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Methodology to Evaluate Active Transportation and Demand Management Strategies

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Abstract

This paper describes a methodology for predicting the impacts of active transportation and demand management (ATDM) measures on highway performance that can be applied using either microsimulation or Highway Capacity Manual (HCM) analysis techniques.
Active transportation and demand management (ATDM) is a comprehensive approach to facility management and operation that seeks to increase facility productivity by proactively balancing supply and demand to avoid or delay facility breakdown. Examples of ATDM measures include: adaptive ramp metering, congestion pricing, speed harmonization, traveler information systems, and adaptive traffic signal control systems. Incident management and work zone management programs may employ one or more of these ATDM measures.
The proposed ATDM analysis methodology is employed as a "wrapper" to a "core" analysis tool, such as the HCM or microsimulation. The core analysis tool is applied several times to a set of demand/capacity scenarios. The demand/capacity scenarios are developed based on observations of annual fluctuations in weekday peak period demands and capacities for the facility. The scenario results are then combined according to their probability of occurrence in order to predict the full-year peak period performance of the street, highway, or freeway facility.
The application of the methodology is illustrated on a real-world freeway facility. The Highway Capacity Manual FREEVAL procedure, the selected "core" analysis tool, was adapted to test ramp metering, HOV (High Occupancy Vehicle) lanes, and HOT (High Occupancy Toll) lanes within the ATDM evaluation methodology. FREEVAL was applied to each of several demand/capacity scenarios and the results combined into an estimate of average performance improvements for each ATDM measure. The predicted facility performance improvements were compared to a before/after field studies reported in the literature.

Keywords: Active Traffic Management, Advanced Traffic Management, Travel Time Reliability

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1. Introduction

This paper describes a methodology for predicting the impacts of active transportation and demand management (ATDM) measures on highway performance. This methodology can be applied using either microsimulation or Highway Capacity Manual (HCM) analysis techniques [i].

Active transportation and demand management (ATDM) is a comprehensive approach to facility management and operation that seeks to increase facility productivity by proactively balancing supply and demand to avoid or delay facility breakdown. Examples of ATDM measures include: adaptive ramp metering, congestion pricing, speed harmonization, traveler information systems, and adaptive traffic signal control systems. Incident management and work zone management programs may employ one or more ATDM measures.

The objective of ATDM is to improve the reliability of facility performance through the dynamic tailoring of demand to better fit the available capacity of the facility. Traditional static analysis methods, such as the Highway Capacity Manual (HCM), are ill suited to capture changes in reliability. Similarly, microsimulation models, although they have a stochastic component, do not capture reliability well, because their stochasticity is related to uncertainty in the modeling of driver behavior rather than day to day variations in demand and capacity due to incidents. Finally, HCM and microsimulation methods generally do not model well the effects of ATDM on demand. They specifically do not model the demand effects of facility performance improvements (induced demand).

The ATDM analysis methodology consequently is designed to be employed as a “wrapper” to a “core” analysis tool, such as the HCM or microsimulation. The core analysis tool provides the accurate estimate of facility performance, while the “wrapper” provides the evaluation of demand and reliability changes that the core tool cannot. The ATDM evaluation methodology works by applying the core analysis tool several times to a set of demand/capacity scenarios. The demand/capacity scenarios are developed based on observations or estimates of annual fluctuations in weekday peak period demands and capacities for the facility. The scenario results are then combined according to their probability of occurrence in order to predict the full-year peak period performance of the street, highway, or freeway facility.

2. State Of the art

Active traffic management (ATM) is a relatively recent refinement of the more general topic of Intelligent Transportation Systems (ITS). The objective of ATM is to monitor system performance in real time and proactively control the system so as to postpone or avoid breakdown (congested) conditions [ii]. The development of value pricing or congestion management technology has enabled the consideration of demand management as well as management of system operations (see DeCorla Souza [iii]). The importance of demand management to the success of ATM has been recognized with the recent coining of the term Active Transportation and Demand Management (ATDM).

The Year 2010 Highway Capacity Manual provides some preliminary information on the known effects of ATDM measures on facility performance and operation. However, practical experience with the more advanced ATDM measures is still relatively limited in the United States. The lack of ATDM installations in the US has also limited the development and validation of analytical tools for evaluating ATDM.

