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ACCOUNTING FOR INDUCED TRAVEL IN EVALUATION OF URBAN HIGHWAY EXPANSION

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Abstract

This paper demonstrates application of the principles of economic analysis to evaluate highway capacity expansion in an urban setting, using a sketch-planning model called "Spreadsheet Model for Induced Travel Estimation" (SMITE). The application takes into account new travel that may be induced by highway expansion over and above that which is simply diverted from other regional highways. We demonstrate how the effects of induced travel can be incorporated into the evaluation process at a sketch planning level of analysis, especially in cases where four-step urban travel models are either unavailable or are unable to forecast the full induced demand effects, such as in small and medium-sized urban areas. The methodology and the SMITE spreadsheet can be used to provide useful information to assist policy makers in evaluating proposals for specific additions to highway capacity for corridor studies. The spreadsheet will soon be made available at: *www.ota.fhwa.dot.gov/steam.*

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1.0 INTRODUCTION

Recently, the Federal Highway Administration (FHWA) (1) showed that the role of highway capacity expansion in increasing highway travel has been small relative to other factors. However, the paper concluded that "..the inducement of travel due to highway capacity expansion is an issue that needs to be and can be addressed..." FHWA has underway a travel model improvement program, which is attempting to develop improved modeling techniques for use in addressing issues such as the magnitude of induced travel. While these improved procedures are being developed, the debate about induced travel and its probable magnitude continues. This paper attempts to demonstrate how less sophisticated but currently available techniques may be used in the interim to estimate the magnitude of induced travel, at a sketch planning level of analysis.

Environmental groups, and occasionally the transportation literature, perpetuate certain misconceptions about induced traffic. For example, Hansen (2) states: "A 1.0 percent increase in lane miles generates a 0.9 percent increase in vehicle miles traveled (VMT) within 5 years. With so much induced traffic, adding road capacity does little to reduce congestion." Statements such as Hansen's are based on several misunderstandings about the sources of "induced" travel and the effects of capacity expansion on congestion levels. Through this paper we hope to clarify the misunderstandings that persist on the subject of travel "induced" by highway capacity expansion, and the value of highway expansion in relieving congestion in metropolitan areas. We discuss how induced travel can be estimated at the corridor level using the sketch-planning model called "Spreadsheet Model for Induced Travel Estimation" (SMITE), and demonstrate our methodology using an example travel corridor involving a proposal to expand freeway capacity.

2.0 DEFINING INDUCED TRAVEL

Much of the misunderstanding about induced travel stems from differing interpretations about its meaning in the context of highway capacity expansion. These interpretations are related to:

- whether the travel being referred to is "person" travel or "vehicle" travel -- for example, shifts from non-highway modes to the highway mode would not be acknowledged to be "induced" by those thinking in terms of person travel, since no *new* person trips are involved;

- whether the vehicle or person travel being referred to as "induced" consists only of absolutely new trips or whether it also includes additional miles of travel on existing trips, i.e., whether the *unit of measure* is "trips" or "miles";

- whether an increase in peak travel resulting from shifts in time of travel from off-peak to peak periods, without an increase in total daily travel, can be considered to be induced travel, i.e., the *time frame of reference*;

- whether travel on a specific facility, or in a specific corridor or sub-area, is being considered or whether it is the regionwide travel market that is of interest, i.e., the *geographic frame of reference* -- for example, much of the travel that may rightfully be considered to be "induced" with respect to a specific improved facility may simply be travel that has been diverted from parallel facilities in the travel corridor, or from other origins and destinations in the region, and is therefore not considered to be "induced" by those taking a regionwide perspective.

