed into law in 2009) and Senate Bill 1059 (in 2010) established targets to reduce GHG emissions in part by efficient land use planning. On the other coast, Virginia's House Bill 2 (in 2014) established a statewide funding program that uses multi-modal accessibility, GHG emissions reductions, and "transportation efficient land use" (among other criteria) in the transportation project selection process (VDOT, 2015).

This focus on VMT reduction represents a dramatic shift for the land use and transportation planning fields, which have traditionally prioritized reductions in vehicle delay, measured by level of service (LOS).

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The concept of measuring the carrying capacity and flow rate of transportation facilities was established in the first edition of the Highway Capacity Manual published in 1950 (Roess, 1984). LOS was formally defined in the 1965 Highway Capacity Manual as a "qualitative measure of the effect of a number of factors, which include speed and travel time, traffic interruptions, freedom to maneuver, safety, driving comfort and convenience, and operating costs" (Highway Research Board, 1965). LOS is measured on individual roadway segments and intersections with letter grades from A to F. LOS A describes faster vehicle speeds, lower vehicle density, and less vehicle delay; LOS F describes a "failure" of transportation system operations (Roess, 1984). Simply put, LOS measures the amount of vehicle delay for a given time and location.

In California, LOS has been the primary measure of transportation-related "environmental impacts" for land development projects under the California Environmental Quality Act (CEQA) – the state-level equivalent to the U.S.'s National Environmental Policy Act (NEPA) – since at least the early 1970s (City of Orange v. Valenti, 1974). CEQA has a broad reach in the development process; it requires impact analyses and mitigations for those impacts for any project requiring "discretionary action" (rather than "ministerial" actions of, say, issuance of building permits) and has arguably "had as much influence on land use patterns in California as any planning law" (Fulton & Shigley, 2012). Nationally, a focus on LOS is implicit throughout the Federal Highway Administration's technical advisory for preparing environmental impact statements under NEPA. "Alleviating traffic congestion" is offered as an example of "project purpose and need," and improving traffic flow rate is listed as a potential energy conservation measure (FHWA, 1987).

This practice met its first official challenge in 2013 when California's Senate Bill 743 triggered the removal of vehicle delay as a metric of environmental impact for CEQA analyses (Senate bill no. 743, 2013). SB 743 (and the accompanying guidelines authored by the California Governor's Office of Planning and Research [OPR]) proposes to replace LOS with VMT as "the most appropriate metric of a project's potential transportation impacts" (Public Resources Code § 21099(b)(2), OPR, 2016). OPR's *Technical Advisory on Evaluating Transportation Impacts in CEQA*: *Implementing Senate Bill 743* ("technical advisory") offers detailed (though non-binding) suggestions for evaluating the VMT associated with land use development and transportation projects. CEQA analysis generally identifies both LOS-related and non-LOS-related transportation impacts; under SB 743, analysis of VMT impacts will replace the LOS-related impacts, though other transportation impacts – such as impacts to emergency access – will continue to be analyzed in the same way.

Though the revised CEQA Guidelines and accompanying technical advisory are still in the adoption process, three bold jurisdictions have already introduced VMT-based metrics and thresholds (standards for performance) in their general plans and CEQA analyses. The City of Pasadena adopted VMT-based thresholds in 2014 as an addition to its existing LOS-based thresholds (City of Pasadena Department of Transportation, 2015). San Francisco and Oakland replaced LOS-based thresholds with VMT-based thresholds in their respective transportation impact analysis guidelines in 2014 (Oakland City Planning Commission, 2016; San Francisco Planning Department, 2016).

The shift to VMT metrics raises many questions for CEQA analyses and the planning field more broadly. An important practical question is how to estimate project-level VMT. Many CEQA analyses use regional travel demand models to evaluate the performance of land use and transportation plans and projects. However, these models are resource intensive and optimized for regional-scale analysis, rather than project-level VMT analysis. In fact, "travel demand forecasting models were never meant to estimate travel impacts of neighborhood-scale projects or developments" because "their resolution tends to be too gross to pick up fine grained design and land-use-mix features" (Cervero, 2006). Even travel demand forecasting models with high resolution can require multiple runs of a single project to produce information that is useful at the scale of individual projects (Castiglione, Freedman, & Bradley, 2003).

This creates need for neighborhood- and project-scale modeling approaches, what Cervero (2006) calls "first cut sketch-planning tools". Cervero (2006) defines two main approaches for sketch planning tools. One is post-processing, which "tweaks" outputs from travel demand models using elasticities to capture relationships not accounted for in the travel model. Direct modeling – "stand-alone models to directly estimate travel for neighborhoods" – is the other approach (Cervero, 2006). These methods are more efficient for local plans and individual projects, and "may do a better job of picking up some of the nuanced relationships between smart growth and travel demand than even enhanced large-scale models" (Cervero, 2006). However, they have notable limitations and enjoy little consensus regarding which is most accurate (Shafizadeh, Lee, Niemeier, Parker, & Handy, 2012; Zhao & Kockelman, 2002). Indeed, in a related in-depth analysis of six sketch VMT models, we found that project-level VMT estimates vary by as much as 200% for a single project (Lee, Fang, & Handy, 2017).

The shift to VMT metrics also raises more fundamental questions for communities. One question has to do with VMT thresholds: how much VMT can a project add to a community before it is too much? Thresholds of significance "play a critical role" in determining the extent of a project's review under CEQA (14 California Code of Regulations § 15064). The restrictiveness of thresholds affects the practical, political, and financial feasibility of projects: preparation of EIRs, mitigation of impacts, and defense of legal challenges can all be cost- or politically-prohibitive elements of the CEQA process (Rothman, 2011).

Another important question is the degree to which replacing LOS with VMT within the CEQA process will change the types of environmental mitigations adopted for land development projects, and the environmental implications of those mitigations. The shift in metric will identify different impacts and thus induce different mitigations. LOS-based mitigations aim to maintain vehicle speeds, often by adding vehicle capacity and optimizing signal timing. Changes to the transportation network, such as adding vehicle capacity to mitigate low LOS, have important implications for both land use and travel patterns. Handy (2005) explains these implications as the "inextricable link" between land use and transportation: simple causal relationships as well as a complex "system of endogenous relationships" exist between transportation investments, land development patterns, and travel patterns. Cervero (2003) quantified the strength of these relationships as they pertain to vehicle capacity on highways. Cervero found a significant positive association between capacity expansion and land development along the expanded corridors. Increased land development, in conjunction with initial increases in travel speeds provided by the additional vehicle capacity, increased the short- and long-term travel demand along the corridor. Increased travel demand led to net increases in VMT and, ultimately, automobile congestion (Cervero, 2003). Other studies (e.g. Downs, 1962, Downs, 1992, Downs, 2004, Duranton & Turner, 2011) have found similar positive associations between additional vehicle capacity, travel demand, and ultimately congestion on "a broad class of major urban roads". The literature thus suggests that many mitigations intended to improve mobility (the ability to move – automobiles, traditionally – easily and freely) in fact increase VMT and ultimately lead to vehicle congestion over the long run. With VMT being imported as the primary metric to evaluate transportation impacts in CEQA, we would expect mitigations that instead decrease auto demand through various strategies that increase accessibility, improve active transportation infrastructure, and enhance transit services.

Further, a shift from LOS to VMT within the CEQA process raises important questions about the types and locations of land development projects that are even proposed. A change in performance metric changes the incentives and disincentives to develop certain types of projects in certain areas. The use of LOS incentivizes projects and

Table 1
Case study projects.

