Comparative Evaluations on the Elasticity of Travel Demand

Wasatch Front Regional Council (WFRC) Model Sensitivity Testing and Training Study

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ABSTRACT

In 2002, the Utah Department of Transportation (UDOT), the Wasatch Front Regional Council (WFRC), and the Sierra Club signed a Memorandum of Agreement (MOA) to conduct a model sensitivity analysis of the WFRC model. The purpose of this analysis was to determine the model's ability to represent induced travel and to calculate the elasticity of vehicle-miles traveled (VMT) for "no-build" and "highway build" scenarios.

The resulting model sensitivity study, completed in November 2003, included a literature review of national research studies aimed at assessing the elasticities of travel demand and the ability to address induced travel; a review and recommendation of different evaluation measures for use in the study; the coding of network alternatives into the WFRC model; and the evaluation of results from model network runs.

The literature review conducted for the model sensitivity study included 31 of the most relevant publications on the topic of induced travel and how to model induced travel. As part of the review, each publication was reviewed across a range of factors. The literature review was intended to obtain the most recent published information on the travel demand effects of roadway improvement projects. From this information, the project team isolated the elasticity of VMT with respect to changes in lane-miles and other variables. An interesting outcome of the review that will be addressed in the paper is the extent of research weaknesses related to induced travel including the use of low quality or unvalidated data that may have affected the research findings.

STUDY BACKGROUND

In 2002, the Utah Department of Transportation (UDOT), the Wasatch Front Regional Council (WFRC), and the Sierra Club signed a Memorandum of Agreement (MOA) to conduct a model sensitivity analysis of the WFRC model. The purpose of this analysis was to determine the model's ability to represent induced travel and to calculate the elasticity of vehicle-miles traveled (VMT) for "no-build" and "highway build" scenarios.

Study Purpose

In January 2001, the Sierra Club filed a complaint in the U.S. District Court for the District of Utah against U.S. DOT, FHWA, FTA, and other parties over a decision to approve an Environmental Impact Statement (EIS) for the Legacy Highway and air quality conformity findings of FHWA and FTA related to the WFRC 1998-2020 and 2030 Long-Range Plans and 2001-2005 Transportation Improvement Program. The Legacy Highway was proposed as a new limited access highway with a southern terminus near the interchange of I-215 and 1700 West in North Salt Lake and a northern terminus near the interchange of I-15 and U.S. 89 in Farmington. In May 2001, Utah intervened as a defendant in the Sierra Club lawsuit.

Subsequently, the Sierra Club, the Federal Defendants, and the State of Utah entered into a Settlement Agreement to resolve their disputes related to the air quality conformity element of the lawsuit (the FEIS element was separated and not related to the Settlement Agreement). One element of the Settlement Agreement was that UDOT and the WFRC enter into an MOA to, among other requirements, undertake a sensitivity testing of the WFRC's travel demand model including an analysis of the contribution of individual WFRC model steps to induced travel. The sensitivity analysis was scheduled for completion by January 1, 2004.

Study Process

The Consultant team of Cambridge Systematics, Inc. (CS) and Fehr & Peers Associates, Inc. (F&P) was selected by UDOT to conduct the required sensitivity analysis. As required by the MOA, UDOT's Consultant team was required to "conduct a sensitivity test that indicates the model's representation of induced travel by simulating a no-build scenario and a highway-build scenario and calculating the elasticity of vehicle miles traveled (VMT) with respect to lane-miles of freeway and travel time. UDOT also will conduct sensitivity tests of the WFRC travel demand submodels' representation of induced travel. This can be done by holding constant the following components of induced travel from the future base case scenario to the highway-build scenario: 1) land use; 2) auto ownership; 3) trip generation; 4) trip distribution; 5) mode choice; and 6) traffic assignment. Following the sensitivity testing described above, UDOT will provide to WFRC and the (Settlement Agreement) Parties a report documenting the results of the sensitivity testing provided for in this MOA. This report shall be issued prior to January 1, 2004."*(1)* It was agreed by study stakeholders that the trip generation elements of the model including auto ownership and land use/population forecasts, would be held constant for all sensitivity scenarios tested.

LITERATURE REVIEW

A literature review was conducted as per the scope of services for this study. The purpose of the literature review was to analyze relevant research on travel demand elasticities and induced travel and identify performance criteria typically used in these studies.

Literature Review Process

The induced travel literature review of the 31 documents provided in the literature review matrix in Table 1 reveals a vast variety of study conditions, methodology, and results. Studies varied across a range of factors, including, but not limited to the following list.

- Type of model;
- Timeframe;
- Geographic location and size;

- Means of measuring independent and dependent variables (independent variables cause variation in a second variable while dependent variables are variables affected by another variable);
- Statistical analysis tests; and
- Terminology for induced travel effects.

The literature review of the documents was intended to obtain the most recent published information on the travel demand effects of roadway improvement projects. From this information, the project team attempted to isolate the elasticity of VMT with respect to changes in lane-miles and travel times. Consistent with the economic theory of supply and demand, the general topic of research concerning induced travel elasticity is that reducing the cost of travel (i.e., reduced travel time due to a new road improvement) will increase the amount of travel. In other words, road improvements alone can prompt traffic increases. To what degree and under what circumstances these increases occur is a matter of debate and the key subject of most induced travel research.

Of the original 18 papers initially identified by the Plaintiffs and UDOT in the Request for Proposals, two more papers were added by the study stakeholders at the project kickoff meeting. Following that meeting, 17 more papers were added by the project team for a total of 37 papers to be reviewed. Initial discussions between the team reduced the 17 new papers to 11 new papers for a new total of 31 papers, as listed in Table 1.

Literature Overview

The general topic of research concerning elasticity is that reducing the cost of travel (i.e., reduced travel time due to a new road improvement) will increase the amount of travel. In other words, road improvements prompt traffic increases and these gains diminish travel time benefits to some degree. To what degree and under what circumstances, however, remains a matter of debate.

The research of induced travel is somewhat limited compared to other transportation subjects, but interest by researchers has grown steadily over the last few years given the controversial nature of the subject as it relates to investments in new roadways. The ability of the research to fully explain the complicated relationships between the variables involved in induced travel has not been completely sorted out. In simple terms, travel time savings to a driver can result in a change of route, change of schedule, consolidation of trips, change in mode of travel and/or change of final destination. All of these changes can have an impact on the number of vehicle trips and the amount of VMT in a study area. Explaining the reasons for these changes is difficult, especially within the context of models attempting to explain human travel behavior, but researchers have found statistically valid relationships between increases in capacity and increases in travel demand.