The debate about induced travel in metropolitan areas has arisen primarily because of the presumed negative environmental impacts of increased vehicle use. These impacts generally do not vary significantly by time of day. Thus, it is clear that what is of concern to environmental groups is additional *daily vehicle miles* of travel that might be generated at the *regionwide* level, and occasionally at the *corridor or facility* level. In other words, of relevance in the induced travel debate are changes in: (1) *vehicle*, not person travel; (2) vehicle *miles*, not vehicle trips; (3) *daily* vehicle miles, not peak period or peak hour vehicle miles; and (4) *regionwide* daily vehicle miles, or daily vehicle miles in a *specific corridor* or on a *specific facility*. In this paper, therefore, we define "induced" travel as an increase in daily vehicle miles of travel, with reference to a specific geographic context.

3.0 THE NEED TO ESTIMATE INDUCED TRAVEL

Induced travel can come from the following sources:

1. An increase in person trip production (P) related development
2. An increase in person trip attraction (A) related development
3. An increase in number of daily motorized person trip P's and A's *per development unit*
4. An increase in average motorized person trip distance
5. An increase in share of person travel by private motorized vehicles
6. A shift in vehicle travel to improved facilities from unimproved facilities within a corridor, or to an improved corridor due to diversion of traffic from other corridors.

When the frame of reference is the regionwide travel market, induced travel comes only from the first five sources. The sixth source comes into play at the facility and corridor levels, and may be more appropriately defined as diverted travel. Most transportation models do not capture induced travel from the first three sources. Most urban modelers do not increase input forecasts of total development regionwide to account for additional business and residential development induced to locate in the region by improvement in transportation levels of service, and often improved corridors are modeled with the same development inputs for the Build and No-Build cases. Environmental groups, on the other hand, believe that improved highways can significantly increase regional development (sources 1 and 2), a belief often shared by Chambers of Commerce. Also, it is believed that development induced by highway expansion is generally inaccessible by non-highway modes, resulting in dependence on automobiles, and consequently more vehicle trips per development unit, i.e. source 3 (3).

Most modelers use doubly-constrained trip distribution models, i.e., trips attracted to locations within the improved corridor are constrained by the number of trip attractions provided by the modeler. Therefore, additional trips attracted to a corridor due to accessibility improvements are not obtained from most four-step models, i.e., a portion of diverted travel (category 6) is not estimated by many four-step models, unless development and trip attractions are increased exogenously to reflect accessibility improvements.

The inability of four-step models to forecast the above sources of induced travel within a corridor may result in lower forecasts of traffic and air pollutant emissions, and higher estimates of speed for the Build case than would actually occur. Thus, four-step models could overestimate highway user travel time savings and underestimate environmental costs. Therefore, it is important for planners to account for induced travel sources not addressed by four-step models.

At the facility or corridor levels, induced travel comes from all six sources shown in Table 1. A study by Goodwin (4) compared model forecasts with observed traffic flows on nine improved urban roads in the U.K. He found that, for an average road improvement for which traffic growth is forecast by travel models, unpredicted traffic in the first year, over and above the forecast, was +5.7%. It is unclear whether the model estimates incorporated trip lengthening effects (source 4) and mode choice effects (source 5). On alternative routes (i.e., "relieved routes"), the average unpredicted traffic was +0.7% above the forecast. Based on long-term studies in six corridors, Goodwin suggests that unpredicted traffic in the long term is double the unpredicted traffic in the short term. He equates an additional 10% traffic to a demand elasticity, with respect to travel time, of -0.5. This suggests a short-term demand elasticity of about -0.28 at the corridor level in urban areas, based on the 5.7% unpredicted traffic, and a long term elasticity of about -0.57 (i.e., double the short-term elasticity).

4.0 ESTIMATING INDUCED TRAVEL IN A CORRIDOR

Only when capacity changes result in a reduction in the total user-perceived price of a trip (including both out-of-pocket and travel time costs) can any new travel be induced. Depending on the context, a capacity addition can either result in no change in price at all (e.g., if congested travel conditions do not exist to begin with); or it can reduce total price by varying amounts, depending on the level of congestion pre-existing. Thus the *context* of the capacity addition is of prime importance in estimating induced travel demand.