	The Cannery	Nishi Gateway	2nd Street Crossing
Acres	100	47	19
Land uses	336 units single-family 314 units multi-family 78 ksf retail 157 ksf commercial 5.5 ksf community center 4.7 acres park	650 units multi-family 325 ksf research/office	173 ksf retail (including Target)
Prior land use	Agricultural Processing	Agriculture	Undeveloped
Adjacent land uses	Residential Commercial Agricultural	Central business district Residential University Commercial Interstate & railroad	Residential Commercial Agricultural Interstate & railroad
Transit within ¼ mile	7 bus lines	10 bus lines Passenger rail (amtrak)	7 bus lines
Distance to downtown	1.5 miles	0.5 mile	3.5 miles

ksf = thousand square feet.

locations that can maintain vehicle speeds and driver convenience surrounding the proposed land use project; analyzing VMT incentivizes projects and locations that reduce VMT. This change would ostensibly incentivize land development in areas with a variety of transportation options rather than areas of auto-oriented sprawl.

2. Research questions & methods

The implications of the shift from VMT to LOS for California's foundational environmental policy are uncertain. How do projects perform when evaluated under each metric? How do the impacts highlighted by each metric differ? What mitigation strategies does each metric suggest? And do those mitigation strategies lead to outcomes that the community desires?

To answer these questions, we evaluate the transportation impacts and corresponding mitigation measures using both LOS and VMT metrics for three land development projects in Davis, California. Each project is summarized in Table 1 and mapped in Fig. 1. We first inventory and analyze the "significant" LOS impacts and their required mitigations in the projects' draft environmental impacts reports (EIRs). We then analyze each project according to the VMT thresholds proposed in the 2016 version of the SB 743 technical advisory and, as necessary, estimate the VMT generated by each project using several available VMT quantification methods. By comparing project-specific VMT to the appropriate thresholds, we make significance determinations for each project.

2.1. LOS impacts & mitigations

To compare LOS- and VMT-based transportation impacts, we inventory and analyze the impacts and mitigations identified using LOS in the projects' EIRs. We identify impacts as being LOS-related or not, as local jurisdictions can choose to measure transportation impacts other than impacts on traffic with metrics other than LOS. Across the three projects, LOS-based impacts are the most common of the "significant" and "potentially significant" impacts identified in the EIRs. The significance of an impact is determined by comparing it to a specified threshold; the setting of thresholds and the comparison of estimated impacts to these thresholds is thus a critical component of CEQA analyses.

Impacts that are found to be significant or potentially significant require mitigation measures "which would substantially lessen the significant environmental effects of such projects" as feasible (California Public Resources Code §21002). We inventory mitigation measures for LOS-based impacts. The impacts identified and mitigation measures implemented under CEQA not only have implications for the contentiousness of the environmental review process and cost of development; they also have implications for the built environment, community design, and the incentives and disincentives that underpin the types and location of development.

2.2. VMT estimation methods

We initially identified all sketch VMT estimation methods that are available for projects in California. A panel of 20 consultants, MPO and state agency staff, and academic researchers with expertise in travel demand modeling gave input about the unique attributes, computational abilities, and practical considerations of each method. With this input, we selected five VMT estimation methods to use in this study (Table 2).

A simple way to estimate VMT is to multiply the number of trips generated by a project by the length of those trips. In the U.S., the Institute of Transportation Engineers' *Trip Generation Manual* (ITE, 2012) has traditionally been the authority for trip generation estimates (Clifton, Currans, & Muhs, 2013). Planners use ITE trip generation rates in LOS analysis and in some VMT estimation methods to estimate the number of trips a project generates. However, ITE trip generation data have widely-known and self-identified limitations. Data collection focused on "single-use, vehicle-oriented trip rates in suburban sites" (Clifton, Currans, & Muhs, 2015); if a project "is located in a downtown setting, served by significant public transport … the site is not consistent with ITE data" (Institute of Transportation Engineers, 2004). Several studies have identified the extent to which ITE trip rates overestimate trip generation for projects in urban settings (e.g. Cervero & Arrington, 2008, Shafizadeh et al., 2012) and some suggest methods for adjusting ITE trip rates to better reflect observed travel in urban areas (e.g. Clifton et al., 2013, Clifton et al., 2015, Currans & Clifton, 2015, Schneider, Shafizadeh, & Handy, 2015). Some sketch VMT estimation models use this type of research to adjust the trip generation rates, trip lengths, or both to account for various characteristics of the project and its surroundings (e.g. MXD, California Smart Growth Trip Generation Adjustment Tool). Others (e.g. Sketch7) use the post-processing method described by Cervero (2006) to adjust baseline travel behavior data from travel demand models.

Three of the VMT estimation methods we use adjust ITE trip generation rates to account for a number of factors: trips internal to the project (for instance, when a person makes several stops within a mixed-use development), and trips that would have passed by the project anyway and thus are not "new" VMT. The California Emissions Estimation Model (CalEEMod) uses this approach to estimate VMT. CalEEMod also includes adjustments of overall project VMT based on characteristics of the project and the built environment surrounding the project (e.g. nearby housing and employment density, distance to transit, distance to the central business district, et cetera) (CAPCOA, 2013). The California Smart Growth Trip Generation Tool (Handy, Shafizadeh, & Schneider, 2013) and the Mixed-Use Trip Generation Model (MXD) (Walters, Bochner, & Ewing, 2013) use statistical relationships (linear regression) to adjust trip generation rates based on the characteristics of the project and the project surroundings. Both methods primarily estimate trip generation, but the estimated number of trips can be multiplied by appropriate trip lengths to find VMT.

Two of the VMT estimation methods use statistical models to draw relationships directly between VMT and project characteristics,

Fig. 1. Map of case study projects and key intersections.

characteristics of the built environment surrounding the project, and demographics. GreenTrip Connect is based on a statistical relationship (also a linear regression) between VMT and demographics, household income, regional context, and location efficiency (Newmark et al., 2015; Newmark & Haas, 2016). Sketch7 adjusts household VMT using elasticities related to the built environment. It is based on Ewing & Cervero's, 2010 meta-analysis of "Ds" variables, thus it estimates the relationship between travel behavior (VMT, walking, transit use) and housing density, employment density, land use mix, street design, destination accessibility, and transit accessibility.

2.3. Project VMT estimates

To estimate VMT, we use the same land use assumptions that were used in the transportation chapters of the projects' respective EIRs (§ 3.14 of the Cannery Park Draft EIR, § 4.14 of the Nishi Gateway Project Draft EIR, and § 3.4 of the Second Street Crossing [Target Store] Project Draft EIR), rather than the land use assumptions described in the Project Description or elsewhere in the EIR. For example, the mix of land uses within the Cannery is described several ways throughout the EIR and includes various types of residential units (e.g. lofts, studios), food market stands, and research and development space. The land uses in the transportation chapter – and those we use to estimate VMT – are single-family residential, apartments, retail, office, and community center.

We use these land use assumptions in each VMT estimation tool. GreenTrip Connect only estimates residential VMT, thus we use it to estimate VMT from the residential components of the Cannery and Nishi Gateway. We did not use GreenTrip Connect on 2nd Street Crossing because the project is exclusively retail. Sketch7's land uses are the same categories as in the MPO's regional transportation plan, rather than ITE land use categories that are used by CalEEMod, MXD, and (usually) the projects' EIRs. When land use categories were not the same as those listed in the EIR's transportation chapter, we use the closest available land use. For example, 2nd Street Crossing includes the ITE categories "free-standing discount store" and "shopping center" in its EIR; we categorize it as "community/neighborhood retail" in Sketch7.

2.4. VMT thresholds – how much is too much?

Under CEQA, a "threshold of significance" is necessary to determine if an impact generated by the project is "significant" or not. The SB 743

Table 2
Selected VMT quantification methods.