Researchers attempting to predict the impacts of the more operational oriented strategies of ATDM (e.g. ramp metering and variable speed limits) have generally relied on microsimulation models (see Toledo [iv], and Tian [v] for example) and have not dealt with demand effects beyond peak spreading and possibly route choice. Researchers focusing on the more demand oriented strategies of ATDM (e.g. congestion or value pricing) have relied on sketch planning models, elasticities, or components of travel demand models (see Kirshhner [vi] or DeCorla-Souza [vii]) with relatively little analytical detail devoted to the traffic operations effects of the measures.

This paper presents a proposed methodology for evaluating both the demand and operational impacts of ATDM measures using relatively detailed operational analysis tools in combination with sketch planning demand forecasting tools to provide a more complete assessment of demand, travel time, and reliability effects of ATDM.

3. Methodology

The ATDM evaluation methodology is designed to be applied in the same context as traditional HCM analyses: facility level planning studies, preliminary engineering, environmental impact analyses, design alternatives analysis, and interchange modification analyses. Analysts would be able to compare the performance of ATDM measures to traditional capacity expansion.

The methodology is intended to help analysts answer the following questions:

- How much can I improve facility performance by implementing more aggressive ATDM strategies?
- How much additional vehicle and person throughput can I achieve for a given facility through the application of aggressive ATDM strategies?
- Which combination of ATDM strategies and at what levels produce a target quality of performance for a facility? (will require multiple applications of methodology)

An overview of the analysis framework is given in Figure 1.

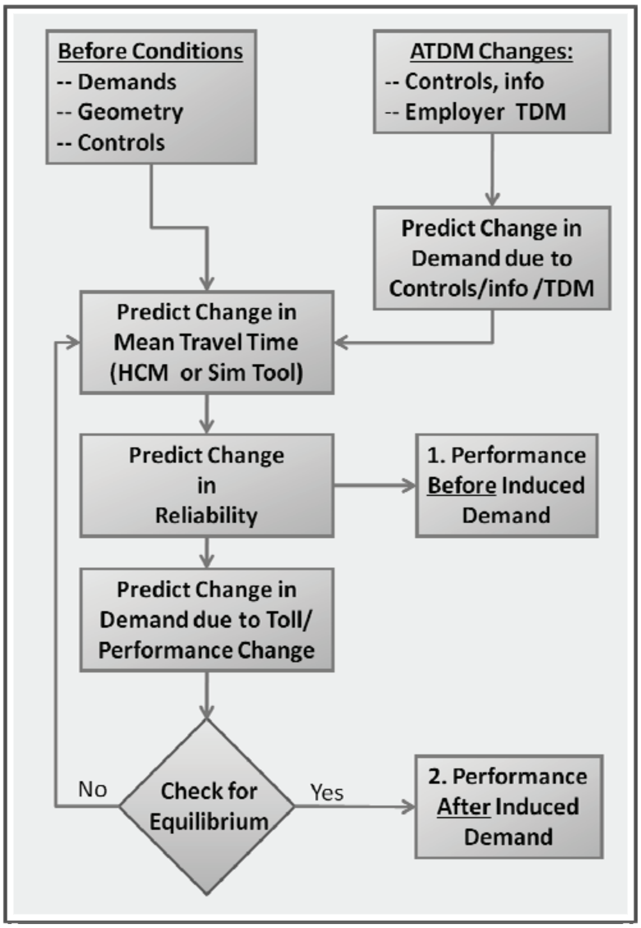

Figure 1: The ATDM Methodology

The proposed methodology is, like the HCM, facility oriented. The analyst inputs changes in the ATDM measures on the facility (the analyst can also input demand changes due to off-facility measures). The methodology is used to compute the impacts of these changes on mean facility travel time, facility travel time reliability, and facility demand. From these outputs the analyst can compute traditional supplemental HCM performance measures, such as, queues, speed, and delay.

Two outputs are produced by the methodology. An intermediate output is provided after the facility performance improvements with ATDM have been computed. The second, and final output shows the facility performance improvement after the demand effects of the improved facility performance have been accounted for.