When capacity is added on a congested facility or to a congested network, new travel is attracted to it, depending on the elasticity of travel demand with respect to the travel time component of the full price of the trip. As discussed in Section 3, the recent literature suggests that *long term* demand elasticity averages -0.57 at the corridor level. However, researchers in the past have produced elasticity estimates as low as -0.2 and as high as -1.0 (5). The wide range results from several factors:

- *The relative importance of travel time in the full context of the trip*: For example, if the trip involves a high parking price at the destination end, it is likely that elasticity with respect to travel time will be relatively low.

- *The time frame*: In the short term, elasticity tends to be low, since route changes (part of source 6 in Table 1) and time of travel are the primary impacts (6). In the mid-term, mode shifts (source 5) and destination shifts (source 4 and part of source 6) become more important. In the long term, origin ends of trips may also shift or new trip origins may be generated due to absolutely new development (source 1), and further destination shifts may occur and new trip destinations may be generated (source 2) as homes and businesses locate in the improved corridor in response to accessibility improvements .

- *Diversion from other parts of the region*: The rate of increase in trips attracted to a corridor and the rate of increase in corridor development may differ based on other location characteristics of the improved corridor, e.g., availability of vacant land.

- *Length of trips served*: For example, Goodwin's study (4) shows that, while urban roads (which carry mainly intra-urban trips) have unpredicted traffic in the short term amounting to +5.7% on average, rural roads (which carry mainly long-distance and inter-urban traffic) have average unpredicted traffic amounting to +13.3%.

If we wish to develop an estimate of induced travel demand using demand elasticities, we must first estimate the reduction in the time "price". This reduction, converted into a percentage reduction, can then be used with elasticity estimates to provide estimates of induced travel demand. However, one complication is that as travel increases due to induced demand, the initial price reduction is slowly eroded. It is therefore necessary to go through a process of equilibration of demand and price. The change in travel time that occurs with increases in demand is easily modeled using speed-volume relationships (7). By iteratively estimating induced travel demand and the resulting time price change, an equilibrium point can be found at which demand and price are in balance.

A sketch planning application of the above methodology is demonstrated in this section for a hypothetical example corridor, using the Spreadsheet Model for Induced Travel Estimation (SMITE) developed by the authors. The analysis represents an 8 mile long corridor with a freeway facility which is proposed to be widened from 4 to 6 lanes, i.e., a 50% increase in capacity. There are several parallel arterial facilities. The analysis is demonstrated for scenarios representing three levels of initial congestion: low, medium and high.

The low congestion scenario assumes an average daily traffic (ADT) of 80,000 on the freeway. Hourly capacity (HC) is assumed to be 2,000 vehicles per lane, or 8,000 vehicles for all four lanes in both directions, yielding a ratio of average daily traffic volume to hourly capacity (ADT/HC) of 10.0. Over the 8 mile length of the facility, the freeway handles 640,000 VMT under this scenario. The moderate congestion scenario assumes a freeway ADT of 96,000, yielding an ADT/HC ratio of 12.0 and a facility VMT of 768,000. The high congestion scenario assumes a freeway ADT of 112,000, yielding an ADT/HC ratio of 14.0 and a facility VMT of 896,000.

Under pre-existing conditions, corridor traffic is assumed to be distributed 40% on the freeway and 60% on the arterials. Traffic diverted from arterials to the expanded freeway is first estimated, by redistributing traffic such that relative levels of congestion on the freeway and the arterials stay the same. This technique is based on principles in NCHRP Report No. 255 (8). Note that, alternatively, these estimates of the redistribution of traffic can be obtained by running traffic assignments with and without the freeway improvement, using a fixed vehicle trip table from the No-Build model run.

SMITE uses speed relationships developed by Margiotta et al. (9) to estimate the effects of congestion on speeds. The ADT/HC ratio is a key variable used to predict congestion-related delays. The speed estimates are sensitive to peak-spreading as well as queuing under congested conditions, and queues carried over from a congested hour to the next hour are accounted for. The speed relationships also consider variations of traffic volumes from day to day, which have a big impact on speeds when demand volumes are close to capacity.