Most of the papers reviewed for this study agreed that induced travel does occur. A number of the papers reviewed (12) did not include quantitative descriptions or calculations of elasticities while many papers described difficulties in specifying the exact magnitude of induced travel resulting from highway capacity expansion. The latest research on the subject by Robert Cervero from U.C. Berkeley (*Road Expansion, Urban Growth, and Induced Travel: A Path Analysis*, July 2001) explains that induced travel involves a two-way causal relationship between road use and road supply and concludes that much of the previous research involving induced travel failed to capture this two-way relationship. Further, many studies according to Cervero have overstated induced-demand effects because they have not correctly specified the chain of events between added roadway capacity and traffic growth. Specifically, Cervero states, "While the magnitude of induced growth effects found in this study is generally consistent with that of previous research, the magnitude of induced demand effects is generally less. To the degree the path model better captures causal relationships than previous studies, many past elasticity estimates are likely inflated. The contention that capacity additions are quickly absorbed by an increase in traffic and that 'you can't build yourself out of traffic congestion' might not hold in all settings."*(2)* These statements are indicative that the research of induced travel is still evolving and that researchers are just beginning to unravel the complex relationships between investments in roadway capacity and the resulting travel demand effects.

Typical Elasticity Results

The elasticity values provided in Table 2 were extracted from the researched papers during the literature review. Papers that did not provide quantitative descriptions or calculations of elasticity are excluded from this summary. Figures 1 and 2 graphically depict typical elasticity results for short-term and long-term calculations.

Research Findings

Some findings and general conclusions in the research of model elasticity seem to have emerged with substantial support. Other findings cannot yet be substantiated.

- **Induced travel effects exist –** The elasticity of VMT with respect to added lane-miles or reductions in travel time is generally greater than zero and the effects increase over time.
- **Short-term induced travel effects are smaller than long-term effects –** As measured by the increase in VMT with respect to an increase in lane-miles, short-term effects have an elasticity range from near zero to about 0.40, while long-term elasticities range from about 0.50 to 1.00. This means that a 10 percent increase in lane-miles under short-term conditions can cause up to a four percent increase in VMT while a 10 percent increase in lane-miles under long-term conditions can cause up to a 10 percent increase in VMT.
- **Induced travel effects for constructing new roadways versus widening existing roadways were not definitive –** The research did not include any examples that isolated the effects of constructing new roadways versus widening existing roadways. However, somewhat higher elasticities where found when "new roadways and widenings" were considered together compared to "widenings only." This finding is based on a limited number of studies and indicates that more research is necessary to isolate these differences.
- **Induced travel effects generally decrease with the size of the unit of study –** Larger effects are measured for single facilities while smaller effects are measured for regions and subareas. This is mainly due to diverted trips (i.e., drivers changing routes) causing more of the change on a single facility, whereas, at the regional level, diverted trips from one route in the region to a new route in the region are not considered induced travel unless the trips become longer as a result.
- **Traditional four-step travel demand models do not fully address induced travel or induced growth –** Land use allocation methods do not always consider accessibility effects, trip generation usually does not account for "latent" trips (i.e., trips that would occur under ideal conditions but do not occur because of congestion), time-of-day shifts are not reflected in many models, and static traffic assignment algorithms may not account for the impacts of queuing on route shifts. Travel demand model tests also demonstrate that weaknesses in models are likely to be greater when congestion, and thus suppression of travel, is greater or user behavior is more responsive to changes in travel costs because of the choices open to travelers. This effect is due to the static nature of four-step models that carry base-year travel behavior parameters into future horizon year model scenarios where congestion may be much greater and could substantially alter travel behavior that is only reflected by hard-coded parameters carried over from the base year model. For example, the percent of daily trips that occur during a peak hour is typically a hard-coded percentage in most traditional four-step models that does not change from the base year to future year model. In reality, the percent of daily trips that occur during peak hours reduces as congestion increases. The failure to capture this effect would ignore the potential trip suppression effects of congestion.
- **Urban versus rural differences in induced travel are unknown –** Past efforts to explain variation in induced demand according to factors such as levels of congestion and urban versus rural settings have proven largely unsuccessful.

The research conducted to date also is subject to a variety of criticisms. Some of the key issues identified in the literature review as well as a recent article by Robert Cervero *(3)* are highlighted below.

- **Difficult to disentangle the many contributors to increased travel –** Many of the studies do not control for social/economic factors influencing out-migration from central cities, increased participation by women in the workforce, changes in personal income, changes in the real price of gasoline, pre-existing congestion levels, availability of transit, etc.
- **Most studies focus on higher-level facilities –** This focus raises the question of whether increases in VMT found in these studies represent shifts from lower-level facilities, either as the result of improvements to the main roads or, more trivially, a designation change in roads from one category to the other, or altogether new traffic.
- **Significance of research findings –** Even if the elasticities obtained are essentially correct, some researchers contend, lane-mile growth accounts for only a small fraction of VMT growth. Moreover, induced travel may increase the benefits from road improvements since the extra VMT is presumably generating some additional surplus that may or may not offset congestion impacts.
- **Induced traffic models confuse, or conflate, cause and effect –** The statistical relationship between road supply and traffic is not the result of a simple, one-way, causal link between the former and the latter, but rather

a simultaneous relationship in which more traffic also spawns more roads. The transportation planning and programming process is designed to anticipate and respond to changes in traffic. Thus, correlation between road supply and traffic could reveal nothing more than that fact that this process is working successfully. Likewise, findings that road expansion fails to relieve congestion could simply indicate that regions are failing to keep pace with burgeoning demand for additional road capacity.

- **The data used in most research is based on statewide traffic count programs –** These programs are the basic source of data for VMT estimates made in the highway performance monitoring system (HPMS). None of the research evaluated the quality of these programs or attempted to discern the credibility of the count data. Many of these programs rely on partial traffic counts and system balancing routines. In addition, the VMT reported by the HPMS program is a derived estimate. None of the research has attempted to evaluate this program or its model of VMT. In many cases, the HPMS program estimates VMT for a region based on very limited traffic count data.