The steps of the ATDM evaluation procedure are as follows:

1. The analyst inputs the starting conditions including the starting level of implementation of ATDM strategies.
2. The analyst then inputs the change in ATDM facility control strategies that he or she wishes to test.
3. The procedure estimates the change in demands directly associated with the change in controls, traveler information, and employer based TDM measures.
4. The procedure then estimates the change in mean travel time (holding demand fixed). It is this step where the "core" analysis tool is applied.
5. The procedure then computes the change in travel time reliability based on the predicted change in mean travel time (again holding demand fixed. At the end of this step Output #1 is produced, "Performance Before Demand Inducement".
6. The procedure then estimates the change in demand caused by changes in facility travel times, costs (tolls), and travel time reliability (changes in the cost of travel on the facility).
7. The procedure then checks to see if the initial and final section demands on the facility are in equilibrium. If not, then the procedure equilibrates until equilibrium is achieved. The result of this step is Output #2, Performance After Induced Demand.

4. Example application

The details of the methodology are best explained through an example application. This example describes the application of the ATDM methodology to evaluating the impacts of ramp metering, HOV (High Occupancy Vehicle) lanes, and HOT (High Occupancy Toll) lanes on a 4.5 mile stretch of the I-580 freeway in Alameda County, California. The methodology was also applied to a second test site on I-15 freeway in San Diego County, California. This second test site is not described in detail in this paper, however; the results of this second test site are included in the validation results cited in this paper.

4.1. Study section and time period

The selected study section is a 4.5 mile section of westbound I-580 freeway covering three interchanges (see Figure 2). The study section was selected to span the bottleneck that exists between Tassajara Road and Hacienda Drive. A hypothetical segment was added upstream of Fallon Road to store the anticipated queues that would back up from the bottleneck. A five hour AM peak analysis period (5 AM to 10 AM) was selected to bound the beginning and end of congestion on the freeway.

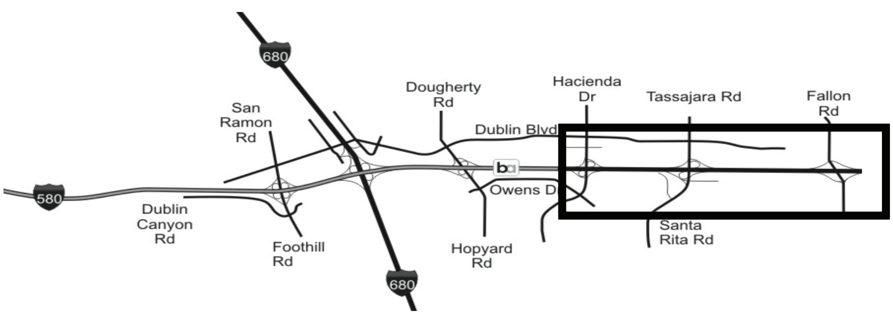

Figure 2: Alameda I-580 Study Site

4.2. Selection and calibration of core analysis tool

The 2010 Highway Capacity Manual FREEVAL spreadsheet program for evaluating freeway facilities was selected as the analysis tool for the ATDM analysis. It has the ability to evaluate freeway performance over multiple subsections for an entire peak period. The spreadsheet format of the software also meant that the program could be easily extended to interface with the proposed ATDM evaluation methodology.

The FREEVAL model was calibrated to field data (volumes and travel times) gathered for the AM peak period of May 13, 2008. Calibration was achieved by adjusting the section capacities until the observed queue formation and dissipation matched observed conditions in the field. The capacity adjustments ranged from -17% to +12% of the default FREEVAL/HCM computed capacity for 8 critical subsections of the facility. The model was considered calibrated when the computed end-to-end speed for the facility for each hour was within 10% of the observed mean vehicle speed for toll tag equipped vehicles using the facility. The calibrated FREEVAL model predicted average peak period speed for the facility within 3% of the observed value.

For comparison purposes, a parallel analysis of the ATDM measures was performed using the CORSIM [viii] microsimulation model as the "core analysis tool", in lieu of FREEVAL. CORSIM was calibrated to the same existing demands and travel times as FREEVAL.

4.3. Identification of demand/capacity scenarios

The selected study site had archived count, speed, and travel time data for a full year. However, since few sites will have such extensive data for measuring reliability, this example will illustrate a more typical application where data is gathered for 10 days and the results extrapolated to an assessment of full year performance.

Ramp and mainline counts were available for 3 sample days (May 13-15, 2008). Mainline counts, but no ramp counts, were available for an additional 7 weekdays.