Method	Adjusts	Methodology	Applicability
CalEEMod 2016	Trip generation VMT	Direct model	• Residential, commercial, retail, industrial, recreational, educational • Any context area in California
California Smart Growth Trip Generation Adjustment Tool	Trip generation	Direct model	• Mid- to high-density residential, office, restaurant, coffee shop, retail • "Smart growth" project location[a]
GreenTrip Connect	VMT	Direct model	• Residential • Any context area in California
MXD	Trip generation	Direct model	• Residential, retail, office, industrial, commercial, educational, other • Any context area
Sketch7	VMT	Post-process	• Mixed use, residential, retail, office, industrial, public, civic, medical, educational, military, airport • Any context area in Sacramento region (currently)

[a] Case study projects do not meet this criterion.

technical advisory recommends several methodologies for setting VMT thresholds for land use projects. The 2016 version of the technical advisory also recommends evaluating individually each land use within a project (e.g. residential, office, retail components of a mixed-use project).

The technical advisory recommends several "screening" thresholds based on project size, location "near transit," or location in a "low-VMT area. The lead agency could generally presume that "small projects" – generating fewer than 100 vehicle trips per day – and development near transit stations[1] cause less than significant transportation impacts (OPR, 2016). Lead agencies could also generally presume that development in low-VMT areas would generate VMT at a similarly low level as its surroundings, and could thus be presumed to cause less-than-significant VMT impacts (OPR, 2016).

Low-VMT areas for residential projects are identified by the average household VMT per capita of the transportation analysis zone (TAZ) in which the project is located. Low-VMT areas for office projects are similarly identified by the average commute VMT per employee of the project's TAZ.

What is considered "low" VMT? The technical advisory suggests the following:

- Low-VMT residential areas are those with household VMT per capita that is 85% the regional average or less
- For offices, low-VMT areas are those with commute VMT per employee that is 85% of the regional average or less.

We analyze each project in relation to each of SB 743's "screening" thresholds. We use information from transit districts to identify high-quality transit areas. We use data from the California Statewide Travel Demand Model (CSTDM) to determine regional average VMT per person and per employee, and to determine average VMT of each TAZ (Caltrans, 2014). GreenTrip Connect and Sketch7 have VMT built-in data that could ostensibly be used to identify low-VMT TAZs, though the data are not currently extractable from either tool.

If a development project is not a small project, near transit, nor in a low-VMT area, the lead agency must estimate the amount of per capita VMT the project would generate and compare it to "numeric thresholds." The technical advisory recommends what may constitute significant transportation impacts:

- Residential development with household VMT per capita exceeding both 85% of the "existing city household VMT per capita" *and* 85% of the "existing regional household VMT per capita"
- Office development with VMT per employee exceeding 85% of the "existing regional VMT per employee"
- Retail projects that cause a "net increase in total VMT."

The technical advisory document expounds on the retail project threshold, suggesting that stores serving a local clientele, rather than drawing regional clientele (as would, say, an auto mall or regional shopping center), "add retail opportunities to the urban fabric and thereby improve retail destination proximity" and thus "shorten trips and reduce VMT" (OPR, 2016). The technical advisory defers to lead agencies to be "in the best position to decide when a project will likely be local serving," though it offers that locally-serving stores may generally be less than 50,000 square feet (OPR, 2016). If retail stores exceed 50,000 square feet, then "lead agencies should undertake an analysis to determine whether the project might increase or decrease VMT" (OPR, 2016).

[1] "Development near transit" includes projects "proposed within ½ mile of an existing rail transit station, a ferry terminal served by either a bus or rail transit service, or the intersection of two or more major bus routes with a frequency of service interval of 15 min or less during the morning and afternoon peak commute periods" (California Public Resources Code § 21064.3).

Academic literature supports the recommended retail threshold in the 2016 technical advisory. Lovejoy, Sciara, Salon, Handy, and Mokhtarian (2013) performed a quasi-experimental before-and-after study of the first "big box" store in Davis, California. They found that overall shopping VMT of survey respondents decreased by 20% after the project opened, due primarily to shoppers choosing the closer shopping option than was previously available. Handy and Clifton (2001) found more complex results from a survey of residents of several neighborhoods in Austin, Texas. Their results showed that local retail options produced minimal overall reductions in auto use, as residents "chose more distant stores enough of the time that they increase total driving significantly." However, Handy and Clifton also found that the respondents' usual mode of travel to local stores is "strongly correlated with their distance to local stores" – fewer people walk or bike to the grocery store when it is farther away. And, "most of the walks to stores did in fact appear to substitute for driving," which is an important point for policy and GHG emission targets (Handy & Clifton, 2001). A permissive threshold for locally-serving retail would likely decrease net VMT and thus GHG emissions: "if residents are given the opportunity to walk to the store, they will at least sometimes choose to walk rather than drive" (Handy & Clifton, 2001).

We analyze project-specific VMT for the project components that do not meet the screening criteria. We analyze each component (residential, employment, retail) in each available VMT estimation model and compare the results to relevant thresholds. We use the residential, employment, and retail thresholds recommended in the 2016 SB 743 technical advisory: 85% of regional household VMT per capita, 85% of regional commute VMT per employee, and locally serving retail, respectively. By comparing project-specific VMT to its appropriate threshold, we make significance presumptions for each project.

3. Findings & discussion

In our analysis, the two performance metrics lead to very different conclusions about significant transportation impacts that result from the three case study projects. The differences in significant impacts also point to substantially different mitigations strategies. We summarize and compare these differences by project.

3.1. The Cannery

The EIR for the Cannery identifies six impacts to transportation, three of which are LOS-related (City of Davis, 2013). One LOS-related impact is identified as "significant" and one as "potentially significant" if not mitigated. The three impacts not related to LOS are "less than significant". The Cannery's LOS-related impacts and mitigations are summarized in Table 3.

The Cannery's most significant LOS impact is at an intersection with the driveway of a nearby shopping center (see Fig. 1). Measures to mitigate decreased LOS include restricting automobile turning movements, construction of a median island for two-stage left-hand turns, and installation of two traffic signals. Regardless, LOS impacts to this intersection remain significant and unavoidable after mitigation. Cumulative LOS impacts from the Cannery and other planned projects are potentially significant; however, the installation of four traffic signals and lane reconfigurations mitigate the cumulative LOS impacts to less than significant.

Table 4 summarizes the VMT-based screening thresholds applicable to the Cannery, using data from the 2010 run of the CSTDM. The TAZ in which the Cannery is currently located is based on its previous agricultural and industrial use as a canning facility. Its TAZ covers unincorporated county that is nearly entirely active agriculture and stretches north to Woodland's city boundary. Upon build-out, the Cannery will operate similarly to the Davis neighborhoods that are immediately adjacent and will almost certainly be incorporated into its adjacent TAZ. Thus we use VMT data for the TAZ immediately to the west of the

Table 3
Cannery LOS-related impacts and mitigations.

Impact & significance	Mitigation measures
3.14–1. Project implementation would result in a significant [LOS] impact at the unsignalized Covell Boulevard/Oak Tree Plaza Driveway Intersection. Significant without mitigation. Significant and unavoidable after mitigation.	1A Prohibit outbound left-turns 1B Construct refuge island in median of Covell Boulevard to enable outbound left turns to merge more easily 1C Install traffic signal at Covell & Oak Tree Plaza Driveway 1D Install traffic signal at Covell & L Street. Operate traffic signals to create more gaps in traffic for outbound left-turns from Oak Tree Plaza 1E Modify permitted turn movements into driveway serving Oak Tree Plaza 1F Accept LOS F
3.14–2. Under cumulative conditions, project implementation would worsen already unacceptable levels of service at study intersections. Potentially significant without mitigation. Less than significant after mitigation.	Contribute fair share funding to cover proportionate cost of the following intersection improvements: • Install traffic signal and dedicated left-turn pocket at 8th & J Streets • Install traffic signal and reconfigure lanes at Pole Line Road & Picasso Avenue • Install traffic signal and reconfigure lanes at Pole Line Road & Moore Boulevard • Install traffic signal and reconfigure lanes at Covell Boulevard & L Street, and add a dedicated right-turn lane. Add second left-turn lane if Covell Village (future project) developed as Light Industrial
3.14–6. Construction traffic may cause significant intersection impacts. Less than significant.	No mitigation required.