In general, the studies on induced travel face many methodological challenges including the issues listed above. All of these issues make identifying the exact magnitude somewhat difficult, but the phenomenon of induced travel (i.e., direction of change) is well supported by the body of literature reviewed in this study.

PERFORMANCE CRITERIA

Based on the literature review, and consultant team experience with other travel demand studies, a set of draft performance criteria was recommended. While the primary focus of the sensitivity analysis was on elasticities, it was felt that other performance measures should be reviewed to give a more complete assessment of model sensitivity to different steps in the modeling process. The final set of performance criteria used in the sensitivity analysis is displayed in Table 3.

The literature review was dominated by the use of VMT as a performance measure either on its own or as a part of the elasticity calculation. Elasticities were calculated in several different manners but generally used the following formula:

$$Elasticity = \frac{\Delta VMT}{\Delta LaneMiles}$$

The above equation means that elasticity is equal to a change in VMT over a change in lane-miles.

Other performance criteria cited included growth in average daily traffic (ADT), vehicle emissions, modal shares, operating speeds, vehicle-hours traveled (VHT), and total trips. While the majority of performance criteria relate most to the traffic assignment process, there are performance measures that relate to other steps in the model chain. For example, congested trip length is a measure from the trip distribution model and trips by travel mode is an output of the mode choice model.

Four different elasticity formulas were recommended by the stakeholders; however, it was later found that several of these use essentially the same equations and/or provide very similar results. Arc elasticity is based on both the original and final values of demand (Q) and price or services (P). When moving along a demand curve from (P1 and Q1) to (P2 and Q2), arc elasticity is defined as follows:

Arc elasticity = change in Q)/((Q1+Q2)/2)/(change in P/((P1+P2)/2)

Arc Elasticity Measure:

$$\left| \frac{\frac{(Q2 - Q1)/[Q1 + Q2]}{2}}{\frac{(P2 - P1)/[P1 + P2]}{2}} \right| = e$$

The point elasticity formula calculates the percentage change in quantity relative to starting quantity whereas the arc elasticity formula calculates the percentage change in quantity relative to the average of the starting and ending quantities.

Point Elasticity Measure:

$$\left| \frac{DQ/Q}{DP/P} \right| = \left| \frac{P}{Q} * \frac{DQ}{DP} \right| = e$$

There is also an older form of arc elasticity still encountered in transit fare analyses known as a shrinkage factor.

Shrinkage Elasticity Measure:

$$(Q2 - Q1)/Q1/(P2 - P1)/P1 \; (4)$$

NETWORK ALTERNATIVES

In accordance with the settlement agreement, the highway networks are the only components of the travel demand model that were varied between alternatives. Other required model inputs, such as socioeconomic data, used the 2030 Long-Range Plan data sets included in the WFRC travel demand model that were current at the time the analysis was conducted.

While discussions took place among the stakeholders regarding the testing of different transit network assumptions, it was agreed that such analyses were beyond the scope of this study and that only limited national research was presently available to assess reasonable ranges of model elasticities related to changes in the transit networks. Additional mode choice sensitivity tests have also been conducted, using a newly updated version of the WFRC travel demand model, as part of ongoing EIS projects in the region.

Highway Network Alternatives

Six different highway networks were executed using the WFRC travel demand model. These may be summarized as follows:

- **No Build –** The No-Build Alternative is based on the 2030 Long-Range Plan. The No-Build Alternative differs from the Long-Range Plan on four facilities. Stated differently, this Alternative assumes that planned improvements in the four corridors do not occur.
- **Alternative 1 –** Highway widening projects planned for the I-15 corridor are added to the No-Build network.
- **Alternative 2 –** Planned six-laning of the U.S. 89 corridor is added to the No-Build network.
- **Alternative 3 –** The Western Transportation Corridor, a six-lane limited access highway, is added to the No-Build network.

- **Alternative 4 –** Lanes are added to the No-Build network along the 700 East/Van Winkle corridor to reflect existing conditions.
- **Alternative 5 –** All projects coded in Alternatives 1 through 4 are included in Alternative 5.

MODEL SENSITIVITY RESULTS

Model sensitivity runs were conducted using the currently available WFRC model based on the five network alternatives. For each network alternative, the WFRC model was executed from trip distribution through traffic assignment. A series of tabular and graphed statistical summaries were produced for each model run to display results for each performance criterion.

As required by the memorandum of agreement, two of the network alternatives each were executed two additional times; once with trip distribution and mode choice held constant from the no-build alternative and once with only trip distribution held constant from no-build conditions. These latter runs utilized trip tables from the no-build alternative and were only executed for the purposes of isolating which steps in the model chain had the greatest impact on elasticities.

Model Sensitivity Runs

As described above, WFRC model simulations were executed by the Consultant team from trip distribution through traffic assignment as per standard model practice. The feedback loop presently included in the model was executed for consistency with typical applications for the WFRC. The version used was the official 2030 LRP model provided by WFRC staff in the spring of 2003. An update to this model was underway during this study but was not completed and therefore unavailable for application during the sensitivity analysis.

The number of equilibrium assignment iterations varied slightly for each model run by time-of-day. The equilibrium algorithm for traffic assignment iteratively adjusts speeds and travel paths based on congestion with the end result being a set of volume estimates weighted to reflect each iteration. All scenarios executed for six iterations during the a.m. peak period and two iterations during the night-time (off-peak) period. The midday assignment achieved equilibrium after three iterations for all scenarios except Alternatives 3 and 5 which required four iterations to achieve equilibrium. The p.m. peak-period assignment required six iterations to achieve equilibrium for all scenarios except Alternative 4, which required eight iterations. The differences between trips output by the mode choice model and those loaded on the highway network were generally small but varied by scenario. The number of feedback loops and convergence criteria were maintained consistent for all scenarios.

Model Sensitivity Results

Statistics for all performance criteria were summarized from the six 2030 model runs, including the no-build, Long-Range Plan, and the four highway network alternatives. Table 4 depicts model output statistics for several of the performance criteria listed earlier.

A review of Table 4 shows that among the four highway network scenarios evaluated, Alternative 3 (the Mountain View Corridor) results in the most dramatic differences from the no-build alternative for nearly every performance measure evaluated. In fact, the only exception to this finding is regional congested travel time for the external-internal purpose, for which the largest difference from the no-build scenario results from Alternative 1 (the U.S. 89 improvements). The reason that Alternative 3 has the greatest impact is because this scenario involves the addition of a new limited access corridor to the model network whereas the other alternatives only involve lane additions or reductions to existing corridors. It should be noted that Alternative 5 actually exceeds the differences experienced with Alternative 3; however this is due to the inclusion of all projects from Alternatives 1 through 4 in Alternative 5.

