2. F. Mills. Effects of Beltways on the Location of Residence and Selected Work-Places. In Transportation Research Record 812, TRB, National Research Council, Washington, D.C., 1981, pp. 26-33.
3. Payne-Maxie Consultants. The Land Use and Urban Development Impacts of Beltways, Guidebook. U.S. Government Printing Office, Washington, D.C., June 1980.
4. Payne-Maxie Consultants. The Land Use and Urban Development Impacts of Beltways, Case Studies. U.S. Government Printing Office, Washington, D.C., June 1980.
5. F.S. Chapin and E.J. Kaiser. Urban Land Use Planning. University of Illinois Press, Urbana, 1979.

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Effects of Freeway Stage Construction on Nearby Land Uses and Vehicle User Costs

JESSE L. BUFFINGTON, MARGARET K. CHUI, and JEFFERY L. MEMMOTT

ABSTRACT

Because of the huge costs involved, most freeways are commonly constructed in lateral or longitudinal stages. In the case of lateral stage construction, service roads are constructed and opened to traffic before the main lanes. In the case of longitudinal stage construction, the service roads or main lanes are constructed on a freeway section-by-section. Impacts of stage construction include adjacent area land use development, user travel time costs, vehicle running and speed change costs, and accident costs. This paper contains the findings of a study of stage construction impacts on two freeways located in Houston, Texas: (a) one completely stage constructed and (b) the other partly stage constructed. Although authorization was given to purchase right-of-way for both freeways within 2 years of each other, the second freeway to receive authorization was completed at least 6 years before the first. During the "before" construction period, the socioeconomic characteristics of the areas adjacent to the two freeways are shown to be generally similar. During the construction and "after" periods these characteristics are shown to be dissimilar, partly because of differences in the construction schedules of the two freeways. A regression analysis of historical land use changes reveals that certain land uses are sensitive to nonstaged freeway construction. Other variables such as abutting and nonabutting, freeway location differences, capacity changes, and average daily traffic volumes are included in the analysis. A user analysis reveals that staging a freeway costs more in vehicle user costs than benefits gained from delaying construction expenditures.

It is recognized that a major thoroughfare, such as a freeway, attracts not only traffic but also affects nearby land uses. The presence of a major thoroughfare can obviously set off a chain reaction among land uses with one land use affecting other land uses. Accessibility resulting from the existence of the thoroughfare is a major contributing factor. People are more willing to live farther from the city or farther from other currently well-developed areas if they can count on a quicker way to get to and from work. Industries are less reluctant to rule out the possibility of locating their firms in rural areas if they are certain of good accessibility for their workers and for their goods and supplies.

Besides the mere presence of a freeway, it is believed that the method of constructing a freeway can influence how land is used. Because of the huge costs involved, most freeways are commonly built in longitudinal or lateral stages. In longitudinal staging, one segment of the freeway is built and opened before the next segment is started. In lateral staging, the service roads, if any, or part of the main lanes are built first. Later, all of the remaining main lanes are constructed.

It is also believed that staging of freeways affects user costs. A freeway does not reach maximum efficiency in carrying traffic until all the main lanes and service roads are constructed and opened for use. Until this is accomplished, part of the traffic that would normally use the freeway will have to choose an alternate route in the corridor that may require more travel time, incur higher vehicle operating costs, and be more hazardous from an accident standpoint.

The land use and user effects of freeway stage construction are not documented in the literature. A study just completed by Chui, Memmott, and Buffington reveals some of the economic effects of staging two freeways in Houston, Texas (1). The results of that study are summarized in this paper. Ideally, one of the freeways should have been staged and the other nonstaged with the latter considered as a control for the purpose of studying the staging effects of a freeway. However, a survey of the construction histories of freeways over the state revealed the absence of an ideal pair of freeways for study. Efforts were then diverted to searching for two staged freeways that had different amounts of lateral stage construction. For example, one of the freeways had to have at least one section nonstaged laterally and the other sections staged over a longer period of time than the other freeway.