SMITE allows the user to provide travel demand elasticity estimates to obtain estimates of induced travel (other than that diverted from arterials). For the example corridor, we used a moderate demand elasticity of -0.5 and an extreme value of -1.0. The -0.5 elasticity means that a reduction of travel time per mile of 10% will result in a demand increase of 5%, while the -1.0 elasticity means that the same 10% reduction will result in a 10% increase in demand. The -0.5 elasticity is close to the -0.57 elasticity estimate for urban areas derived from Goodwin's work (see Section 3), while the extreme -1.0 elasticity is reflective of a scenario where abundant vacant developable land exists within a corridor.

Note that SMITE applies these elasticities to estimates of traffic and travel time obtained *after* traffic diversion from arterials to freeway (part of source 6) is estimated. We believe this base is comparable to the modeled traffic used by Goodwin (4) in estimating unpredicted traffic growth. Induced VMT estimates are calculated for the freeway as well as for parallel arterials using these elasticities. Induced traffic associated with increases in highway speeds is calculated as follows:

$$F = \frac{1}{1 - \frac{1}{E_s * E_d}}$$

$$E_s = M * S_{av}$$

where:

- F is the fraction of an initial decrease in travel time that is off-set by induced traffic; e.g., F = 0 implies that none of the initial decrease is off-set. For very high values of both E_d and E_s, F approaches 1.0.

- E_d is the elasticity of demand for highway travel with respect to travel time; i.e., the percent change in demand due to a one percent increase in highway travel time (E_d is negative because an increase in highway travel time will reduce demand).

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- E_s is the elasticity of supply price (travel time) for highway travel with respect to demand; i.e., the percent change in the highway travel time per vehicle mile due to a one percent increase in VMT.

- M is added hours of congestion delay to other vehicles per added vehicle mile.

- S_{av} is average speed.

For highway capacity improvements:

$$F = \frac{H_i}{H_o}$$

where:

- H_o is the "initial" time savings for current users due to the improvement

- H_i is the subsequent increase in travel time for current users due to induced traffic

Recognizing that by definition $H_i = V_i * M$ (with all variables defined above), the following equation results from substituting for F, H_i, and E_s:

$$V_i = \frac{H_o}{M - \frac{1}{E_d * S_{av}}}$$

This is the equation used in SMITE to calculate induced travel for improvements to highway capacity, with S_{av} estimated as vehicle miles of travel divided by vehicle hours of travel after traffic diverted from arterials is accounted for. Table 1 summarizes the results. As indicated in the table, induced VMT estimates for the freeway vary by a factor of more than 2 between the low congestion and high congestion scenarios. Under severe initial congestion levels and an assumption of high demand elasticity, the 50% increase in capacity is almost "consumed" by the 47.5% VMT increase due to diverted and induced travel. When the entire corridor (including arterials) is considered, however, induced traffic ranges from 4.8% of base corridor traffic for low elasticity and low congestion to 11.5% for moderate to high congestion with high demand elasticity.

The increase in daily VMT on the freeway at high initial congestion levels would generally be accompanied by a shift in traffic from off-peak to peak periods, creating the perception that congestion has not been reduced significantly. This is the source of the misperception that "..adding road capacity does little to reduce congestion"(2). However, as the freeway and arterial average daily speeds shown in Table 2 suggest, congestion is reduced significantly, on both the freeway as well as the arterials, under all scenarios.