Changes in ADT, p.m. peak-period traffic, and trips by mode reflect different travel patterns resulting from changes in the highway network and their subsequent impacts on trip distribution and mode choice, since trip generation was held constant. As expected, the addition of roadway laneages and new corridors generally resulted in an increase in travel speeds for congested conditions with a corresponding decrease in congested travel times as higher speeds typically equal shorter travel times.

Regional elasticities, calculated as the change in VMT over the change in lane-miles, are presented in Table 5. As with the statistical comparisons provided in Table 4, Alternative 3 once again shows the greatest change when compared to the other network scenarios. In the case of regional elasticities, Alternative 3 (1.23) shows even higher values than Alternative 5 (0.91), the Long-Range Plan or full build scenario. The lowest elasticities (0.08) are experienced with Alternative 4 (700 East), as this alternative involves laneage changes to a relatively short section of arterial roadway. In addition to total regional elasticities, values were calculated for individual facility types affected by each alternative. As noted previously, ranges of elasticities cited in the literature review ranged from values of approximately 0.1 to 1.1. The greater the value, the more elastic the model, and higher values are expected for long-term elasticities than for short term.

By stakeholder request, elasticities also were calculated using alternative formulas including arc, point, and elasticity with shrinkage factor. As noted previously, these different equations either resulted in the same or very similar elasticity values. Another suggestion was to calculate elasticities using the change in capacity over the change in lane-miles, as an alternative to VMT. This approach generally increased the elasticity values; however, the same Alternative 3 had the highest elasticities (2.82) while the same Alternative 4 as before displayed the lowest elasticity values (0.20).

Model Sensitivities with No-Build Trip Tables

In order to isolate the effects of elasticities to specific steps in the model chain, additional model runs were executed using no-build trip tables along with network changes. In the interest of minimizing unnecessary duplication of work, it was decided to focus these supplemental model runs on the two alternatives that had the greatest and least impacts. This resulted in four additional model runs as follows:

- **Alternative 3A –** Mountain View Corridor with both trip distribution and mode choice held constant;
- **Alternative 3B –** Mountain View Corridor with only trip distribution held constant;
- **Alternative 4A –** 700 East Corridor with both trip distribution and mode choice held constant; and
- **Alternative 4B –** 700 East Corridor with only trip distribution held constant.

Table 6 depicts the resulting elasticities for these four supplemental alternatives. As expected, elasticity values are considerably lower for these alternatives than for the original alternatives (3 and 4). This shows that the greatest impact of including network changes was on the trip distribution step of the model chain. Impacts from mode choice were fairly small as indicated by the similarity of elasticities between Scenarios 3A and 3B as well as 4A versus 4B. Significant differences from the earlier alternatives shows that the impacts of trip assignment are fairly minimal when compared to trip distribution (the only change between Scenarios 3 and 3B as well as 4 and 4B).

For example, Alternative 3, with only trip generation held constant, resulted in a total elasticity value of 1.2328 (as depicted in Table 5) while elasticities decreased to 0.2040 with trip distribution also held constant and 0.1864 with both trip distribution and mode choice (in addition to trip generation) held constant. This pattern is depicted in Figure 3.

SUMMARY AND CONCLUSIONS

This study focused on assessing then currently available WFRC models to simulate induced travel and conform to expected ranges of model elasticity. Based on analyses conducted during this study, the project team concluded that this version of the WFRC model is sensitive to changes in the highway network and appears to result in logical cause and effect relationships based on summaries of a wide range of model-generated statistics. These expected relationships include the following:

- Model elasticities fall within the expected range of acceptability based on comparisons with elasticities cited in a variety of research papers;
- The most dramatic elasticities equate with adding the most significant highway corridor project, the Mountain View Corridor (Alternative 3);
- Elasticities reported under "build" conditions are impacted more by the trip distribution step than the mode choice or highway assignment steps;

- Vehicle-miles traveled generally increased with the addition of specific roadway projects while vehicle-hours traveled generally decreased; and
- Regional congested roadway speeds increased with the addition of each highway project while the percent transit trips decreased as did trip lengths.

It is hoped that the findings of this study will add credence to the findings of recent and ongoing Environmental Impact Studies in showing that the WFRC travel demand model appears to provide logical results. It is further desired that this effort will add to the body of research on induced travel and provide a better understanding of the anticipated effects new roadway projects have on vehicle-miles traveled and percent transit mode split. Finally, it is anticipated that the results from this study will be useful in conducting additional sensitivity assessments with updated versions of the WFRC model and will establish an anticipated set of performance standards for future year model simulations.

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TABLE 1 Literature Review Master Document List

No.	Literature
1	Chu, X. (2000), *Highway Capacity and Areawide Congestion*. Preprint for the 79th Annual Meeting of the Transportation Research Board. National Research Council, Washington, D.C.
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TABLE 1 Literature Review Master Document List (continued)

No.	Literature
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29	Boarnet, M. (2001), *New Highways, urban development and induced travel*, 80th TRB paper 01-2996.
30	Barr, L.C. (2000), *Testing significance of induced highway travel demand in metropolitan areas*, Transportation Research Record 1706.
31	Cervero, R. (August 2002), *Induced Travel Demand: Research Design, Empirical Evidence, and Normative Policies*.

TABLE 2 Induced Travel Literature Review Elasticity Summary

List No.	M/S/E	Paper	Year	Location/Model	Data	Lane-Mile Elasticity				Travel Time Elasticity		Improvement Type
						Short-Term		Long-Term		Short-Term		
						Low[a]	High	Low[a]	High	Low[a]	High	
20	E	Cervero, Hansen, 2001	2001	34 CA Counties	TSLS	0.56	–	0.78	0.84	–	–	Widening
7	E	Hansen, Huang, 1997	1997	California County Level	TS/CS	0.3	–	0.68	–	–	–	Not Specified
7	E	Hansen, Huang, 1997	1997	California Metro Level	TS/CS	0.5	–	0.94	–	–	–	Not Specified
26	E	Marshall, 1996	1996	TTI Congestion Study Data		–	–	0.76	0.85	–	–	Not Specified
12	E	Rodier, et al, 2001	2001	Sacramento Regional	DM	–	–	0.8	1.1	–	–	New Roadway and Widening
21	E	Strathman, et al, 2000	2000	Nationwide NPTS data	CS	–	–	0.29	–	–	–	Not Specified
19	M	Cervero, 2001	2001	24 CA corridors	TSLS	0.29	–	0.64	–	–	–	Widening
5	M	Fulton, et al, 2000	2000	County Level (MD,VA,NC,DC)	TSLS	0.3	0.5	0.47	0.89	–	–	Not Specified
2#	M	Hansen et al, 1993	1993	CA Highway Widenings	TS/CS	0.2	0.3	0.3	0.6	–	–	Widening
2	M	Mokhtarian et al, 2000	2000	CA Highway Widenings	TS/CS	0.0	–	–	–	–	–	Widening

Notes:

Compilation of information provided in Noland and LEM (2001, Lit Rev No. 25), and Cervero (2001, Lit Rev No. 31).

