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The Vehicle-Miles of Travel—Urban Highway Supply Relationship

An NCHRP staff Digest of the essential findings from the final report on NCHRP Project 8-19, "The Relationship of Changes in Urban Highway Supply to Vehicle-Miles of Travel" by E. R. Ruiter, W. R. Loudon, C. R. Kern, D. A. Bell of Cambridge Systematics, Inc., Cambridge, MA, and M. J. Rothenberg and T. W. Austin of JHK and Associates, Inc., Alexandria, VA.

THE PROBLEM AND THE CONCLUSIONS REACHED

The concept that highways generate their own demand and subsequent vehicle-miles of travel (VMT) has been so widespread over the past 5 years that it has gained legitimacy if only by sheer repetition. Challenges to proposed highway improvements are based on perceived adverse air quality and energy impacts on the belief that such impacts increase in severity as VMT increases. VMT reduction requirements have been placed on many transportation planning agencies, resulting in plans being promulgated which implement VMT reduction measures. Highway agency attempts at both air quality improvements and energy conservation efforts have been based on the argument that increased highway supply frees traffic flow and leads to more efficient operation of the system. Such improvements, it is argued, more than offset any increase in overall travel. A clear understanding of the effect of highway supply on VMT was needed to adequately address the interrelationship of transportation, air quality, and energy consumption.

The objective of this research was to determine whether a relationship exists between measures describing urban highway supply and VMT and, if so, to quantify the relationships. Furthermore, highway supply measures were to be related to air pollution rates and fuel consumption through the use of known VMT/air pollution/fuel consumption relationships. To be useful to practitioners, the relationships were to be generalized and in the form of tables, graphs, and monographs.

The review of previous research and the analysis process carried out in this project have led to the conclusion that there is a relationship between urban highway supply and vehicle-miles of travel (VMT). Although this conclusion is not unanimous among previous analysts of the topic, many previous studies point to this relationship. The work reported here shows that when urban travel is simulated using a detailed set of empirical models, validated against observed data, VMT changes do occur as highway supply changes are specified. Even when the total VMT change in a large urban area is predicted to be insignificant, its variations by location, type of highway facility, and highway speed result in much more significant changes in a wide range of VMT-related impacts: mobility, quality of travel service, air quality, fuel consumption, and safety.

This research produced the required relationhsips but in the form of complex, computer software rather than in the intended tables and graphs. The relationship of VMT to the highway supply measures, vehicle-miles of capacity (VMC) was found to be complex and difficult to generalize for all situations. With the resources available for this research, only two cases could be analyzed. Both cases were urban radial freeways where substantial capacity was added. VMT generally increased with vehicle-miles of capacity, but the increases were small -- 1/3 percent or less. For one case, VMT increases in the peak period were offset by VMT decreases in the off-peak period.

More important than changes in VMT itself are changes in the VMT-related impacts, air pollution, and fuel consumption. For both cases, measures of air quality (with the exception of NO_x pollutants) and fuel consumption are improved. Also, travel-related impacts such as mobility, quality of travel service, and travel safety are improved.

Inasmuch as these changes, found from applying a complex system of disaggregate travel demand models, are probably within the error range of the system, they must be treated with caution. This research has not been conclusive and, therefore, in addition, evidence from future research must be considered in evaluating site-specific situations. Nevertheless, the conclusions drawn represent the most informed judgments to date.

FINDINGS

Although the researchers have concluded that there is a highway supply relationship, this relationship is not direct. A complex causal linkage exists: highway supply changes bring about travel time and cost (level-of-service) changes, which, in turn, effect travel pattern changes. In the short run, travel patterns and levels of service interact, resulting in an equilibrium. In the long run, the short-run changes (with many other factors) influence future land-use patterns. These land uses influence travel patterns, which must again reach an equilibrium by interacting with highway levels of service. In both the short run and the long run, VMT levels exist as one of many aggregate measures of the impacts of the highway supply changes.

The complexity of this causal linkage between highway supply and VMT has two important consequences: first, the direction of VMT changes because a given highway supply change can vary; second, there are many variables that affect both the direction and the magnitude of VMT changes. In order to quantify the relationship, all of the following variables must be considered:

- The type of highway supply change. Many reasons suggest that such changes as new freeway construction, freeway expansion, arterial street improvements, high-occupancy vehicle incentives, and pricing policies (tolls) can have major differences in their impacts on VMT.

- The scale of the highway supply change. VMT changes per unit of capacity added are likely to decrease as the number of capacity units increase.

- The context within which the supply change takes place. Highway and transit travel patterns, levels of congestion, alternative travel routes, land uses, and socioeconomic characteristics in the corridor containing the facility, and the orientation of this corridor (radial versus circumferential, for example).

- The time scale. Short-run changes (before changes in land use have time to occur) versus long-run changes.