Using the preceding guidelines, the Northwest (NW) freeway or US-290 was selected to be the study facility and the Southwest (SW) freeway or US-59 was selected to be the control facility. All of the study sections of the NW freeway were constructed in lateral and longitudinal stages. All but Section 1 of the SW freeway were constructed in lateral stages. Figure 1 shows the location of the two freeways and the study sections. The first section of the SW freeway (SW1) had both its service roads and its main lanes opened at the same time, and the other three sections were staged over a much shorter period of time than those of the NW freeway. Even the longitudinal staging of the SW freeway was different from that of the NW freeway. The service roads were not staged longitudinally on the SW freeway, whereas both the service roads and the main lanes were staged longitudinally on the NW freeway.

This paper contains a comparison of staging as opposed to nonstaging of freeway construction by studying various sections of the NW and SW freeways. The various historical characteristics of the two freeways and the surrounding areas are compared to determine major before and after construction differences. Among the characteristics analyzed are the following: (a) construction schedule, travel volume, and cost characteristics of the study freeways; and (b) socioeconomic characteristics of the study areas.

The impact of stage construction of the study freeways is determined by measuring changes in abutting or nearby land use and vehicle user costs. The land use impact of stage construction is determined by evaluating historical land use data with two simultaneous equation estimation techniques, and the vehicle user cost impact is determined by inputting historical traffic data into the Texas Highway Economic Evaluation Model (HEEM) (2).

Finally, this paper contains conclusions and recommendations that are based on the findings of the user cost and land use analyses.

CHARACTERISTICS OF THE STUDY FREEWAYS AND AREAS

Based on definitions given earlier on staging and nonstaging freeway construction, Section 1 of the SW freeway (Figure 1) is nonstaged because both the service road and the main lanes were built simultaneously and opened for use in 1962, whereas the other sections of the SW freeway and all sections of the NW freeway are staged.

In this section of the paper, various characteristics of these two freeways and the areas along them are discussed separately.

Construction, Traffic Volume, and Cost Characteristics of Study Freeways

Table 1 gives the section lengths, opening dates, and time lapse from the date of authorization to purchase of right-of-way (ROW) until the date of opening the service roads and main lanes, for each section of the freeways under study. Figure 1 shows the location of the two study freeways in relation to the Houston metropolitan area. All sections of the two freeways are of adequate length for study. The total lengths of the study portions of the two

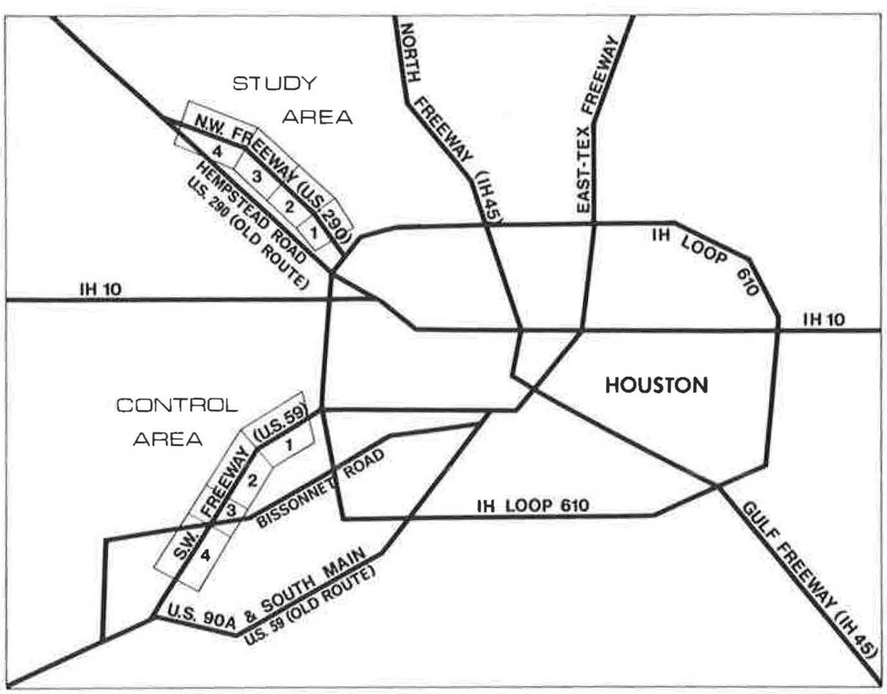

FIGURE 1 Location of the NW and SW freeways and study sections in Houston, Texas.