One of the selected 10 sample days had to be discarded because an incident occurred downstream of the study section, backing up traffic into the study section. It was not practical to model the larger geographic area (either with the HCM method or microsimulation) that would have been required to fully contain the resulting congestion.

Two methods were considered for extrapolating the ramp counts to the full 9 day period. One method applied a single set of global adjustment factors (based on a single set of mainline detectors) to the ramp counts to obtain the other 7 days of ramp volumes. The second method developed ramp specific adjustment factors based on the nearest of 7 mainline detectors. Tests showed that applying the single set of global adjustment factors affected the predicted freeway mean travel time rate by less than 1% (while predictions of vehicle-hours of delay were within 4%), so the single adjustment factor method was used to extrapolate the ramp volumes to the additional days.

The counted volumes at one mainline detector location from the Caltrans PeMS database [ix] were compared with the base day of May 13th at the same location to find the ratio between the reported volumes for each 15-minute period. This ratio for each 15-minute period was then applied globally to all ramp volumes entries for that 15-minute period. This was repeated for each 15-minute period until all the volumes for each of the days were determined. This method accounts for changes in volume for each 15-minute period but does not adjust for variations among the ramp demands.

After determining the initial baseline volumes from mainline loop detector ratios, the final task was to calibrate each day to the mean end-to-end mainline travel time rate (TTR) reported by the toll tag readers, also from the Caltrans PeMS database. Capacities were left at the same values determined in the initial FREQ/FREEVAL calibration step. Each 15-minute period demand level was then adjusted until the TTR reported by FREEVAL matched that reported by toll tag readers. This method allowed for direct calibration to each sample day.

Each of the 9 sample days were completed using this method to obtain 9 scenarios where each 15-minute's TTR matches the real values reported by electronic toll tags for that day. The results (aggregated to peak period averages to facilitate their display) are shown in Figure 3.

With the calibration of 9 FREEVAL data sets for 9 AM peak period weekdays, the core analysis tool was then ready for testing of the ATDM measures.

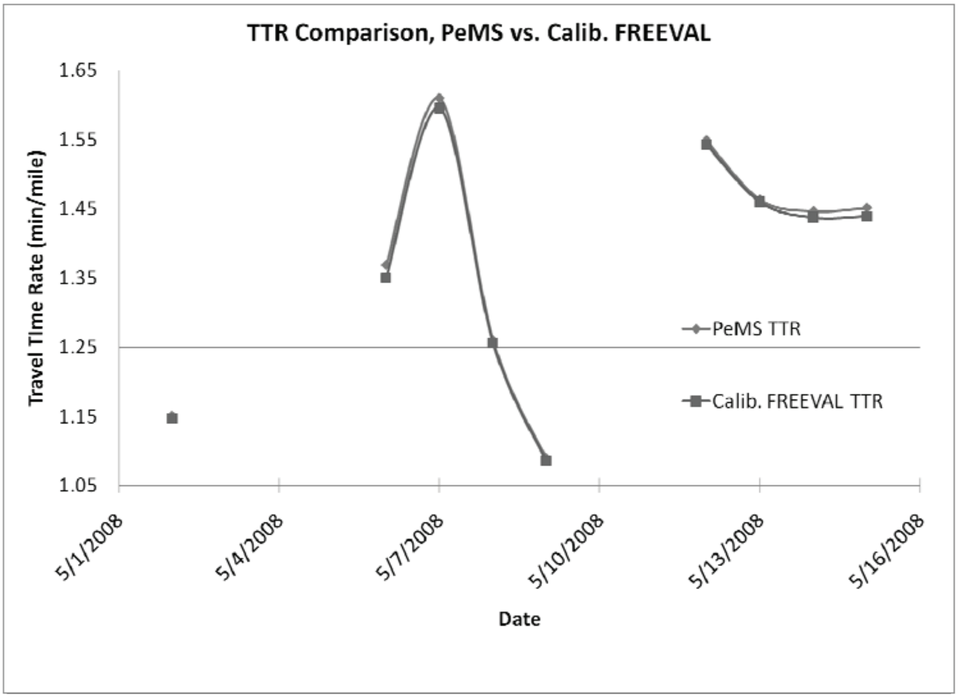

Figure 3: Calibration of FREEVAL to Observed Daily Peak Period Travel Times

4.4. Extension of FREEVAL to ramp metering, HOV lane, and HOT lane analysis

The FREEVAL spreadsheet that was developed for the 2010 Highway Capacity Manual is capable of evaluating fixed metering rates, but not HOV lanes or HOT lanes. Research is underway to add these capabilities to FREEVAL, but the results were not yet available at the time of preparation of this paper. Consequently, in the interim, the 2010 FREEVAL was manually adapted to illustrate the application of the ATDM methodology to HOV and HOT lanes, with the understanding that this core model can later be replaced with the final version coming out other concurrent research efforts.