M = Measured Study, S = Synthesis of other studies, E = Estimate of Elasticity.

TS = Time Series, CS = Cross Section, DMFX = Difference Model with Fixed Effects.

TSLS = Two Stage, Least Square, DM = Disaggregate Modeling.

2# = Not included as a separate article, but reviewed as part of article 2.

[a] Low in a range, or average if only one value provided.

TABLE 2 Induced Travel Literature Review Elasticity Summary (continued)

List No.	M/S/E	Paper	Year	Location/Model	Data	Lane-Mile Elasticity				Travel Time Elasticity		Improvement Type
						Short-Term		Long-Term		Short-Term		
						Low[a]	High	Low[a]	High	Low[a]	High	
10	M	Noland, 2001	2001	State-Level Data	TS/CS	0.3	0.68	0.7	1.0	–	–	New Roadway and Widening
10	M	Noland, 2001	2001	State-Level Data	DMFX	–	–	0.5	0.8	–	–	New Roadway and Widening
11	M	Noland, Cowart, 2000	2000	Nationwide Metro Level	TS/CS/FX	–	–	0.81	1.0	–	–	Not Specified
11	M	Noland, Cowart, 2000	2000	Nationwide Metro Level	TSLS	0.3	–	–	–	–	–	Not Specified
30	M	Barr, 2000	2000	Nationwide NPTS data	CS	–	–	–	–	-0.3	-0.4	Not Specified
6	M	Goodwin, 1996	1996	Gas Price Evaluation		–	–	–	–	-0.5	-1.0	Not Specified
31	S	Cervero, 2002	2002	24 CA corridors	TS/CS	0.1	–	0.39	–	–	–	Not Specified
2#	S	Hansen et al, 1993	1993	California County Level	TS/CS	0.46	0.5	–	–	–	–	Widening
2#	S	Hansen et al, 1993	1993	California Metro Level	TS/CS	0.54	0.61	–	–	–	–	Widening

Notes:

Compilation of information provided in Noland and LEM (2001, Lit Rev No. 25), and Cervero (2001, Lit Rev No. 31).

M = Measured Study, S = Synthesis of other studies, E = Estimate of Elasticity.

TS = Time Series, CS = Cross Section, DMFX = Difference Model with Fixed Effects.

TSLS = Two Stage, Least Square, DM = Disaggregate Modeling.

2# = Not included as a separate article, but reviewed as part of article 2.

[a] Low in a range, or average if only one value provided.

TABLE 3 UDOT-WFRC Model Sensitivity Performance Criteria

No.	Recommended Performance Criteria	Comments
1	Regional Vehicle-Miles Traveled (VMT)	Comparisons of change with different network alternatives but socioeconomic data held constant
2	Regional Vehicle-Hours Traveled (VHT)	Comparisons of change with different network alternatives but socioeconomic data held constant
3	Regional Average Daily Traffic (ADT)	Comparisons of change with different network alternatives but socioeconomic data held constant
4	Average Daily Traffic (ADT) for Specific Corridors	Comparisons of change with different network alternatives but socioeconomic data held constant
5	p.m. (or a.m.) Peak-Hour Volumes for Specific Corridors	Application of documented factor against peak-period volume estimates
6	Regional Trips by Mode	As output by mode choice model
7	Regional Congested Trip Lengths by Purpose	Derived from trip distribution gravity model after running first pass mode choice and assignment
8	Regional Congested Speed by Facility Type	Derived from loaded highway network assignment
9	Regional Elasticity by Facility Type	Change in VMT/change in lane-miles
10	Regional Arc Elasticity	(Change in VMT)/((VMT1 + VMT2)/2)/(change in lane-miles/((lane-miles1 +lane-miles2)/2)
11	Regional Point Elasticity	(dQ/dP) * (P/Q)
12	Regional Elasticity with Shrinkage Factor	(Q2-Q1)/Q1/(P2-P1)/P1