Table 4
VMT screening thresholds for the Cannery.

	Threshold	Cannery	Significance presumption
Near transit	Within ½ mile of rail or frequent bus service	Not near transit	Not LTS
Low-VMT residential area – Household VMT per capita	11.2[1]	9.9[2]	Less than significant
Low-VMT office area – Commute VMT per employee	12.4[1]	15.2[2]	Not LTS – Further analysis required
Retail	Locally-serving	Locally-serving	Less than significant

LTS = less than significant.
[1] 85% of regional average from 2010 CSTDM data.
[2] TAZ average from 2010 CSTDM Data.

Cannery for screening analysis.

Per the screening thresholds, the residential and retail components of the Cannery would be presumed to have "less than significant" impacts on VMT and would thus require no further analysis. The office component cannot be presumed to have less than significant VMT impacts, so we estimate VMT from the offices in the Cannery. Table 5 shows office-generated VMT estimates and compares it to 85% of regional average commute VMT per capita.

Not every VMT estimation method can be used for setting thresholds, nor can every method be used for every component of the Cannery's land use mix. Neither CalEEMod nor MXD can be used to set VMT thresholds; however, the technical advisory suggests use of CSTDM data for thresholds and for average trip lengths in each method. Sketch7 and GreenTrip Connect calculate the regional average household VMT per capita, but the aggregated VMT cannot be used to evaluate the individual components of projects (e.g. residential, office, retail). Similarly for MXD, we cannot separate commute VMT from total VMT outputs, so we cannot compare its results to the recommended thresholds. Table 5 shows these omissions.

Analysis of the Cannery's office-generated VMT shows that it may be presumed to have significant VMT impacts. Like significant LOS impacts, VMT impacts can be mitigated to lessen the severity of impacts. Some characteristics inherent to the Cannery's office component – like adding jobs to a housing-rich community (thus increasing the jobs-housing balance) – could reduce commute VMT. The Cannery's office-generated VMT would require an aggressive 45% reduction to fall below the threshold, so it is likely that the office VMT impacts would be presumed to be "significant and unavoidable" after mitigation, as were the LOS impacts at the intersection of Covell Boulevard and the Oak Tree Plaza driveway.

Table 5
Commute VMT per employee from Office Component of Cannery.

	Threshold	Cannery	Significant presumption
CalEEMod	12.4[1]	22.4	Significant without mitigation
GreenTrip Connect	–	–	–
MXD	12.4[1]	–	–
Sketch7	–	–	–

[1] 85% of regional average commute VMT per employee from 2010 CSTDM data.

3.2. Nishi Gateway

The EIR for the Nishi Gateway identifies ten transportation impacts; five are LOS-related (City of Davis, 2015). Of the five LOS-related impacts, three are identified as significant without mitigation, and two are significant and unavoidable after mitigation. The LOS-related impacts and associated mitigation measures are summarized in Table 6.

Two of the LOS impacts from the Nishi Gateway are significant and unavoidable, even after mitigation. These impacts increase vehicle delay at surrounding local intersections and at the Interstate 80-Richards Boulevard interchange (see Fig. 1). The EIR identifies substantial and costly mitigation measures for these impacts, notably the realignment and widening of roadways at the Interstate 80 interchange that serves downtown Davis. Mitigation also includes the construction of a protected bicycle facility over Interstate 80 to connect south Davis to downtown.

VMT impacts for Nishi Gateway are unique because, unlike the Cannery, the Nishi Gateway is within a half-mile of the Davis Amtrak station. This proximity qualifies the project as "near transit", and it can be presumed to generate less than significant VMT, requiring no further VMT analysis nor mitigation (Table 7).

Table 6
Nishi Gateway LOS-related impacts & mitigations.

Impact & significance	Mitigation measures
4.14-1. The addition of project-related traffic would increase delay at local intersections outside freeway interchange areas. Significant without mitigation. Significant and unavoidable after mitigation.	4.14-1. Project applicant shall fund the design and construction of modifications to the single-lane roundabout at the intersection of Old Davis & La Rue Road. Modifications shall consist of constructing a right-turn bypass lane from southbound La Rue to westbound Old Davis Road.
4.14-2. The additional of project-related traffic would increase delay at local intersections within the Richards Boulevard Freeway Interchange Areas. Significant without mitigation. Significant and unavoidable after mitigation.	4.14-2. Conduct focused traffic assessment, or provide fair share contribution to roadway and intersection widening within the Richards Boulevard interchange area: • Widen south leg of Richards Boulevard to add second northbound left turn lane • Widen north leg of Richards Boulevard to add second southbound through/turn lane (widening of south leg may require some widening of the approach to the underpass) • Widen west leg of West Olive Drive to provide two westbound lanes and three eastbound lanes (left turn lane, through/right lane, right turn lane) • Place barriers in median to restrict driveway access between West Olive Drive and I-80 westbound ramps • Realign I-80 westbound ramps to eliminate the two loop ramps to provide a diamond ramp configuration and install traffic signal. Provide left turn lane and two right turn lanes on westbound off-ramp, two through lanes and right turn lane on southbound approach • Widen I-80 eastbound off-ramp to provide second left turn lane • Construct a separated cycle track on west side of Richards Boulevard from West Olive Drive to Research Park Drive.
4.14-3. Implementation of project would not contribute substantial traffic volumes to freeway segments in the area such that LOS of the freeway segments would be considered unacceptable. Less than significant.	No mitigation required.
4.14-4. While the project would increase daily trips to and from the project site, the project would not result in substantial increase in local residential street volumes. Less than significant.	No mitigation required.
4.14-7. During construction of the project, construction activities and temporary construction vehicle traffic would increase traffic congestion in the area. Significant without mitigation. Less than significant with mitigation.	4.14–7. Project applicant shall prepare a detailed Construction Traffic Control Plan.

A finding that the Nishi Gateway causes a less-than-significant VMT impact is substantially different than the significant and unavoidable impacts identified in the EIR's LOS analysis. The significant LOS impacts triggered extensive mitigation to improve traffic operations and decrease delay around the interstate. A high-density mixed-use project within the urban boundary (i.e. the Nishi Gateway) is the type of project California's climate policies attempt to promote, but costly mitigation measures like interchange reconfiguration hinder the state's efforts. For one thing, the costly mitigation measures may make the project financially infeasible in this location, potentially pushing development to areas with less traffic but also less potential for other travel modes. If the mitigation measures are implemented, they are likely to accommodate more traffic flow leading to an increase in VMT.

3.3. 2nd Street Crossing

The EIR for 2nd Street Crossing identifies ten transportation impacts; eight of them are LOS-related (City of Davis, 2006). Five of the eight LOS-based impacts are significant. One non-LOS-based impact (impacts to parking) is identified as significant. Table 8 summarizes the LOS-related impacts and mitigations.

All eight LOS impacts caused by 2nd Street Crossing are mitigated to be less than significant. Mitigation measures include installation and timing of one traffic signal (and potentially three more), reconfiguration and addition of automobile lanes, restriction of automobile movements, and installation of crosswalks and bicycle parking.