4.4.1. Adaptations for ramp metering

A static, time of day metering plan, matching what was actually implemented at the study site in 2007, was coded in FREEVAL. The metering rates were set at 820 vph to match the field implementation. FREEVAL compares the on-ramp demand to the metering rate storing any excess demand to release in the following time slice. FREEVAL cannot model HOV bypass lanes on the metered on-ramps, however; in the field installation both HOV's and other vehicles are metered at the established metering rate. The HOV bypass lane on the on-ramps merely enables HOV's to wait in their own queue.

The mainline capacity effects of ramp metering were modeled by increasing by 3% the FREEVAL computed capacities of the mainline section immediately downstream of each metered on-ramp. (see FHWA [[x]], Zhang [[xi]], Cassidy [[xii]] for effects of ramp metering on merging capacity)

4.4.2. Adaptations for HOV lane

Two plus person occupancy HOV's currently account for 11% of the AM peak period traffic. Operations of the HOV lane were assumed to be continuous for the duration of the AM peak. The HOV lane was tested as a limited access facility with three 1,500 long access points located between the off and on-ramps at each interchange.

Ninety-five percent of the eligible HOV's at each on-ramp were assumed to access the HOV lane and the next downstream access point. Ninety-five percent of the eligible HOV's at each off-ramp were assumed to exit the HOV lane at the first upstream access point closest to the off-ramp. A further 5% of the vehicles in the HOV lane were assumed to be violators with the same entry and exit patterns as the HOV's.

Access to and from the HOV lane was coded in FREEVAL as a left hand on-ramp going from HOV to the mainline, followed 1500 feet later by a left hand off-ramp going from the mainline to the HOV lane.

The HOV lane was not explicitly coded in FREEVAL, but given the low maximum HOV volume of 1200 vehicles per hour for the highest D/C ratio scenario. The HOV lane was assumed to be free-flowing for all scenarios. Weaving effects within the HOV lane at the access points were neglected.

4.4.3. Adaptations for HOT lane

The HOT lane was assumed to have the same access points as the HOV lane. A dynamic tolling policy was assumed to be in place to keep an average of 1650 total vehicles per hour (mix of HOV's and toll paying vehicles) in each section of the HOT lane. The number of vehicles entering the HOT lane at each access point was assumed to be proportional to the ratio of the on-ramp volume to the mainline volume for the immediately upstream on-ramp. A similar approach was used to compute the HOT lane exiting volume at each access point.

The HOT lane was not explicitly coded in FREEVAL, on the assumption that operations would be relatively free-flowing at 1650 vph. Weaving effects within the HOT lane at the access points were neglected.

4.5. First pass demand adjustments

The first pass demand adjustment step modifies the "before" origin-destination (OD) demand table in direct response to any ATDM controls, such as ramp metering. This first pass adjustment excludes the effects on facility demand of facility travel cost changes (e.g. travel time, delay, and tolls) which will be handled in the second pass, induced (or reduced) demand analysis step later. For the example ATDM measures being studied; only the ramp metering will have a "first pass" effect on demand by flattening the peaks in demand at each ramp, and deferring the stored demand to a later time slice.

Any off-facility ATDM demand adjustments, such as the effects of an area-wide employer based transportation demand management program, or an area-wide toll would be applied at this step.

4.6. Computation of mean travel time

The FREEVAL (and CORSIM) reported end-to-end mainline travel times averaged over the peak period were then averaged across the 9 sample days to obtain the estimated mean average travel time rates (minutes per mile) for the facility before and after implementation of ATDM. The mean travel time results produced by the two core analysis tools applied across the 9 sample days are shown in Table 1.