TABLE 4 UDOT-WFRC Model Sensitivity Statistical Summary

		2030 No-Build	*I-15 Imprv.* 2030 ALT 1	2030 ALT 1 Percent Change	*U.S. 89 Imprv.* 2030 ALT 2	2030 ALT 2 Percent Change	*MVC Added* 2030 ALT 3	2030 ALT 3 Percent Change	*700E Imprv.* 2030 ALT 4	2030 ALT 4 Percent Change	*Full Build* 2030 ALT 5	2030 ALT 5 Percent Change
1	Regional Vehicle-Miles Traveled (VMT)	67,702,895.5	68,085,793.9	0.57%	67,841,772.04	0.21%	69,148,900.78	2.14%	67,731,092.59	0.04%	69,752,245.93	3.03%
2	Regional Vehicle-Hours Traveled (VHT)	2,307,280.7	2,282,805.1	-1.06%	2,296,829.09	-0.45%	2,272,815.89	-1.49%	2,283,847.58	-1.02%	2,240,131.87	-2.91%
3	Regional Average Daily Traffic (ADT)	193,059,484.0	193,934,340.0	0.45%	193,546,779	0.25%	195,914,508	1.48%	193,009,985	-0.03%	197,461,566	2.28%
4	Average Daily Traffic (ADT) for Modified Corridor											
	I-15 (10493-10032, 10033-10494)	207,992	225,756		209,754		207,808		205,748		227,308	
	U.S. 89 (9324-9322, 9321-9323)	108,299	110,612		124,317		108,517		110,277		124,594	
	WTC (10436-10434, 10433-10435)	–	–		–		134,328		–		135,690	
	700E (4738-4739, 4739-4738)	37,970	37,055		37,603		40,069		101,028		98,833	
5	P.M. Peak-Period Volumes for Modified Corridor											
	I-15 (10493-10032, 10033-10494)	49,625	56,166		50,666		49,297		47,571		56,452	
	U.S. 89 (9324-9322, 9321-9323)	26,186	27,698		35,130		26,044		27,955		35,934	
	WTC (10436-10434, 10433-10435)	–	–		–		38,006		–		39,479	
	700E (4738-4739, 4739-4738)	7,315	6,713		6,940		6,865		27,709		25,616	
6	Regional Trips by Mode											
	Daily Auto Trips	9,539,131	9,539,721	0.01%	9,539,388	0.00%	9,550,079	0.11%	9,540,680	0.02%	9,552,857	0.14%
	Daily Transit Trips	240,347	239,757	-0.25%	240,090	-0.11%	229,399	-4.56%	238,798	-0.64%	226,621	-5.71%
7	Regional Congested Travel Times by Purpose											
	HBW	27.47	27.38	-0.33%	27.50	0.11%	26.01	-5.31%	27.30	-0.62%	25.83	-5.97%
	HBO	13.25	13.24	-0.08%	13.25	0.00%	13.74	3.70%	13.25	0.00%	13.76	3.85%
	NHB	14.16	14.20	0.28%	14.18	0.14%	14.21	0.35%	14.14	-0.14%	14.25	0.64%
	IX	61.28	61.19	-0.15%	61.33	0.08%	57.44	-6.27%	61.07	-0.34%	57.24	-6.59%
	XI	48.85	48.24	-1.25%	48.38	-0.96%	49.03	0.37%	48.85	0.00%	48.13	-1.47%
	COMM	13.54	13.56	0.15%	13.55	0.07%	13.63	0.66%	13.52	-0.15%	13.63	0.66%
8	Regional Congested Speed by Facility Type											
	_FWYSPD	42.88	44.64	4.10%	43.68	1.87%	45.33	5.71%	43.82	2.19%	47.68171	11.20%
	_RMPSPD	25.64	25.41	-0.90%	25.48	-0.62%	27.55	7.45%	27.36	6.71%	27.54	7.41%
	_ARTSPD	24.76	24.83	0.28%	24.79	0.12%	25.25	1.98%	24.93	0.69%	25.46	2.83%
	_LCLSPD	20.00	20.00	0.00%	20.00	0.00%	20.00	0.00%	20.00	0.00%	20	0.00%
9	Regional Elasticity by Facility Type	See Table 3										

TABLE 5 UDOT-WFRC Model Elasticity Analysis Using VMT

Model	VMT	Lane Miles	VMT	Lane Miles	Percent Change VMT	Percent Change LM	Elasticity
	2030 No-Build	**ALTERNATIVE 1**		***2030 Long-Range Plan with Addition of I-15 Improvements***			
Freeway	27,974,383	1318.84	28,584,448	1386.35	2.18%	5.1%	0.4260
Ramp	1,235,447	148.39	1,235,729	148.39	0.02%	0.0%	
Arterial	33,045,773	5526.56	32,819,488	5526.56	-0.68%	0.0%	
Local	5,447,292	1400.59	5,446,129	1400.59	-0.02%	0.0%	
Total	**67,702,896**	**8394.38**	**68,085,794**	**8461.89**	**0.57%**	**0.8%**	**0.7032**
	2030 No-Build	**ALTERNATIVE 2**		***2030 Long-Range Plan with Addition of U.S. 89 Improvements***			
Freeway	27,974,383	1318.84	28,147,633	1344.13	0.62%	1.9%	0.3229
Ramp	1,235,447	148.39	1,223,599	148.39	-0.96%	0.0%	
Arterial	33,045,773	5526.56	33,023,024	5526.56	-0.07%	0.0%	
Local	5,447,292	1400.59	5,447,516	1400.59	0.00%	0.0%	
Total	**67,702,896**	**8394.38**	**67,841,772**	**8419.67**	**0.21%**	**0.3%**	**0.6808**
	2030 No-Build	**ALTERNATIVE 3**		***2030 Long-Range Plan with Addition of Mountain View Corridor***			
Freeway	27,974,383	1318.84	29,539,659	1433.10	5.60%	8.7%	0.6458
Ramp	1,235,447	148.39	1,336,945	148.39	8.22%	0.0%	
Arterial	33,045,773	5526.56	32,793,463	5557.73	-0.76%	0.6%	
Local	5,447,292	1400.59	5,478,834	1400.59	0.58%	0.0%	
Total	**67,702,896**	**8394.38**	**69,148,901**	**8539.81**	**2.14%**	**1.7%**	**1.2328**
	2030 No-Build	**ALTERNATIVE 4**		***2030 Long-Range Plan with Addition of 700 E. South 1 Lane/Direction***			
Freeway	27,974,383	1318.84	27,890,866	1318.84	-0.30%	0.0%	
Ramp	1,235,447	148.39	1,210,121	148.39	-2.05%	0.0%	
Arterial	33,045,773	5526.56	33,180,120	5567.92	0.41%	0.7%	0.5431
Local	5,447,292	1400.59	5,449,986	1400.59	0.05%	0.0%	
Total	**67,702,896**	**8394.38**	**67,731,093**	**8435.74**	**0.04%**	**0.5%**	**0.0845**
	2030 No-Build	**ALTERNATIVE 5**		***2030 Long-Range Plan with All Improvements (Alts 1-4)***			
Freeway	27,974,383	1318.84	30,264,783	1525.90	8.19%	15.7%	0.5215
Ramp	1,235,447	148.39	1,330,376	148.39	7.68%	0.0%	
Arterial	33,045,773	5526.56	32,675,887	5599.09	-1.12%	1.3%	
Local	5,447,292	1400.59	5,481,199	1400.59	0.62%	0.0%	
Total	**67,702,896**	**8394.38**	**69,752,246**	**8673.98**	**3.03%**	**3.3%**	**0.9088**