Two of the four VMT screening thresholds are applicable to the exclusively-retail 2nd Street Crossing (Table 9). The project is not located “near transit,” though it is considered locally-serving retail in the project's EIR. The retail opportunities planned for 2nd Street Crossing (primarily Target) duplicate those in several nearby communities. Its development would presumably shorten shopping trips, reducing VMT, and would thus have less than significant VMT impacts. Indeed, this concept is supported by the before-and-after study performed by Lovejoy et al. (2013). Because the retail project is locally-serving, no further VMT analysis and no mitigation would be required. This would relieve 2nd Street Crossing of installing up to four traffic signals required to mitigate LOS impacts.

4. Implications for practice

Quantifying VMT rather than LOS in project-level evaluation and

Table 7
VMT screening thresholds for Nishi Gateway.

	Threshold	Nishi Gateway	Significance presumption
Near transit	Within ½ mile of rail or frequent bus service	Near transit	Less than significant – No further analysis required
Low-VMT residential area – Household VMT per capita	11.2[1]	8.4[2]	Less than significant
Low-VMT office area – Commute VMT per employee	12.4[1]	15.7[2]	Not less than significant
Retail	Locally-serving	None	N/A

[1] 85% of regional average from 2010 CSTDM data.
[2] TAZ average from 2010 CSTDM Data.

Table 8
2nd Street Crossing LOS-related impacts & mitigations.

Impact & significance	Mitigation measures
4.3-1. Impacts related to increases in traffic as a result of the proposed project on 2nd Street/Faraday Avenue. Significant without mitigation. Less than significant with mitigation.	4.3-1. Applicant shall fully fund the design and installation of a traffic signal at 2nd Street/ Faraday Avenue. The intersection should have the following lane configuration: • Eastbound 2nd Street: One left-turn pocket; two through lanes • Westbound 2nd Street: One left turn pocket, one through lane; one right turn lane • Project Driveway: One left-turn lane, one shared through/right lane • Additional design features should include crosswalks; future transit stops should be located west of the intersection to avoid queueing that would back up in intersection.
4.3-2. Mace Boulevard Overcrossing Less than significant.	No mitigation required.
4.3-3. Impacts regarding the provision of efficient site access and circulation. Significant without mitigation. Less than significant with mitigation.	4.3-3. The following elements shall be incorporated into the site plan: • Add center strip and outbound Stop and Right-Turn Only signs to the northernmost driveway • Add center stripe and outbound Stop and Right-Turn Only signs to driveway south of northernmost driveway • At primary project driveway, stripe outbound portion of the driveway to provide separate left-turn and shared through/right lanes. Inbound portion should be striped for separate shared through/left and right-turn lanes. At internal intersection of the primary driveway and the primary north-south aisle, provide Stop signs on the northbound, southbound, and eastbound approaches. • At southernmost driveway on 2nd Street, provide center stripe, outbound Stop and Right-Turn Only signs. Median opening will be closed at this location. • Large Target delivery truck access routes should be defined in accordance with the primary (not 'alternate') entry and exit routes shown on page 4.3–67 of the DEIR. • Provide bicycle parking spaces near Target store and near each of the other four buildings
4.3-5. Impacts to traffic flow from construction traffic associated with grading and development of project site. Significant without mitigation. Less than significant with mitigation.	4.3-5. Project applicant shall prepare a Construction Traffic Management Plan.
4.3-7. Cumulative impacts regarding the deterioration of LOS of the 2nd Street/ Mace Boulevard intersection. Significant without mitigation. Less than significant with mitigation.	4.3-7 Prior to occupancy, applicant shall either (a) pay for a traffic operations analysis to support the development of a new optimized signal timing plan for 2nd Street/Mace Boulevard to restore LOS E, or (b) pay for the design and construction of a second northbound left turn lane to better accommodate the northbound left turn volume, and re-time the signal, to provide LOS D conditions in the Cumulative With Project case.
4.3-8. Cumulative impacts regarding the LOS at the intersections of 2nd Street/ Cantrill Drive, 2nd Street/Peña Drive, and 2nd Street/Cousteau Place. Significant without mitigation. Less than significant with mitigation.	4.3-8. The City of Davis shall monitor the intersections of 2nd Street/Cantrill, 2nd Street/ Peña, and 2nd Street/Cousteau to determine when and if signals should be installed based on a full warrant analysis. The City shall require a fair share payment of the cost of new signals from the applicant.
4.3-9. Impacts to Remainder Access Road. Less than significant.	No mitigation required.
4.3-10. Cumulative freeway mainline and ramp impacts. Less than significant.	No mitigation required.

CEQA review has many implications. Practically, our analysis shows that the available VMT quantification models have notable strengths and weaknesses. Some methods are simpler to implement "off-the-shelf" than others, such as GreenTrip Connect and CalEEMod. Others – namely Sketch7, and CalEEMod to run well – require baseline land use and VMT data, but can be run efficiently once those data are acquired. Some methods allow customization of inputs to reflect project contexts – CalEEMod's trip rates and trip lengths, for example – which can increase precision but also bias as well as burden on the analyst. However, simply using VMT quantification methods "off-the-shelf" with default values is unlikely to produce robust and defensible VMT estimates.

Analytically, we see from three case studies that the available VMT quantification methods estimate a wide range of project-generated VMT. These VMT estimation methods have not been validated with surveys or data, so we cannot say which is most accurate. Lovejoy et al.'s before-and-after study provides the rare empirical data to validate the analysis of 2nd Street Crossing; without similar studies of various types of projects in different contexts, we cannot say which of these methods is most accurate.

For the purposes of CEQA review, an important consideration regarding the use of VMT estimation models is the ability to compare

Table 9
VMT screening thresholds for 2nd Street Crossing.

	Threshold	2nd Street Crossing	Significance presumption
Near transit	Within ½ mile of rail or frequent bus service	Not near transit	Not less than significant
Low-VMT residential area – Household VMT per capita	11.2[1]	11.8[1]	N/A
Low-VMT office area – Commute VMT per employee	12.4[1]	16.0[1]	N/A
Retail	Locally-serving	Locally-serving	Less than significant – No further analysis required

[1] Regional and TAZ averages from 2010 CSTDM Data.

VMT results to a threshold (or generically, a baseline). Baselines – average VMT per capita, average VMT per household, et cetera – are critical for the formation of significance thresholds in CEQA review, and thus the determination of "significant" impacts. However, not all VMT estimation methods produce results that can be easily compared to a baseline. A baseline is ideally created from the same data and modeling method as the project-specific VMT estimate to ensure an "apples-to-apples" comparison between a chosen threshold and a measured impact. However, sketch-level models are explicitly created for project-level VMT assessment, rather than for calculating city- or region-wide averages. For example, analysts can find the average VMT for single-family homes in a given geography by multiplying the single-family trip generation rate by the average trip length in a model like CalEEMod or MXD. However, the city- or region-side housing stock is likely a mixture of single-family, apartments, duplexes, townhomes, et cetera. The average VMT per household would reflect a weighted average of this mixture, though calculating a weighted average for a city or region with a tool built for project-level assessment pushes the analytical limits of sketch models.

The ability to standardize VMT outputs is critical for use of project-level VMT in decision-making. Only a subset of models produces VMT estimates that are easily standardized (e.g. VMT per household or per employee) simply because of how the VMT estimates are reported. This is particularly the case for mixed-use projects, like the Cannery and Nishi Gateway, where a single project includes several different land uses (housing, employment, and retail). The output from some models (e.g. MXD) reports a singular project-level VMT without specifying the amount of VMT generated by each land use. If we simply divide total project VMT by the number of people or households, we overestimate household VMT by the amount of driving generated by the employment and retail uses. We thus cannot determine from models like MXD how the travel patterns of residents and employees in mixed-use developments would compare to average residents and employees in the region. However, a simple line-item report of total VMT by land use would allow calculation of VMT per household (and per capita or employee) and would solve this limitation.