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TABLE 1. EFFECTS OF FREEWAY EXPANSION IN THE EXAMPLE CORRIDOR

	Level of Congestion		
	LOW	**MODERATE**	**HIGH**
For demand elasticity of -0.5			
Freeway:			
Initial VMT	640,000	768,000	896,000
Diverted VMT	160,000	192,000	224,000
Induced VMT	43,810	102,410	135,865
Total VMT after improvement	843,810	1,062,410	1,255,865
Percent change in VMT	31.85%	38.33%	40.16%
Arterials:			
Initial VMT	960,000	1,152,000	1,344,000
Diverted VMT	(160,000)	(192,000)	(224,000)
Induced VMT	37,799	45,365	51,359
Total VMT after improvement	837,799	1,005,365	1,171,359
Percent change in VMT	-12.73%	-12.73%	-12.85%
Corridorwide:			
Initial VMT	1,600,000	1,920,000	2,240,000
Diverted VMT	0	0	0
Induced VMT	81,609	147,774	187,224
Total VMT after improvement	1,681,609	2,067,774	2,427,224
Percent change in VMT	4.85%	7.15%	7.71%
For demand elasticity of -1.0			
Freeway:			
Initial VMT	640,000	768,000	896,000
Diverted VMT	160,000	192,000	224,000
Induced VMT	81,692	167,891	201,802
Total VMT after improvement	881,692	1,127,891	1,321,802
Percent change in VMT	37.76%	46.86%	47.52%
Arterials:			
Initial VMT	960,000	1,152,000	1,344,000
Diverted VMT	(160,000)	(192,000)	(224,000)
Induced VMT	69,555	82,097	88,639
Total VMT after improvement	869,555	1,042,097	1,208,639
Percent change in VMT	-9.42%	-9.54%	-10.07%
Corridorwide:			
Initial VMT	1,600,000	1,920,000	2,240,000
Diverted VMT	0	0	0
Induced VMT	151,246	249,988	290,441
Total VMT after improvement	1,751,246	2,169,988	2,530,441
Percent change in VMT	8.64%	11.52%	11.48%

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TABLE 2. ESTIMATED AVERAGE DAILY TRAVEL SPEEDS

	Level of Congestion		
	LOW	MODERATE	HIGH
For demand elasticity of -0.5			
Freeway:			
Initial speed before improvement (mph)	48.12	35.86	25.88
Final speed after improvement (mph)	53.79	41.64	29.92
Arterials:			
Initial speed before improvement (mph)	18.59	18.03	16.92
Final speed after improvement (mph)	19.15	18.71	17.93
For demand elasticity of -1.0			
Freeway:			
Initial speed before improvement (mph)	48.12	35.86	25.88
Final speed after improvement (mph)	52.22	37.38	26.80
Arterials:			
Initial speed before improvement (mph)	18.59	18.03	16.92
Final speed after improvement (mph)	19.01	18.56	17.72

5.0 EVALUATING HIGHWAY EXPANSION IN A CORRIDOR

For policy makers faced with the controversial issue of induced travel, the critical issue is not the magnitude of induced travel. Rather, the issue is whether the user benefits, including benefits to induced travelers and pre-existing travelers, and other benefits will exceed the external costs of induced travel (e.g., increases in air, water and noise pollution) and the public, social and environmental costs to be incurred in providing the added capacity. SMITE produces estimates of user benefits of the capacity addition, both for induced travelers as well as for pre-existing travelers, using conventional benefit-cost analysis procedures (10). User benefits calculated for the various scenarios for the example corridor are shown in Table 3.

SMITE also computes "external" costs of induced travel using user-provided estimates of external costs per VMT. For our example corridor, we used lower bound and upper bound estimates of average external costs per VMT of 3.7 cents and 86 cents respectively, based on research by Delucchi (11). Results for the example corridor are shown in Table 3. To account for the fact that some induced travel at the corridor level is actually due to diversion of traveler destination or diversion of development, SMITE allows a portion of the corridor-wide induced traffic attributable to these diversions to be first subtracted out to obtain true "regional-level" induced travel. The results in Table 3 suggest that, while the magnitude of induced travel as well as social costs associated with it increase with increasing levels of initial congestion, user mobility benefits also increase, due to larger reductions in congestion delays.