TABLE 6 UDOT-WFRC Model Elasticity Analysis Using No-Build Trip Tables

Model	VMT	Lane Miles	VMT	Lane Miles	Percent Change VMT	Percent Change LM	Elasticity
	2030 No-Build	**ALTERNATIVE 3A**		***2030 Long-Range Plan with Addition of Mountain Valley Corridor, both trip distribution and mode choice constant***			
Freeway	27,974,383	1318.84	28,864,137	1433.10	3.18%	8.7%	0.3671
Ramp	1,235,447	148.39	1,302,932	148.39	5.46%	0.0%	
Arterial	33,045,773	5526.56	32,306,161	5557.73	-2.24%	0.6%	
Local	5,447,292	1400.59	5,448,256	1400.59	0.02%	0.0%	
Total	**67,702,896**	**8394.38**	**67,921,485**	**8539.81**	**0.32%**	**1.7%**	**0.1864**
	2030 No-Build	**ALTERNATIVE 3B**		***2030 Long-Range Plan with Addition of Mountain View Corridor, only trip distribution constant***			
Freeway	27,974,383	1318.84	28,854,490	1433.10	3.15%	8.7%	0.3631
Ramp	1,235,447	148.39	1,299,104	148.39	5.15%	0.0%	
Arterial	33,045,773	5526.56	32,338,422	5557.73	-2.14%	0.6%	
Local	5,447,292	1400.59	5,450,157	1400.59	0.05%	0.0%	
Total	**67,702,896**	**8394.38**	**67,942,173**	**8539.81**	**0.35%**	**1.7%**	**0.2040**
	2030 No-Build	**ALTERNATIVE 4A**		***2030 Long-Range Plan with 700 E. Improvement, both trip distribution and mode choice constant***			
Freeway	27,974,383	1318.84	27,845,572	1318.84	-0.46%	0.0%	
Ramp	1,235,447	148.39	1,216,027	148.39	-1.57%	0.0%	
Arterial	33,045,773	5526.56	33,161,175	5567.92	0.35%	0.7%	0.4666
Local	5,447,292	1400.59	5,447,644	1400.59	0.01%	0.0%	
Total	**67,702,896**	**8394.38**	**67,670,418**	**8435.74**	**-0.05%**	**0.5%**	
	2030 No-Build	**ALTERNATIVE 4B**		***2030 Long-Range Plan with 700 E. Improvement, only trip distribution constant***			
Freeway	27,974,383	1318.84	27,857,093	1318.84	-0.42%	0.0%	
Ramp	1,235,447	148.39	1,215,773	148.39	-1.59%	0.0%	
Arterial	33,045,773	5526.56	33,169,625	5567.92	0.37%	0.7%	0.5007
Local	5,447,292	1400.59	5,448,342	1400.59	0.02%	0.0%	
Total	**67,702,896**	**8394.38**	**67,690,834**	**8435.74**	**-0.02%**	**0.5%**	

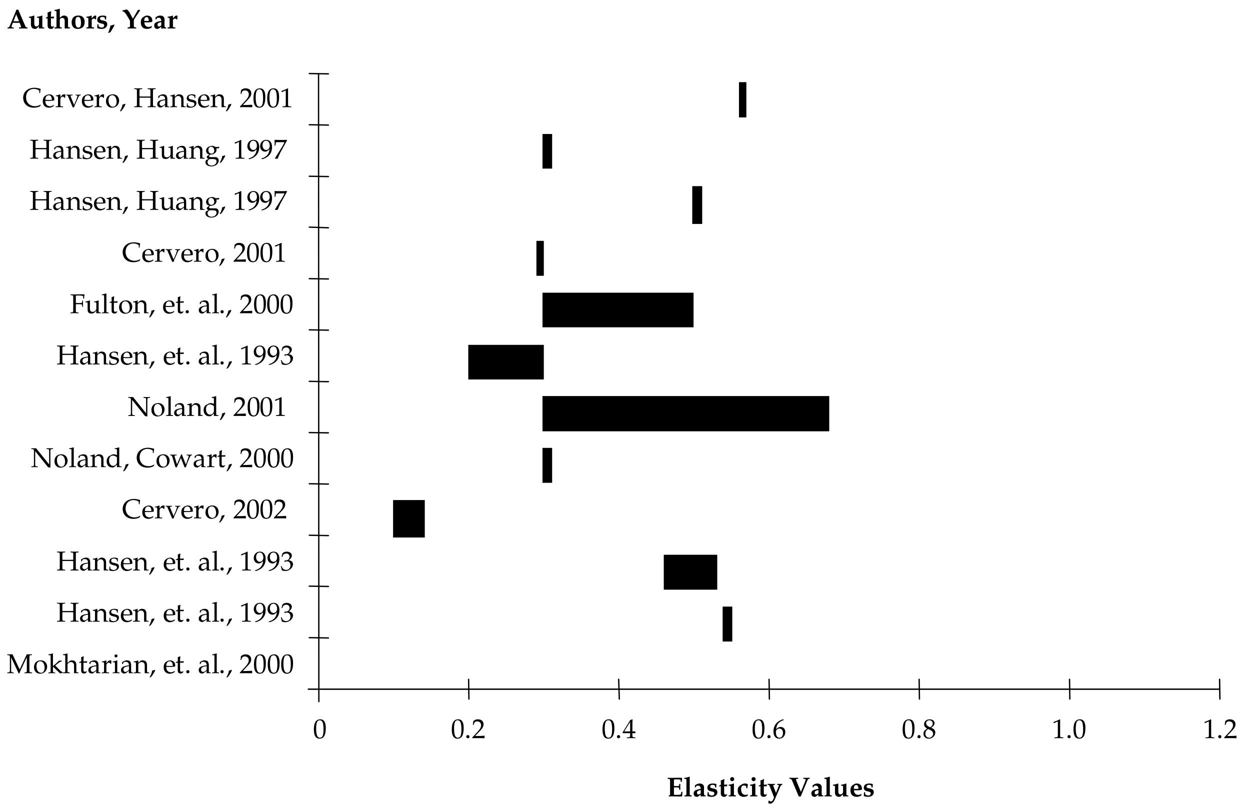


FIGURE 1 Short-term elasticity for all project types.