Beyond these general findings, the following conclusions were reached specifically with respect to the test cases studied in this project and are limited to short-run impacts. The freeway construction case, called Test Facility 1, was the construction of 5 miles of new 8-lane freeway located in the City of Oakland, which provided connections to the Oakland Bay Bridge leading to San Francisco on the west and the Caldecott Tunnel (leading to the East Bay suburbs from Orinda to Concord) on the east. The freeway expansion case, called Test Facility 2, was an expansion of 12 miles of freeway from 4 lanes to either 6 lanes or 8 lanes, depending on geographical location. The facility begins at the Caldecott Tunnel on the west and proceeds eastward to the suburbs of Orinda and Concord. Both facilities are urban radial freeways.

- Changes in VMT occur as the urban highway system is changed (see Table 1). Both the model results and corroborating observed highway traffic count data show this to be the case.

TABLE 1

COMPONENTS OF DAILY VMT CHANGES

Travel Characteristic	Test Facility 1		Test Facility 2	
	%Δ[a]	E[b]	%Δ[a]	E[b]
Vehicle-Miles of Capacity (VMC)	+0.855	--	+0.647	--
Total Person Trips (TRIPS)	+0.622	+0.748	+0.170	+0.263
Auto Mode Split (AMS)	+0.053	+0.060	+0.021	+0.032
Autos per Auto Person Trip[c] (1/OCC)	+0.021	+0.024	+0.005	+0.008
Average Trip Distance (ATD)	-0.365	-0.412	-0.205	-0.317
Vehicle-Miles of Travel (VMT)	+0.335	+0.379	-0.006	-0.009

[a] %Δ = (Base Case - Test Facility)/Test Facility

[b] E = elasticity of travel characteristic with respect to VMC.
= %Δ(Travel Characteristic)%ΔVMC

[c] This characteristic is expressed as the inverse of auto occupancy so that the sign of its change is directly related to the sign of the resulting impact on VMT.

- In the freeway construction case, VMT increases as highway supply increases, both in peak and off-peak periods. In the freeway expansion case, peak-period VMT increases are offset by off-peak periods; they have quite different impacts on VMT.

- In absolute magnitudes, off-peak VMT changes dominate peak-hour changes. In percentage terms, however, peak-period changes are more significant.

- Geographically, new highway capacity has the primary result in the peak period of new VMT on the facility itself; the secondary result of increased VMT in the transportation corridor of which the facility is a part (to obtain access to the new facility); and finally a reduction in VMT outside this corridor (because of diversion into the corridor). However, this reduction only partially offsets the increases within the corridor.

- The most important components of VMT changes for both facilities are total person-trips, which increase, and average trip distance, which decreases (Table 1). Less important (by an order of magnitude) are the auto mode split and auto occupancy components.

- None of the existing aggregate areawide VMT models were successful in matching the results obtained in this project for both test facilities. Although this fact in itself does not invalidate either modeling approach, it does suggest that the inability of the areawide models to reflect differences in types of highway supply changes severely limits their potential usefulness.

- Although VMT increases for one test facility and remains essentially unchanged for the other, VMT-related impacts for both cases generally improve when studied at the urban area level (see Tables 2 and 3). Measures of urban mobility, quality of travel service, air quality (with the exception of the relatively less critical level of NO_x pollutants), fuel consumption, and travel safety all are improved at this level.

- The common practice of expressing the relationship of VMT and highway supply as a constant elasticity of VMT with respect to average highway speed is potentially misleading. This elasticity varies from 1.2 to 3.3 for the two facilities studied, whereas other normalized measures varied much less. Two measures directly relating VMT and highway supply are recommended. These are the fraction of new capacity "used" ($\Delta VMT/\Delta VMC$) and the elasticity of VMT with respect to vehicle-miles of capacity ($E[VMT/VMC]$). Both of these measures are also more useful because they do not require the prediction of changes in average highway speed as supply changes are made.

- In the test cases analyzed in this project, the range of values for these two normalized measures for regionwide data are given in Table 4.

TABLE 4

THE HIGHWAY SUPPLY/VMT RELATIONSHIP

Period	$\frac{\Delta VMT}{\Delta VMC}$	$E(\frac{VMT}{VMC})$
Peak	+.25 to +.35	+.50 to +.70
Off-Peak	-.03 to +.05	-.20 to +.33

TABLE 2

TEST FACILITY 1 RESULTS: VMT-RELATED IMPACTS

Impact(a) (units)	Value			Difference: Base Case versus Test Facility 1(b) (percent)		
	Peak Hour	Average Off-Peak Hour	24 Hours	Peak Hour	Average Off-Peak Hour	24 Hours
Carbon Monoxide (pounds/time period)	778,300	198,100	5,915,000	-1.09	-0.61	-0.74
Hydrocarbons (pounds/time period)	120,500	33,830	985,100	-0.26	-0.36	-0.36
Nitrogen Oxides (pounds/time period)	70,330	24,470	679,100	+0.87	+0.94	+0.92
Fuel (gallons/time period)	515,600	177,200	4,929,000	-0.16	-0.02	-0.05
Operating Costs (dollars/time period)	706,600	n/a(c)	n/a	-1.16	n/a	n/a
Accidents (number/time period)						
Total	67.38	n/a	n/a	-1.57	n/a	n/a
Injury	12.05	n/a	n/a	-1.16	n/a	n/a
Fatal	0.17	n/a	n/a	0	n/a	n/a

(a) All pollutants based on the distribution of auto model years existing in 1972.