4.7. Computation of travel time reliability

The travel time reliability is measured in terms of the 80th percentile highest end-to-end travel time for the facility. The following formula developed by the SHRP2-L03 project for urban freeways (see Margiotta [xiii]) is used to convert the mean travel time computed in the previous step into the 80th percentile travel time. Other equations are available in Margiotta for urban arterials and rural freeways.

$$80\%TTI = Mean\ TTI^{1.365} \qquad (2)$$

Where:

80% TTI = the ratio of the 80th percentile highest travel time to the free-flow travel time.

Mean TTI = The ratio of the mean travel time to the estimated free-flow travel time.

Travel time reliability was not estimated from the CORSIM runs in order to preserve project resources.

4.7.1. Computation of induced demand effects (second pass demand adjustment)

The origin-destination table for the facility is estimated from the ramp flows using proportional demands and assuming no ramp to ramp travel for facilities under 5 miles in length. The total (on-facility plus off-facility) trip time is computed according to the following formula.

$$ATT = TR + TF / (1+0.65TR/TF) \quad (3)$$

Where
ATT = average total trip time (min.)
TF = travel time on the facility for the entry-exit pair (min)
TR = peak period regional average travel time (min)

The effects of reliability are added to the average travel trip time using the following equation.

$$TTE = ATT + a * (80th\%TT – 50th\%TT) \quad (4)$$

Where:
TTE = the travel time equivalent on the facility for the entry-exit pair (min)
ATT = the average total trip time (min)
"a" = the value of unreliability parameter (default = 1.00)
80%TT = the 80th percentile travel time (min)
50%TT = the 50th percentile travel time (min)

The new demand is then calculated as a function of the existing demand for each origin-destination pair using the following equation.

$$V = V0 * (TTE/TTE0)\beta * exp[\gamma * (TTE-TTE0)] \ (5)$$

Where:
TTE0 = The original travel time equivalent (min.)
TTE = The new travel time equivalent (min.)
V0 =The original demand (vehicles)
V = The predicted demand (vehicles)
β = Beta parameter, elasticity of demand to time. Recommended default value is -0.2
Y = Gamma (route diversion) parameter. Recommended default value is zero for isolated facility.

The predicted demand change is equilibrated with the predicted travel time change using a damping factor of 0.50 to reduce oscillations. The induced demand was not computed for the CORSIM runs in the interests of conserving project resources.

4.7.2. Results

The results for the "before" (Base) case are shown in Table 1 along with the predicted results for ramp metering, adding an HOV lane (which includes ramp metering), and for adding an HOT lane (which also includes ramp metering).

As one would expect each improvement results in a modest increase in demand for the freeway and modest to major reductions in delay, travel time, and reliability. Reliability is measured in terms of the 80th percentile highest travel time. CORSIM tends to predict more modest travel time gains than FREEVAL for the ATDM measures before demand inducement is considered.

Table 1: Results of Whole Year Performance Evaluation

ATDM Measure	Performance Measure	Before ATDM	After ATDM: Before Induced Demand	After ATDM: After Induced Demand	Percent Change: Before Induced Demand	Percent Change: After Induced Demand
Metering	Travel Time Rate	1.37 (1.26)	1.24 (1.22)	1.28	-10% (-3%)	-6%
	VMT (Demand)	1,619,000	1,619,000	1,645,000	0%	2%
	VMT (Served)	1,572,000	1,597,000	1,612,000	2%	3%
	Veh Hrs Delay	11,600	8,300	9,600	-28%	-17%
	Max D/C	1.2	1.2	1.2	-3%	-2%
	80% TTI	1.9	1.6	1.7	-15%	-10%
	Speed	45	49	47	10%	7%
HOV+Meter	Travel Time Rate	1.37 (1.26)	0.96 (1.00)	1.03	-30% (-20%)	-25%
	VMT (Demand)	1,619,000	1,619,000	1,715,000	0%	6%
	VMT (Served)	1,572,000	1,619,000	1,713,000	3%	9%
	Veh Hrs Delay	11,600	1000	3,700	-92%	-69%
	Max D/C	1.2	1.0	1.1	-16%	-8%
	80% TTI	1.9	1.1	1.2	-43%	-36%
	Speed	45	62	58	40%	31%
HOT+Meter	Travel Time Rate	1.37 (1.26)	0.95 (1.00)	0.98	-31% (-21%)	-28%
	VMT (Demand)	1,619,000	1,619,000	1,722,000	0%	6%
	VMT (Served)	1,572,000	1,619,000	1,722,000	3%	10%
	Veh Hrs Delay	11,600	500	1,700	-96%	-86%
	Max D/C	1.2	0.9	1.1	-21%	-13%
	80% TTI	1.9	1.0	1.1	-45%	-41%
	Speed	45	63	61	42%	37%