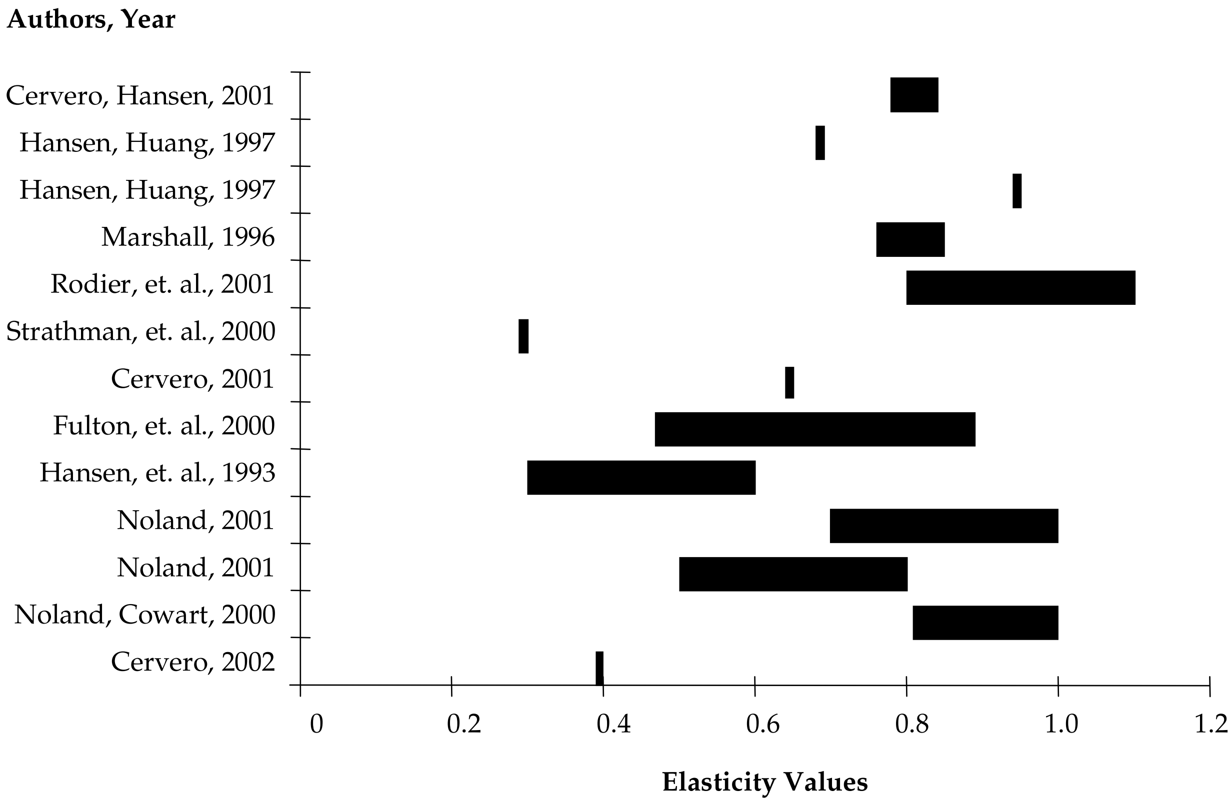
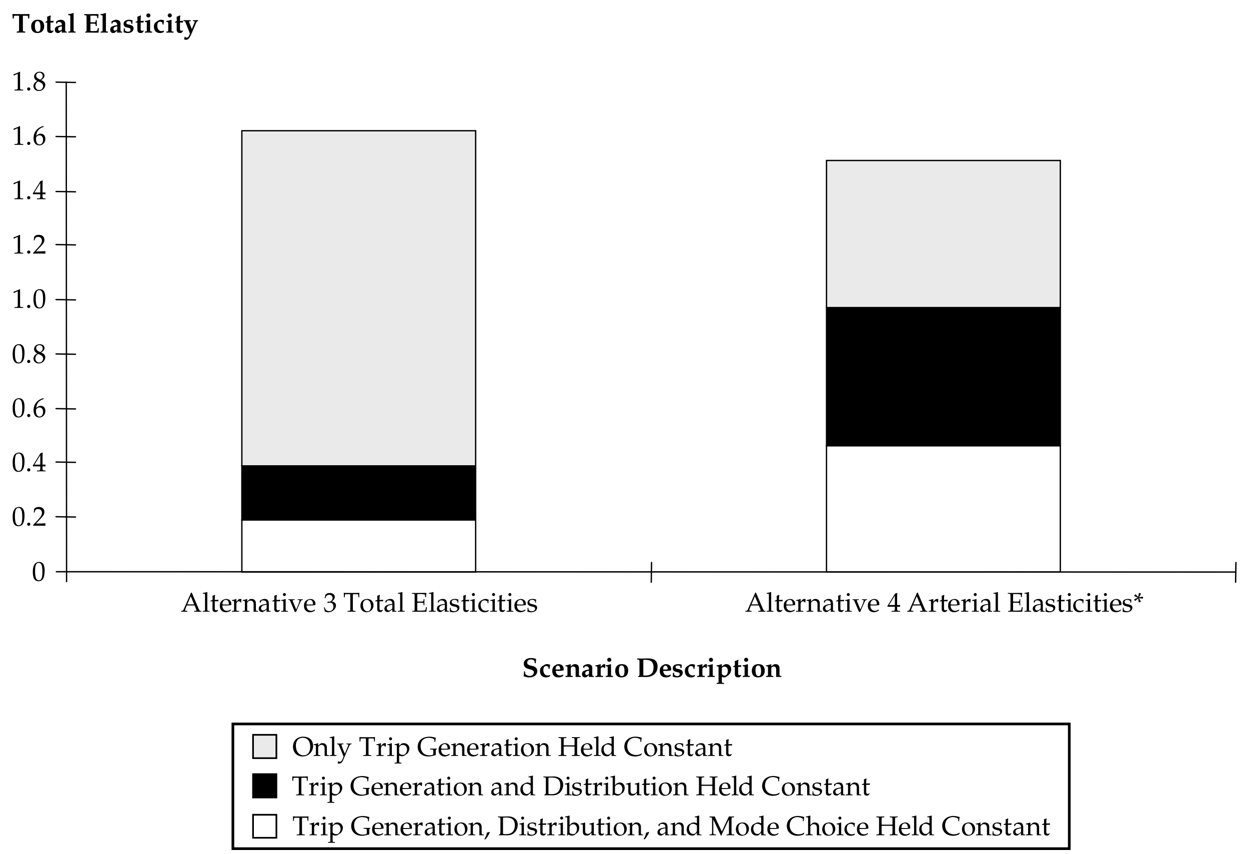


FIGURE 2 Long-term elasticity for all project types.



* Arterial elasticities reported for Alternative 4 because total elasticity values were very small.

FIGURE 3 Elasticities by model step.