TABLE 3. USER BENEFITS, EXTERNAL COSTS AND NET BENEFITS

	Level of Congestion		
	LOW	MODERATE	HIGH
For demand elasticity of -0.5			
Daily user mobility benefits	$34,816	$66,307	$113,299
Other user benefits	$8,704	$16,577	$28,325
Total daily user benefits	$43,520	$82,883	$141,624
Daily external costs:			
Lower bound cost	$1,177	$2,034	$3,047
Upper bound cost	$27,357	$47,275	$70,821
Net benefits daily:			
(a) with lower bound external costs	$42,343	$80,849	$138,577
(b) with upper bound external costs	$16,163	$35,609	$70,803
NPV of net benefits per lane mile (million $):			
(a) with lower bound external costs	$8.41	$16.06	$27.53
(b) with upper bound external costs	$3.21	$7.07	$14.06
For demand elasticity of -1.0			
Daily user mobility benefits	$26,802	$31,857	$55,338
Other user benefits	$6,700	$7,964	$13,835
Total daily user benefits	$33,502	$39,821	$69,173
Daily external costs:			
Lower bound cost	$880	$938	$1,457
Upper bound cost	$20,456	$21,791	$33,871
Net benefits daily:			
(a) with lower bound external costs	$32,622	$38,883	$67,716
(b) with upper bound external costs	$13,046	$18,030	$35,302
NPV of net benefits per lane mile (million $):			
(a) with lower bound external costs	$6.48	$7.72	$13.45
(b) with upper bound external costs	$2.59	$3.58	$7.01

SMITE next computes net daily societal benefits (or disbenefits), and the Net Present Value (NPV) of a stream of benefits over the life of the investment. The capacity addition is economically justified if public agency, social and environmental costs to implement the capacity addition do not exceed NPV of societal benefits. To obtain the NPV, daily external costs were first subtracted from daily user benefits to get net daily societal benefits. These daily net benefits were then annualized using an annualization factor of 300, and a stream of uniform net annual benefits over a period of 20 years was converted to a NPV of benefits, using a 7% discount rate. This value was then converted to a NPV of benefits per lane mile, by dividing corridor net benefits by the 16 lane miles of added freeway capacity proposed for the example corridor. Table 3 shows the results. The NPV of benefits per lane mile is the maximum present value (PV) of public expenditure, including both capital and operating and maintenance costs, that is economically warranted per lane mile, so that economic benefits to society might exceed costs to society, assuming no uncompensated environmental or social impacts from the expansion itself.

The results suggest that, when demand elasticity is -0.5, depending on pre-existing congestion levels and monetary values ascribed to external costs per VMT, public costs ranging from $3.2 to $27.5 million per lane mile could be justified in the corridor. For the high demand elasticity extreme of -1.0, $2.6 million to $13.5 million per lane mile could be justified. For comparison, the U.S. DOT
uses a typical cost of $2.283 per lane mile in 1989 dollars (i.e., $3.0 million per lane mile in 1997 dollars) for freeway lane additions in national policy analysis (12).

6.0 CONCLUSIONS

For policy makers faced with the controversial issue of induced travel, the critical issue is not whether highway capacity additions result in induced travel, but whether net societal benefits, after accounting for the external costs of induced travel, will exceed the public costs and social costs to be incurred in implementing the capacity addition. The application example in this paper shows how answers to this question can be obtained under typical scenarios at the corridor level of analysis, using the spreadsheet software SMITE. The application example also demonstrates how the effects of induced travel can be incorporated into the evaluation process at a sketch planning level of analysis, especially when urban travel models are either unavailable or are unable to forecast the full induced demand effects.

The results of the example analysis provide a basis for some broad conclusions about the user benefits and external costs of vehicle use resulting from highway capacity additions. The results suggest that, while the magnitude of induced travel as well as social costs associated with it increase with increasing levels of initial congestion, user mobility benefits also increase, due to larger reductions in congestion delays. Consequently, even when the magnitude of induced travel is high, capacity expansion could be warranted, depending on the public and social costs to be incurred in implementing the capacity expansion.

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