TABLE 1 Section Lengths, Opening Dates, and Time Lapse from Date of Authorization to Purchase of Right-of-Way Until Date of Opening Service Roads and Main Lanes of Study Freeways

Freeway	Section	Section Length (miles)[a]	Opening Dates		Time Lapse Since ROW Authorization[b]	
			Service Roads	Main Lanes	Opening of Service Roads	Opening of Main Lanes
SW	1	2.1	1962	1962	4	4
SW	2	2.5	1962	1965	4	7
SW	3	1.4	1962	1969	4	11
SW	4	2.5	1962	1974	4	16
NW	1	0.8	1970	1975	10	15
NW	2	1.4	1970	1979	10	19
NW	3	1.4	1975	1981	15	21
NW	4	2.5	1975	Not open	15	Not open

[a]The combined length of the four study sections is 8.5 mi for the SW freeway and 6.1 mi for the NW freeway.
[b]Time lapse since year when authorization was given to purchase the right-of-way for each freeway. The authorization date is 1958 for the SW freeway and 1960 for the NW freeway.

freeways are comparable, with 8.5 mi of the SW freeway and 6.1 mi of the NW freeway.

The authorization date to purchase the right-of-way is 1958 for the SW freeway and 1960 for the NW freeway. As indicated in Table 1, there are considerable lateral stage construction time lapses from the right-of-way authorization until the opening of the service roads and main lanes. Only in the case of Section 1 of the SW freeway is there no time lapse between opening the service roads and the main lanes. For Section 1 of the NW freeway, the time between opening the service roads and the main lanes is 5 years.

Also, there are considerable longitudinal construction time lapses between opening one section of service roads or main lanes until opening another section of service roads or main lanes on both freeways. Such time lapses are smaller for the SW freeway than for the NW freeway. Again, there is no time lapse between opening each section of service roads on the SW freeway. In the case of the NW freeway, there is a 5-year time lapse between the 1970 opening of Sections 1 and 2, and the 1975 opening of Sections 3 and 4.

Design and Traffic Volumes of the Study Freeways and Alternate Routes

The designs of the study freeways and the alternate routes that they replace are similar. Both freeways have six to eight main lanes and four- to six-lane service roads serving each section. The alternate routes for each of the study freeways have four undivided lanes. As shown in Figure 1, Hempstead Road is the alternate route for the NW freeway and South Main is the alternate route for the SW freeway.

Table 2 gives the average daily traffic (ADT) volumes on the study freeways and alternate routes according to freeway right-of-way purchase and construction stage. The ADT on alternate routes is near the same level at the time of authorization to purchase the right-of-way for the two freeways. With such a small difference in ADT on the alternate routes at that time, and with other things being equal, it would be expected that both freeways would be built on about the same time schedule. As indicated in Table 1, the completion date for all four sections of the SW freeway is 6 years before the completion date for three sections of the NW freeway.

Table 2 gives the effects of delayed construction of the NW freeway on its ADT as well as the ADT of

TABLE 2 Average Daily Traffic Volumes on Study Freeways and Alternate Routes, by Freeway Right-of-Way Purchase and Construction Stage

Freeway Right-of-Way Purchase and Construction Stage	Study Freeways		Alternate Routes	
	SW	NW	South Main	Hempstead Road
Right-of-way purchase authorized[a]	–	–	13,705	12,205
Service roads open[b]				
Section 1	9,700	12,400	14,330	22,280
Section 2	9,700	12,400	14,330	22,280
Section 3	9,700	27,915	14,330	17,526
Section 4	9,700	27,915	14,330	17,526
Main lanes open[b]				
Section 1	9,700	27,915	14,330	17,526
Section 2	12,060	48,000	13,880	17,526
Section 3	66,450	Not obtained	16,420	20,714
Section 4	111,495	Not open	21,060	Not obtained

Note: Dash = not applicable.
[a]Year that authorization was given to purchase right-of-way for freeways, which is 1958 for the SW freeway and 1960 for the NW freeway.
[b]Year after opening service roads or main lanes.

its alternate route at the same construction stage of the SW freeway. As can be seen, the ADT on the NW freeway and its alternate route is higher than the ADT on the SW freeway and its alternate route at any comparable stage of construction.