Transportation efficiency – measured by VMT per unit (household, capita, employee, et cetera) – more closely aligns with state policies like AB 32 and SB 375 than an aggregate project-level VMT. AB 32 and SB 375 set increasingly stringent targets for statewide VMT per capita, while acknowledging that *total* statewide VMT will actually increase as the state's population grows. To implement California's state and regional VMT targets, the project-by-project CEQA process would demonstrate that the residents and employees of new developments generate less per capita VMT than their counterparts in existing homes and offices. Put simply, new residential and office projects are not expected to reduce *total* VMT in a community or region. Rather, new projects are expected to generate less VMT per person than the status quo by the efficiency of their location and design. However, this topic is ripe for future research. A new residential development may, in fact, be occupied by some residents moving from higher VMT areas in the region, rather than from outside the region, in which case total regional VMT may in fact decline. Study of travel behavior before and after moving to a new home (like the homes in the Cannery and Nishi) would allow for better understanding of the net effects of new land use developments.

The question and complexity of "whose VMT" is also important. Sketch methods are generally designed to estimate the project-specific ingress and egress of VMT, rather than projects' overall effect on VMT in the community or region. In the case of retail projects like 2nd Street Crossing, the new retail opportunity ostensibly redistributes existing household VMT rather than generating entirely new trips. However, VMT estimates from most sketch models are blind to the redistributive effect of new retail opportunities in the community; they output a VMT value based on traditional ITE trip generation rates used in LOS analysis to measure localized vehicle volumes. By this accounting, the retail VMT is estimated as new VMT and would theoretically be counted twice – once as part of household VMT and again for the retail project. It engenders an important research question as to the appropriate ways to attribute VMT to land use projects, industries, and even jurisdictions.

How VMT is allocated has implications for policy and GHG emissions. It creates incentive and disincentive for certain development types and locations via policies like SB 743 and SB 375. For example, locally-serving retail within an urbanized area is incentivized over more "attractive" regional retail projects when its system-wide VMT effects are considered, rather than accounting for impacts via the ingress and egress approach. Allocating VMT entirely to households may create disincentive for residential projects compared to employment and retail projects, particularly between jurisdictions. How VMT is allocated – which development and jurisdiction "owns" which VMT – is a policy question that has land use development implications and merits future research.

In addition to practical and policy considerations, replacing LOS with VMT within the CEQA process has implications for the built environment. In the short-term, we see from just three case studies that projects near transit and in low-VMT areas will benefit from a more streamlined CEQA process and fewer costly mitigation measures aimed at maintaining automobile flow rate. Streamlining and facilitating transit-oriented, low-VMT development corresponds with California's policy goals to reduce transportation GHG emissions via coordinated land use and transportation planning.

This is perhaps best illustrated by the case of the Nishi Gateway. The elimination of a costly, capacity-adding mitigation measure for a mixed-use infill project has quantifiable benefits. It streamlines the planning process and eases the financial burden of a project that adds housing to a housing-poor community. Rather than saddling infill development with the costs of easing auto congestion onto the Interstate – an externality of systemic undersupply of housing near employment – or locating employment opportunity away from its workforce, this policy shift creates a less burdensome CEQA process for a project that brings housing to employment-rich, highly-bikeable downtown core. This change is significant for creating more efficient land development patterns that provide a range of transportation options.

Mitigation for projects farther than a half-mile from transit and in high-VMT areas will also certainly change. Mitigating VMT impacts will require increasing accessibility and decreasing automobile demand, whereas mitigation of automobile delay has largely focused on optimizing traffic operations and increasing automobile capacity at specific intersections or roadway links (see Fig. 2). For example, all three case study projects required traffic signal timing and additional turn lanes as mitigation. But, some LOS mitigation strategies have focused on decreasing automobile demand, exemplified by the bicycle and pedestrian facilities required at 2nd Street Crossing. With a shift to VMT instead of LOS, we will likely see mitigations addressing travel distance to a variety of destinations (i.e. accessibility) in addition to mitigations addressing automobile demand (i.e. number of auto trips). We may see projects mix land uses (add housing to, say, an office or retail project) to increase accessibility, in addition to or instead of traditional travel demand strategies like installing bicycle facilities.

In fact, the Nishi Gateway EIR includes several mitigations to address the VMT impacts it identifies (per voluntary city policy, as Nishi Gateway went through CEQA review prior to SB 743). VMT mitigations for Nishi Gateway include bicycle and pedestrian infrastructure, transit infrastructure and incentives, parking pricing strategies, as well as the provision of on-site housing to employees of the commercial component of the project. These strategies not only decrease VMT (CARB, 2017), they can also mitigate congestion by decreasing the vehicle volumes that are loaded onto roadways. One of the many co-benefits of VMT reduction is that it "alleviates congestion in the specific locations where net vehicle travel is curtailed" (Fang & Volker, 2017), whereas traditional congestion mitigations facilitate vehicle speeds and volumes through roadway capacity increases. The VMT induced by increased

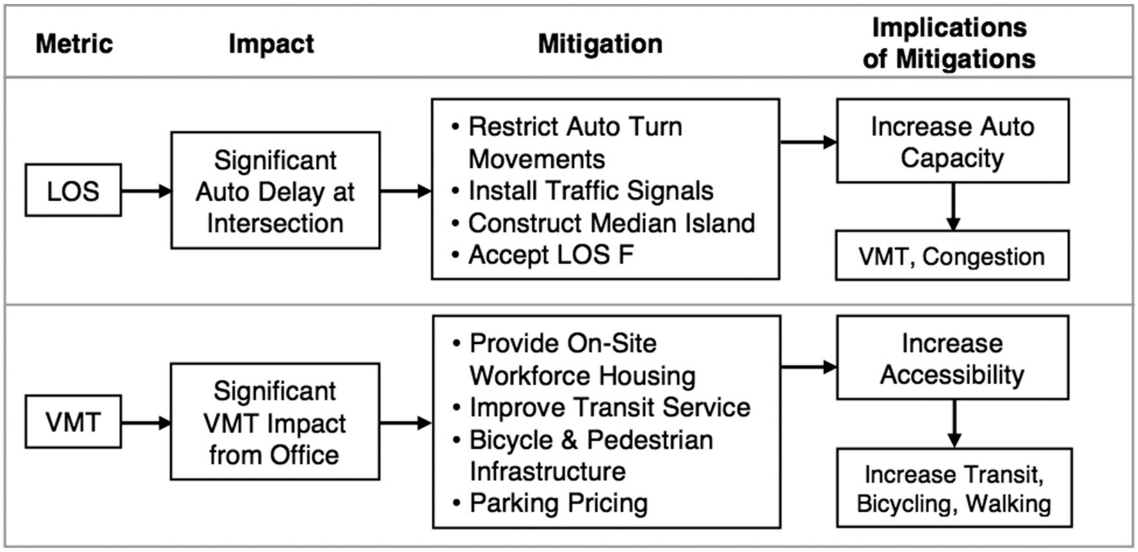

Fig. 2. Comparison of mitigations for the Cannery in Davis.