CORSIM results (where available) shown in parentheses, otherwise results are from FREEVAL

5. Validation check

A search of the literature was conducted to identify "before and after" studies (as opposed to simulation and other model analyses) of the measured effects of ramp metering, HOV lanes, and HOT lanes on: demand, mean travel time, and reliability. A list of the reports consulted can be obtained from the Draft Final Report for this project.[xiv] The ranges of results suggested by the literature are documented in Table 2.

Table 2: Comparison of ATDM Results to Validation Targets

Metering				
	San Diego I-15	Alameda I-580		
MOE	FREEVAL	FREEVAL	CORSIM	Validation Target
VMT (Demand)	1.3%	1.6%	0.0%	+3% to +5%
VMT (Served)	1.4%	1.0%	0.2%	Insufficient Data
Travel Time Rate	-8.7%	-6.3%	-3.2%	-5% to -25%
80% TTI	-14.3%	-9.9%	-4.4%	-7% to -33%
HOV + Metering				
	San Diego I-15	Alameda I-580		
MOE	FREEVAL	FREEVAL	CORSIM	Validation Target
VMT (Demand)	3.9%	5.9%	0.0%	Insufficient Data
VMT (Served)	4.0%	6.0%	2.6%	Insufficient Data
Travel Time Rate	-21.9%	-24.6%	-20.4%	-4% to -6%
80% TTI	-34.3%	-36.5%	-27.1%	-6% to -9%
HOT + Metering				
	San Diego I-15	Alameda I-580		
MOE	FREEVAL	FREEVAL	CORSIM	Validation Target
VMT (Demand)	4.9%	6.4%	0.0%	+4% to +8%
VMT (Served)	5.1%	6.6%	2.7%	Insufficient Data
Travel Time Rate	-27.4%	-28.2%	-20.7%	-6% to -40%
80% TTI	-41.9%	-41.2%	-27.6%	-9% to -50%

Notes: All entries show percent change in performance measures after implementation of ATDM and accounting for induced demand. Data shown for additional test site (I-15) as well as original test site described in body of paper. CORSIM was run with the same demands in all cases. VMT(served) is how much demand was processed through the facility during the analysis period.

5.1. Ramp metering

Predicted change in demand for both test sites is +1% to +2%, while the literature suggests it may be on the order of 3% to 5%. The FREEVAL predicted change in mean travel time for both sites ranges from -6% to -9% which falls on the low side of the range suggested by the literature. The FREEVAL predicted change in reliability (the 80% time) for both sites ranges from -10% to -14% which also falls within the range suggested by the literature.

5.2. HOV lane

The predicted change in demand for both sites ranges from +4% to +6%. The literature did not provide sufficient information to identify an expected range for changes in demand caused by HOV lanes. The FREEVAL predicted change in mean travel time for both sites ranges from -22% to -25% which much greater than the range suggested by the literature. The CORSIM model tended to confirm the FREEVAL analyses, predicting a -20% change in mean travel time. The FREEVAL predicted change in reliability (the 80% time) for both sites ranges from -34% to -37% which also falls well outside the range suggested by the literature.

5.3. HOT lane

The predicted change in demand for both sites ranges from +5% to +6% which is within the range suggested by the literature. The FREEVAL predicted change in mean travel time for both sites falls in the range of -27% to -28% which falls within the range suggested by the literature. The FREEVAL predicted change in reliability (the 80% time) for both sites is -41% to -42% which also falls within the range suggested by the literature.

The results of the preliminary validation suggest that the ATDM methodology will predict impacts on demand, mean travel time, and reliability that are in the expected direction of the effect and often (but not always) within the same order of magnitude as observed in the literature.

6. Conclusions

This paper has presented a proposed methodology for evaluating the facility performance effects of active transportation demand and management measures. The methodology is practical to apply with either Highway Capacity Manual or microsimulation analysis tools. The methodology produces results in the appropriate direction and approximately the same magnitude as has been suggested by the literature.

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