Right-of-Way and Construction Costs

Table 3 gives the right-of-way costs for the two freeways, as measured in 1962 dollars, using the U.S. Consumer Price Index (CPI). A comparison of the cost per mile reveals that the right-of-way cost for the SW freeway is about 28 percent lower than that for the NW freeway. Part of this difference can be explained by the fact that some of the right-of-way for the SW freeway was donated by one or more landowners. Stage construction allowed more time for purchasing the right-of-way, but this time delay resulted in higher right-of-way costs, in real terms, for the NW freeway.

Table 3 also gives the construction costs, measured in 1962 dollars, of the study portions of the two freeways. These costs include traffic signal and lighting costs. The construction cost per mile for the NW freeway is 2.2 times that for the SW freeway. Most of the extra construction cost incurred on the NW freeway is a result of the delay in construction

TABLE 3 Right-of-Way and Construction Costs of the Study Portions of NW and SW Freeways in Constant 1962 Dollars

Freeway and Freeway Element	Cost per Mile[a] ($)	Total Cost[a] ($)
NW freeway		
Right-of-way	110,469	673,860
Construction[b]	3,694,590	22,537,000
Total	3,805,059	23,210,860
SW freeway		
Right-of-way	79,983	679,854
Construction[b]	1,716,118	14,587,000
Total	1,796,101	15,266,854

Source: Texas State Department of Highways and Public Transportation.
[a]Cost of the four study sections of each freeway, covering a total distance of 6.1 mi for the NW freeway and 8.5 mi for the SW freeway. The U.S. Consumer Price Index is used to deflate these costs.
[b]Includes traffic signal and lighting costs.

of the main lanes and the rise in construction costs in excess of prices in general.

Socioeconomic Characteristics of Study Areas

The study areas defined in this study include a one-half mile strip of land on each side of the study freeways. It is believed that an investigation of the changes in population, housing units, housing costs, and family income in the study area should reveal some of the social and economic characteristics of the general areas where the freeway facilities are located. Census tract data collected by the U.S. Bureau of Census are used to analyze these characteristics in each study area.

Table 4 gives the socioeconomic characteristics of the study areas in the before period (1950-1960) and in the during and after period (1960-1970). In 1950 and 1960, the socioeconomic characteristics of the two areas were generally similar. By 1970 the socioeconomic characteristics of the two areas became dissimilar. By that time the construction schedules of the two freeways were quite different, thus encouraging faster settlement and development along the SW freeway than along the NW freeway.

IMPACT OF STAGE CONSTRUCTION OF STUDY FREEWAYS

Even though lateral and longitudinal stage construction occurred on both of the study freeways, the primary emphasis of the analysis presented here is on determining the economic impact of lateral stage construction. The SW freeway, which has one section (Section 1) that was not constructed in lateral stages, is regarded as the control freeway in the land use analysis presented in the next section. Because construction of the service roads and main lanes of the NW freeway occurred over a much longer period of time than in the case of the SW freeway, the effects of long-term staging can be determined. The extent of land use and vehicle user impacts of freeway stage construction are presented under separate headings.

Land Use Impact

The land use impact evaluation of freeway stage construction is based on the historical land use data obtained from the records of the Houston City Planning Department and from aerial photographs of the U.S. Department of Agriculture.

The land use data represent one-half mile strips on each side of the SW and the NW freeways for the following 6 years: 1953, 1957, 1962, 1970, 1975, and 1980. The year closest to the opening date of a certain facility is used to represent the opening date of that facility because most of the actual opening dates do not fall exactly on any of these 6 years but rather fall in between.

The one-half mile study strip on either side of each freeway is divided into two parts: the abutting portion, which is 100 ft wide next to the freeway and the nonabutting portion, which encompasses the remainder of the study strip. Therefore, the 4 sections of each of the 2 study freeways are multiplied into 8 subsections, yielding a total of 16 subsections for both freeways. With 6 years of land use data on each of these subsections, a total of 96 observations or data points can be used in the regression analysis presented next.

A regression model is formulated in order to relate each land use to the lateral staging effects of freeway construction by use of a set of binary variables. The staging effect is divided into two phases, the first phase denoting completed service roads, with no main lanes, and the second phase denoting the completed freeway main lanes, along with the service roads. Besides the staging effects, other effects such as abutting versus nonabutting, freeway location differences, capacity changes, and average daily traffic volumes are also investigated. Out of the many types of land use, five of the more dominant ones are chosen for the study. They include single residential, multiple residential, commercial, industrial, and undeveloped lane uses. The dependent variables (DV) in the model are represented by these five lane uses and are defined as follows:

1. SHP = percentage of single residential acreage to total acreage in each study subsection.
2. MHP = percentage of multiple residential acreage to total acreage in each study subsection.
3. COMP = percentage of commercial acreage to total acreage in each study subsection.
4. INDP = percentage of industrial acreage to total acreage in each study subsection.
5. UDEVP = percentage of undeveloped acreage to total acreage in each study subsection.