(b) The percentage difference between the base case (the situation in which the freeway construction, Test Facility 1, is included) minus the results for the situation without this facility: 100*(Base Case - Test Facility 1)/Test Facility 1.

(c) n/a = not available; only provided by peak-period traffic assignments.

SOURCE: HBTRIPS program results, expanded to include nonhome-based travel. Peak-hour values based on average rates for work travel; off-peak values based on average rates for home-based nonwork travel.

TABLE 3

TEST FACILITY 2 RESULTS: VMT-RELATED IMPACTS

Impact(a) (units)	Value			Difference: Base Case versus Test Facility 2(b) (percent)		
	Peak Hour	Average Off-Peak Hour	24 Hours	Peak Hour	Average Off-Peak Hour	24 Hours
Carbon Monoxide (pounds/time period)	777,200	198,100	5,913,000	-0.95	-0.63	-0.71
Hydrocarbons (pounds/time period)	120,300	33,830	984,900	-0.16	-0.36	-0.31
Nitrogen Oxides (pounds/time period	70,710	24,710	685,300	+0.33	+0.05	+0.03
Fuel (gallons/time period)	515,000	177,100	4,926,000	-0.03	-0.00	-0.01
Operating Costs (dollars/time period)	705,500	n/a(c)	n/a	-1.01	n/a	n/a
Accidents (number/time period)						
Total	67.02	n/a	n/a	-1.04	n/a	n/a
Injury	11.99	n/a	n/a	-0.67	n/a	n/a
Fatal	0.17	n/a	n/a	0	n/a	n/a

(a) All pollutants based on the distribution of auto model years existing in 1972.

(b) The percentage difference between the base case (the situation in which the freeway expansion, Test Facility 2, is included) minus the results for the situation without this facility: 100*(Base Case - Test Facility 2)/Test Facility 2.

(c) n/a = not available; only provided by peak-period traffic assignments.

SOURCE: HBTRIPS program results, expanded to include nonhome-based travel. Peak-hour values based on average rates for work travel; off-peak values based on average rates for home-based nonwork travel.

APPLICATIONS

Because only a limited amount of experiments was conducted, it was not possible to generalize the findings to obtain an estimate of the complete relationship between highway supply and VMT. Nevertheless, short-range results have been obtained for urban radial freeway construction and expansion that could be compared with both observed data and alternative estimation methods. These results demonstrate the validity of the approach, as well as the care that must be taken in applying the existing more simple models. They show the importance of considering all of the types of variables listed previously, as well as explicitly dealing with each of the steps of the causal linkages that have been described. They also show the feasibility of determining the VMT level and its related impacts for a specific urban highway supply change, using the analysis process developed in this project.

The product of this research for use by analysts is a system of computer programs with supporting documentation. This system has been named EDS because it is an urban transportation planning system based on:

- Predicting the Equilibrium of travel supply and demand in a transportation network;
- Using Disaggregate (household- and individual-based) travel-demand models; and
- Using Sampling techniques, including the sampling of both households and trip destinations, to reduce analysis costs.

The system was developed to be fully compatible with the UMTA/FHWA Urban Transportation Planning System (UTPS) and, therefore, is designed to operate in the same computer environment--an IBM 360 or 370 series computer (or equivalent) with disk and tape input/output units, at least 60,000 bytes of real or virtual computer memory, and the full Operating System. Therefore, an agency with resources to apply UTPS is in a position to use EDS. Running costs are approximately $1,500.00 per three-iteration run for a 440-zone system having 9000 links. Three iterations are usually required to reach equilibrium between highway supply and vehicle demand.

THE FINAL REPORT AND COMPUTER SOFTWARE

The products of this research are the final report, computer tape, EDS program documentation, and sample run. The final report of this project will not be published in the regular NCHRP series. A microfiche copy of the agency's final report may be purchased from the TRB Publications Office, 2101 Constitution Avenue, N.W., Washington, D.C., 20418, for $3.50 prepaid; or a paper copy may be obtained, on a loan basis, by request to the Director, Cooperative Research Programs.

The computer tape and EDS program documentation are available from the Director, Cooperative Research Programs, at a cost of $30.00 (the cost of duplication). Requestors should provide a blank, 9 track, 1600 BPI tape. The sample run, if required, is only available on a loan basis.

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