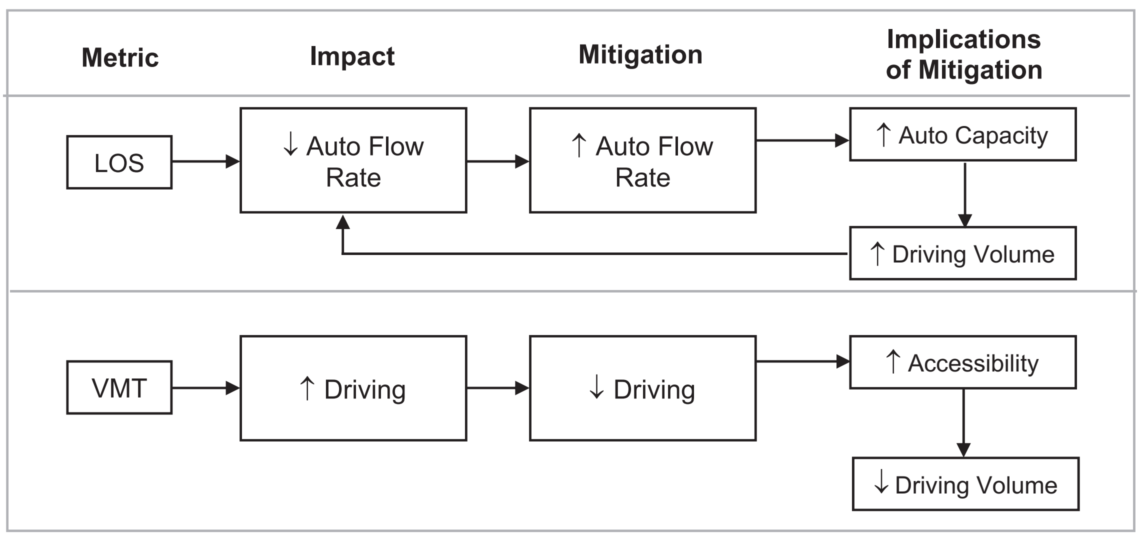

Fig. 3. Impacts, mitigations, and travel behavior – LOS versus VMT.

capacity ultimately causes congestion to rebound to pre-existing levels over the long term, negating the intent and short-term benefit of congestion relief (Downs, 2004; Duranton & Turner, 2011). Fig. 3 illustrates the interaction between LOS, VMT, mitigation measures, and induced travel.

A comparison of mitigation measures under these two metrics raises a fundamental question about what type of built environments communities want, and how they use the CEQA process to achieve them. Does Davis want more traffic signals and turn lanes? Will replacing LOS with VMT in CEQA facilitate – or make it more challenging – for communities to finance and construct the built environment they desire? General plans tell us the aspirations of the community, and the City of Davis has visions for its built environment that include (City of Davis, 2007):

- Foster a safe, sustainable, healthy, diverse, and stimulating environment for all in the community.
- Become a community where the impacts of traffic, noise, pollution, crime, and litter are minimized.
- Maintain Davis as a cohesive, compact, university-oriented city surrounded by and containing farmland, greenbelts, natural habitats, and natural resources.
- Reflect Davis' small town character in urban design that contributes to and enhances livability and social interaction.
- Maintain a strong, vital, pedestrian-oriented and dynamic downtown area
- Encourage carefully-planned, sensitively-designed infill and new development to a scale in keeping with the existing city character.
- Encourage a clean, quiet, safe, and attractive transportation system that harmonizes with the city's neighborhoods and enhances quality of life.
- Promote alternative transportation modes such as bicycling, walking, public transit, and telecommuting.

In many cases across these three projects, the goals of the General Plan are inconsistent with the built environment created by mitigating vehicle delay. The significant automobile delay that the Cannery causes at the intersection of the Oak Tree Plaza, for example, triggers the restriction of automobile turn movements, installation of traffic signals, construction of a median island, and the City Council accepting LOS F at this location (see Fig. 2). These measures attempt to maintain a certain vehicle flow rate around a community grocery store. This is perhaps in line with the goal of "minimizing traffic," but not in line with "encouraging a clean, quiet, safe, and attractive transportation system that harmonizes with the city's neighborhoods," nor do they "promote alternative transportation modes."

When we evaluate transportation impacts with VMT metrics, the Cannery causes significant impacts from the employees commuting to its offices. Potential VMT mitigations include the provision of on-site workforce housing (as was required of the Nishi Gateway), improvements to transit service, installation of active transportation infrastructure, and parking pricing. Each metric likely results in significant and unavoidable transportation impacts, but the alterations to the built environment to mitigate those impacts are drastically different. The VMT-related mitigations align closely with the General Plan's goals for the community – a "cohesive" and "compact" city, "enhance livability and social interaction" – whereas the capacity-increasing mitigations to combat vehicle delay may hamper them, and still result in auto delay (given that one LOS mitigation is to accept LOS F).

In the longer-term, researchers and planners should watch for changes in the types and locations of developments that are proposed. This shift in performance metric changes the incentives and disincentives to develop certain types of projects in certain areas. Where LOS analysis has favored projects and locations that can maintain "driver comfort and convenience" per the *Highway Capacity Manual*, VMT analysis incentivizes projects and locations that generate less driving. We will presumably see dense urban areas with well-mixed land uses and high-quality transit – areas with inherently high vehicle delay but often low VMT – become more attractive to developers as they prompt fewer transportation impacts and requisite mitigations.

5. Contribution to scholarly knowledge

Our analysis is one of the first academic comparisons of the use of LOS and VMT metrics in transportation impact assessment under the California Environmental Quality Act. Analysis of impacts and thresholds is important for understanding the short- and long-run incentives for different types and location of development. As SB 743 is implemented across California, and the concept is perhaps adopted elsewhere, longitudinal research will show how the use of VMT as a performance metric influences long-term planning and development decisions, how it incentivizes certain types of development decisions, and ultimately the types of communities that are built.

In the shorter term, we show the short-term influence that each metric has on communities via impact mitigations. Our analysis of LOS mitigation shows how the CEQA process per se impacts the built environment, often in ways that increase vehicle capacity and thus VMT (see Figs. 2 & 3). Over time, the VMT induced by mitigating LOS with capacity increases will cause further vehicle delay and trigger more LOS impacts. Breaking the congestion-capacity-congestion cycle requires addressing the demand for travel, which is inextricably linked with the accessibility provided by land development patterns (Fig. 3).

We further show that under its current framework of SB 743, expensive capacity-increasing mitigation measures aimed at easing automobile congestion may be supplanted by streamlining for projects that reduce travel demand by locating near transit or in low-VMT areas. Projects sited in urban cores near transit will enjoy an expeditious transportation impact analysis, as well as fewer mitigations to finance.

Finally, we show that the vehicle capacity constructed to mitigate LOS may contravene the goals and aspirations of many communities in California, as well as the state's goals for GHG reductions. Further investigation of LOS mitigation across a larger sample of projects and jurisdictions would shed light on the extent of vehicle capacity that has been built in the name of CEQA.

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References

California Air Pollution Control Officers Association (CAPCOA) (2013). California Emissions Estimator Model (CalEEMod). http://www.caleemod.com.

California Air Resources Board (2017). Senate Bill 375 – research on impacts of transportation and land use-related policies. arb.ca.gov/cc/sb375/policies/policies.htm.

California Code of Regulations Title 14 Natural Resources, Division 6 Resources Agency, Chapter 3 Guidelines for Implementation of the California Environmental Quality Act (§ 15000–§15387). https://govt.westlaw.com/calregs/Browse/Home/California/CaliforniaCodeofRegulations?guid=I95DAAA70D48811DEBC02831C6D6C108E&originationContext=documenttoc&transitionType=Default&contextData=(sc.Default).

California Department of Transportation (Caltrans) Office of Multi-Modal Planning (2014). California Statewide Travel Demand Model 2.0. dot.ca.gov/hq/tpp/offices/omsp/VMT_Analysis_2015_11_19.xlsx.

California Public Resources Code Division 13: Environmental Quality (§ 21000 - §21189.57). https://leginfo.legislature.ca.gov/faces/codes_displayexpandedbranch.xhtml?tocCode=PRC&division=13.&title=&part=&chapter=&article.

Castiglione, J., Freedman, J., & Bradley, M. (2003). Systematic investigation of variability due to random simulation error in an activity-based microsimulation forecasting model. *Transportation Research Record: Journal of the Transportation Research Board, 1831*, 76–88.