The effects tested are the explanatory variables (EV), which include six sets of binary (qualitative) variables and one continuous variable defined as follows.

1. Binary variable for abutting effect: DA = 1 if land is abutting study freeway section, DA = 0 otherwise;

TABLE 4 Socioeconomic Characteristics of the Study Areas in the Before Period (1950-1960) and the During and After Periods (1960-1970)

Year	Area	Population	Family Income ($)	No. Dwelling Unit	No. Single Dwelling Unit	Medium House Price ($)	Medium Gross Rent ($)
1950	NW	11,097	3,308	3,438	2,954	6,432	29.00
	SW	5,463	3,054	1,830	1,736	8,971	29.20
1960	NW	27,938	6,377	8,787	7,403	12,200	59.00
	SW	21,665	7,822	6,213	6,191	15,333	79.00
1970	NW	41,203	10,585	13,249	10,953	17,000	110.00
	SW	58,783	13,100	20,493	12,409	23,640	167.00
Change in the before period (1950-1960), %	NW	16,841	3,069	5,349	4,449	5,768	30.00
		151.8	92.8	155.6	150.6	89.7	103.4
	SW	16,202	4,756	4,383	4,455	6,362	50.00
		296.6	156.1	239.5	256.6	70.9	171.2
Change in the during and after period (1960-1970), %	NW	13,265	4,208	4,462	3,550	4,800	51.00
		47.5	66.0	50.8	48.0	39.4	86.4
	SW	37,118	5,278	14,280	6,218	8,307	88.00
		171.3	67.5	229.8	100.4	54.2	111.3

2. Binary variable for freeway location differences: LC = 1 if land is along the Southwest Freeway, LC = 0 otherwise;

3. Binary variable for the first phase of freeway construction staging where only service roads have been built: SR = 1 if freeway section is staged with just the first phase completed, SR = 0 otherwise;

4. Binary variable for the second phase of freeway construction staging where both the service roads and main lanes have been built: SFS = 1 if freeway section is staged, with the second phase completed, SFS = 0 otherwise;

5. Binary variable for freeway construction type where freeway section has not been staged, main lanes and service roads were built together: SFN = 1 if freeway section is nonstaged, SFN = 0 otherwise;

6. Binary variable for capacity change: CP = 1 if number of freeway main lanes changes, CP = 0 otherwise; and

7. Continuous variable for average daily traffic volume, ADT.

Because it is believed that interaction among land uses is highly probable, the model is, therefore, expressed in a set of simultaneous equations. Each of the dependent variables is expressed as a function of other dependent variable(s) and some combination of explanatory variables (3). In functional form it is shown as follows:

$$DV_i = \alpha_i + \sum_j \beta_{ij} + DV_j + \sum_k \gamma_{ik} EV_k \qquad \text{for } i \neq j$$

where

i = type of land use, where $i = 1, \ldots, 5$;
j = type of land use, which is different from i;
k = number of explanatory variables, where $k = 1, \ldots, 7$; and
α, β, γ = estimated coefficients.

Because the staging effect is the most relevant effect investigated in this study, the three sets of binary variables, SR, SFS, and SFN, attempting to capture this effect, are included in all the equations.

The simultaneous equation model is estimated first by two stage least squares (2SLS) to give consistent and unbiased estimated of the coefficients. Because it is likely that there are interactions among disturbances across equations, third stage least squares (3SLS) is also used to reestimate the model in order to improve the efficiency of the estimated coefficients.

Tables 5 and 6 give the estimated results of the regression model using 2SLS and 3SLS, respectively. Among the large number of explanatory variables, some are found to have little significant influence on one type of land use but a significant influence on another type, and some are found to have no significant influence on any type of land use. The capacity change is found to be in the latter category and, therefore, is eliminated completely in the final model formulated. The resulting model consists of a set of simultaneous equations, with each equation relating one type of land use acreage, in percentage of the total acreage, to one or two influential endogenous variables together with various combinations of mostly significant binary variables.

An examination of the estimated coefficients in Tables 5 and 6 shows that the two statistical methods (2SLS and 3SLS) have similar impacts on all variables, except that two of the estimated coefficients differ in levels of significance and in magnitudes. The estimated coefficient of SR in the equation for commercial land use, COMP, is significant statistically at the 10 percent level when 2SLS is used but narrowly misses that level of significance when 3SLS is adopted. The reverse is found to be true for the estimated coefficient of SFS in the equation for undeveloped land use, UDEVP.

R^2 for the 2SLS set of estimated equations ranges from 0.2620 to 0.9343, whereas the set using 3SLS, R^2 is 0.6032. The effects of the three binary variables most closely related to freeway stage construction (SR, SFS, and SFN) on land use changes, using the results for 3SLS, are summarized in the following paragraphs.

Single Residential Acreage

Single residential acreage is significantly and positively influenced by all three types of freeway construction: (a) first phase of the staged freeway segment (SR), (b) second phase of the staged freeway segment (SFS), and (c) the nonstaged freeway segment (SFN). Among the three, the nonstaged freeway segment construction has the greatest influence on single residential acreage, which is estimated to be 16.4 percentage points higher than would have occurred with no freeway construction. As expected, a

TABLE 5 Estimated Coefficients Using Two Stage Least Squares

		Independent Variable										
		Exogenous Variable						Endogenous Variable				
Dependent Variable	Constant	DA	LC	SR	SFS	SFN	ADTX10^{-4}	SHP	MHP	COMP	R^2	F Ratio
SHP												
Coefficient	15.9431[a]	−5.3771[a]	−10.2050[a]	8.5989[a]	15.7813[a]	16.6607[a]			.2138		.2620	5.27
t-statistic	6.09	−2.03	−3.37	2.64	4.08	2.21			−.53			
MPH												
Coefficient	1.7440[a]	−4.0859[a]		1.5131	−3.7463[b]	4.0612[b]				.3963[a]	.3750	10.81
t-statistic	1.77	−3.22		1.10	−1.55	1.38				3.86		
COMP												
Coefficient	3.4274[a]			3.1015[a]	8.2992[a]	7.2605[a]	2.4648[a]	−.2006[b]	−1.0980[a]		.7100	36.32
t-statistic	1.89			1.40	2.67	1.85	6.44	−1.29	−2.83			
INDP												
Coefficient	1.6734[a]		−2.9449[a]	.6717	4.1950[a]	5.0917[a]			.3183		.4248	13.29
t-statistic	2.64		−3.34	.71	3.75	2.36			2.78			
UNDEVP												
Coefficient	102.4407[a]	.9463		1.8683	4.0655	2.5595		−1.3510[a]	−1.1675[a]	−1.2552[a]	.9343	178.80
t-statistic	50.02	.51		.94	1.20	.71		−9.33	−4.57	−8.12		

[a] Significant at 5 percent
[b] Significant at 10 percent.

TABLE 6 Estimated Coefficients Using Third Stage Least Squares

Dependent Variable	Constant	Independent Variable: Exogenous Variable: DA	LC	SR	SFS	SFN	$ADTX10^{-4}$	Endogenous Variable: SHP	MHP	COMP
SHP										
Coefficient	16.548[a]	−7.7758[a]	−8.3099[a]	8.7963[a]	15.3543[a]	16.4194[a]			−.2959	
t-statistic	6.34	−3.08	−2.79	2.70	3.98	2.18			−.73	
MHP										
Coefficient	1.3085[b]	−3.1690[a]		1.5232	−3.5111[b]	4.3018[b]				.3843[a]
t-statistic	1.34	−2.56		1.10	−1.45	1.47				3.75
COMP										
Coefficient	3.5886[a]			2.6473[a]	8.9043[a]	5.1946[b]	2.1622[a]	−.2283[b]	−.6279[a]	
t-statistic	2.04			1.21	3.01	1.33	6.20	−1.55	−1.77	
INDP										
Coefficient	1.7732[a]		−3.2234[a]	.6724	4.3229[a]	5.3207[a]			.3143	
t-statistic	2.80		−3.68	.71	3.87	2.47			2.74	
UDEVP										
Coefficient	103.8327[a]	−.9895		2.1558	3.2552[b]	.7807		−1.4109[a]	−1.0746[a]	−1.2002[a]
t-statistic	56.68	−.88		1.12	1.48	.23		−10.99	−5.77	−18.89

Note: $R^2 = .6032$.