Cervero, R. (2003). Road expansion, urban growth, and induce travel: A path analysis. *Journal of the American Planning Association, 69*(2), 145–163.

Cervero, R. (2006). Alternative approaches to modeling the travel-demand impacts of smart growth. *Journal of the American Planning Association, 72*(3), 285–295.

Cervero, R., & Arrington, G. B. (2008). Vehicle trip reduction impacts of transit-oriented housing. *Journal of Public Transportation, 11*(3).

City of Davis (2006). Draft environmental impact report – Second street crossing (target store) project. community-development.cityofdavis.org/Media/Default/Documents/PDF/CDD/Planning/Special-Projects/Target-Store/Environmental-Review/Environmental-Impact-Report/04d-Transportation-and-Circulation.pdf.

City of Davis (2007). City of Davis general plan – Amended 2007. cityofdavis.org/city-hall/community-development-and-sustainability/planning-and-zoning/general-plan.

City of Davis (2013). Draft environmental impact report – Cannery Park. cityofdavis.org/city-hall/community-development-and-sustainability/development-projects/the-cannery/environmental-review.

City of Davis (2015). Nishi gateway project – Draft environmental impact report. http://cityofdavis.org/city-hall/community-development-and-sustainability/development-projects/nishi-and-downtown-university-gateway-district/environmental-review.

City of Oakland Planning Commission (2016). Modification of CEQA thresholds of significance guidelines. *Staff report for September 21, 2016 hearing*www2.oaklandnet.com/government/o/PBN/OurOrganization/PlanningZoning/o/Commissions/OAK062917.

City of Orange v. Valenti (1974). *37 Cal. App. 3rd 240*.

City of Pasadena Department of Transportation (2015). Transportation impact analysis current practice & guidelines. ww5.cityofpasadena.net/transportation/wp-content/uploads/sites/6/2015/12/Current-Practice-and-Guidelines.pdf.

Clifton, K., Currans, K., & Muhs, C. (2013). Evolving ITE trip generation handbook: Proposal for collecting multimodal, multicontext, establishment-level data. *Transportation Research Record: Journal of the Transportation Research Board, 2344*, 107–117.

Clifton, K. K., Currans, K. M., & Muhs, C. (2015). Adjusting ITE's trip generation handbook for urban context. *Journal of Transport and Land Use, 8*(1), 5–29.

Currans, K. M., & Clifton, K. (2015). Using household travel surveys to adjust ITE trip generation rates. *Journal of Transport and Land Use, 8*(1), 85–119.

Downs, A. (1962). The law of peak-hour expressway congestion. *Traffic Quarterly, 16*(3).

Downs, A. (1992). *Stuck in traffic*. Washington, DC: The Brookings Institution.

Downs, A. (2004). Why traffic congestion is here to stay … and will get worse. *Access Magazine, 25*, 19–25.

Duranton, G., & Turner, M. (2011). The fundamental law of road congestion: Evidence from US cities. *American Economic Review, 101*, 2616–2652.

Ewing, R., & Cervero, R. (2010). Travel and the built environment. *Journal of the American Planning Association, 76*(3), 265–294.

Fang, K., & Volker, J. (2017). *Cutting greenhouse gas emissions is only the beginning: A literature review of the co-benefits of reducing vehicle miles traveled.* National Center for Sustainable Transportationncst.ucdavis.edu/wp-content/uploads/2017/03/NCST-White-Paper-VMT-CoBenefits-White-Paper-LP_EB.pdf.

Federal Highway Administration (1987). Technical advisory 6640.8A: Guidance for preparing and processing environmental and section 4(f) documents. environment.fhwa.dot.gov/projdev/impTA6640.asp#back.

Fulton, W., & Shigley, P. (2012). *Guide to California planning* (4th Edition). Point Arena: Solano Press Books179.

Governor's Office of Planning and Research (2016). Revised proposal on updates to the CEQA guidelines on evaluating transportation impacts in CEQA: Implementing senate bill 743 (Steinberg, 2013). opr.ca.gov/docs/Revised_VMT_CEQA_Guidelines_Proposal_January_20_2016.pdf.

Handy, S. (2005). Smart growth and the transportation-land use connection: What does the research tell us? *International Regional Science Review, 28*(2), 146–167.

Handy, S., & Clifton, K. (2001). Local shopping as a strategy for reducing automobile travel. *Transportation, 28*(4), 317–346.

Handy, S., Shafizadeh, K., & Schneider, R. (2013). Final report: California smart-growth trip estimation study. University of California. Davis for the California Department of Transportationdownloads.ice.ucdavis.edu/ultrans/smartgrowthtripgen/Final_Report.pdf.

Highway Research Board of the Division of Engineering and Industrial Research (1965). *Highway capacity manual 1965.* Washington, DC: National Academy of Sciences – National Research Council.

Institution of Transportation Engineers (ITE) (2012). *Trip generation handbook* (9th Edition). Institute of Transportation Engineers.

ITE (2004, June). *Trip Generation Handbook* (2nd ed.). 15.

Lee, A., Fang, K., & Handy, S. (2017). *Evaluation of sketch-level vehicle miles traveled quantification tools.* National Center for Sustainable Transportationncst.ucdavis.edu/wp-content/uploads/2017/06/NCST-SGC_Handy-VMT-Quant_Final-Report-AUGUST-2017.pdf.

Lovejoy, K., Sciara, G. C., Salon, D., Handy, S., & Mokhtarian, P. (2013). Measuring the impacts of local land-use policies on vehicles miles of travel: The case of the first big-box store in Davis, California. *The Journal of Transport and Land Use, 6*(1), 25–39.

Newmark, G., Haas, P., Pappas, J., Schwartz, M., Kenyon, A., & Unit, M. O. (2015). Income, location efficiency, and VMT: Affordable housing as a climate strategy. *Center for neighborhood technology working paper, produced for the california housing partnership*.

Newmark, G. L., & Haas, P. M. (2016). Does the vehicle-miles traveled associated with location efficiency vary by income group? *Transportation Research Board 95th Annual Meeting (No. 16-4242)*.

Roess, R. P. (1984). Level of service concepts: Development, philosophies, and implications. *Transportation Research Record: Journal of the Transportation Research Board, 971*, 1–6.

Rothman, L. D. (2011). CEQA turns forty: The more things change, the more they remain the same. *Environmental Law News, 20*(1) (Winter 2011).

San Francisco Planning Department (2016). Executive summary: Resolution modifying transportation impact analysis. commissions.sfplanning.org/cpcpackets/Align-CPC%20exec%20summary_20160303_Final.pdf.

Schneider, R. J., Shafizadeh, K., & Handy, S. L. (2015). Method to adjust Institute of Transportation Engineers vehicle trip-generation estimates in smart-growth areas. *Journal of Transport and Land Use, 8*(1), 69–83.

Senate bill no. 743. *California State Senate*https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201320140SB743.

Shafizadeh, K., Lee, R., Niemeier, D., Parker, T., & Handy, S. (2012). Evaluation of operation and accuracy of available smart growth trip generation methodologies for use in California. *Transportation Research Record: Journal of the Transportation Research Board, 2307*, 120–131.

Virginia Department of Transportation (VDOT) (2015). HB2 implementation policy guide. vasmartscale.org/documents/hb2policyguide_8-1-2015.pdf.

Walters, J., Bochner, B., & Ewing, R. (2013). *Getting trip generation right: Eliminating the bias against mixed-use development.* American Planning Associationasap.fehrandpeers.com/wp-content/uploads/2016/03/APA_PAS_May2013_GettingTripGenRight-2.pdf.

Zhao, Y., & Kockelman, K. M. (2002). The propagation of uncertainty through travel demand models: An exploratory analysis. *The Annals of Regional Science, 36*(1), 145–163.