[a]Significant at 5 percent.
[b]Significant at 10 percent.

freeway with main lanes and service roads constructed by either the staging or nonstaging method influences the percentage of single residential acreage more than by construction in the first phase of staging, with only service roads completed.

Multiple Residential Acreage

The first phase of staged freeway construction with only service roads opened has no significant influence on this land use category. A freeway with both main lanes and service roads built by the staging method has a negative and significant influence on MHP land use. The nonstaged freeway construction method is positively and significantly related to MHP. Therefore, among the three types of freeway construction, only the nonstaged type has a positive influence on this land use category and that effect is relatively small with only a 4.3 point increase in the percent of MHP land use compared to areas with no freeway construction.

Commercial Acreage

Freeway construction with only service roads opened is found to be positively related to COMP but barely below the 10 percent level of significance, whereas the other two freeway construction types are found to positively and significantly influence COMP. In comparing the second phase staged and nonstaged freeway construction, it is found that the former type exerts greater influence on COMP than the latter type. This finding is not consistent with what had been expected. However, commercial development is likely to be greatly stimulated along a freeway where the service roads have been built in anticipation of the main lane construction. Together the staged and nonstaged main lanes and service roads increase commercial acreage by about 14.1 percentage points compared to areas with no freeway construction.

Industrial Acreage

Among the three dummy variables for freeway construction types, the coefficient of SR is found to be statistically insignificant whereas those of both SFS and SFN are found to be positive and significant. The estimated coefficient of SFN is larger than that of SFS, implying that the nonstaged freeway construction is more influential on the mean INDP than the staged freeway construction. The two influences combined increase industrial land use by about 9.6 percentage points compared to areas with no freeway construction.

Undeveloped Acreage

The only type of freeway construction that is significant at the 10 percent level in relating to UDEVP is the second phase, staged construction type. The positive estimated coefficient of SFS is surprising because it is expected that any type of freeway construction should have a negative effect on UDEVP (a positive effect on development). In this case the coefficient is not significant at the 5 percent level and the sign appears to be dominated by the highly significant endogenous variables. These variables appear to be, in effect, overcompensating for the staging effect on overall development, thus, causing the surprising sign of the coefficient SFS in the equation. This could also be the result of losses of existing land use development when the right-of-way was purchased.

VEHICLE USER IMPACT

The decision to stage a new freeway construction rather than build the entire facility at once should include the additional user costs that would result if access to the facility is delayed for a period of time as the staging progresses.

Obviously, there are benefits to staging, mainly from the delay in expenditures for highway construction. However, those benefits should be compared to the costs to users of the delayed facility in order to determine the overall direct effects of staging a highway facility.

Calculation of User Costs

The additional user costs of staging for a particular highway section can be defined as the difference in user costs between the costs generated while the facility was not open and the costs if the facility had not been staged. In mathematical terms,

$$AUC = \sum_{i=1}^{n} UC_{Ai}-UC_{Ei}/(1+r)^{i} \quad (1)$$

where

AUC = present value of additional user costs resulting from staging,
UC_{Ai} = actual corridor user costs in year i,
UC_{Ei} = expected corridor user costs in year i if facility had been open,
n = number of years staging delayed opening of facility, and
r = discount rate (assumed 8 percent).

Vehicle user costs consist of four major components: time costs, vehicle running costs, speed-change cycling costs, and accident costs. An improved version of the Highway Economic Evaluation Model (HEEM), which uses a more realistic corridor traffic allocation procedure, provides equations and parameters to calculate each one of these user costs components in a simple and consistent manner (4). Therefore, these equations are used to calculate the user costs as a result of staging for the two Houston freeways examined in this paper, the NW freeway, US-290, and the SW freeway, US-59. Three sections of each freeway are included in the analysis. The first section (NW1) of the NW freeway is deleted from the analysis because of the lack of traffic count station data for the corresponding section on Hempstead Road. The first section (SW1) of the SW freeway was not staged.

There is evidence that improved capacity induces additional vehicles to use a particular facility (5). However, because induced traffic could not be handled with any degree of precision, it is not included in this analysis. Therefore, the additional user cost numbers reported here should be regarded as a minimum value because the true value would be higher if induced traffic were included.

Calculation of Construction Costs

Construction cost savings from staging are handled in a similar fashion as user costs. Only construction costs attributable to staging the service roads or main lanes are included in this analysis. The costs of right-of-way, utility adjustments, storm sewers, and preparation of right-of-way are not included. Because it would be difficult, if not impossible, to identify the projects that would have been deferred in Texas if these freeways had not been staged, direct motorist benefits cannot be calculated and are, therefore, calculated indirectly by using the cost of capital (or discount rate) as a proxy for those benefits.

$$BDC = \sum_{i=1}^{n} C_i[1-(1+r)^{-i}] \quad (2)$$

where

BDC = benefits of delayed construction for a given highway segment,
C_i = construction cost in year i,
n = number of years staging delayed opening of facility, and
r = discount rate (assumed 8 percent).

Effects of Staging on Costs

The changes in user costs and construction costs for each freeway as a result of staging are given in Table 7. The net cost of staging, which represents the difference between the additional user costs and the benefits of delayed construction, is also given.

For each of the highway segments, the net cost of staging is positive. This indicates that the costs to users of staging are greater than the benefits of delaying construction expenditures. There is also a significant difference in the effects of staging service roads compared to staging the main lanes. On both sections of the NW freeway, the net staging costs for the service roads are substantially less than the comparable net staging costs for the main lanes.

TABLE 7 Additional Costs as a Result of Staging of NW and SW Freeways

Freeway Section and Design Element	Years	Thousands of 1962 Dollars: Additional User Costs[a]	Benefits of Delayed Construction	Net Cost of Staging
Northwest Freeway				
Section 2				
Service road	1962-1969	1,085.9	457.5	628.4
Freeway	1962-1978	4,652.7	1,714.7	2,938.0
Sections 3 and 4				
Service road	1962-1974	3,307.8	2,216.1	1,092.6
Freeway	1962-1980	13,390.5	8,049.6	5,340.9
Southwest Freeway				
Section 2				
Freeway	1962-1965	1,060.6	79.0	981.6
Section 3				
Freeway	1962-1969	1,664.3	274.7	1,389.6
Section 4				
Freeway	1962-1974	4,303.6	2,420.8	1,882.8

[a]Assumes 8 percent trucks, value of time for cars of 9 cents per vehicle minute, and a value of time for trucks of 18 cents per vehicle minute.

The difference between the costs of service road staging and main lane staging is due, in part, to the longer delay in building the main lanes. The service roads were opened sooner and avoided the accumulation of user costs as corridor traffic volume increased in recent years. But there is a significant difference in user costs between the service roads and main lane freeway even in the earlier years. It is, therefore, reasonable to infer that the delay of main lane freeway construction has a greater impact on user costs than delay of service road construction. This implies that the current practice of first opening the service roads, then the main lanes, may not be the optimal strategy, especially in a rapidly growing area such as Houston.

Additional costs as a result of staging are higher for the NW freeway than for the SW freeway (Table 7). In the case of the NW freeway, all sections were staged and the construction of each stage has been spread out over a much longer period of time than was the case of the SW freeway. The results indicate staging decisions should be carefully evaluated, incorporating both user and nonuser impacts, and should not be made exclusively on the basis of budget constraints.

CONCLUSIONS

The economic effects of stage construction of a freeway on users and nonusers is investigated in this study. The effects on users are limited to time costs, vehicle operating costs, and accident costs, and the effects on nonusers include a comparison of land use changes on property adjacent to or near the freeways under study. The following conclusions can be drawn as a result of the study:

1. The designs of the two study freeways and the "before" construction characteristics of the alternate routes and the surrounding areas are very similar. However, the construction schedules of the two freeways are considerably different. Therefore, significant differences in land use changes and user costs for the two freeways can be partially attributed to differences in their service road and/or main lane construction schedules.

2. The analysis of actual land use changes reveals that single and multiple residential uses, as well as industrial uses, are sensitive to staging freeway construction. Residential land use is by far the most sensitive to freeway construction, with main lanes having a greater impact than service roads. Overall, residential development is 40.6 percentage points higher in areas that have freeway access compared to areas that have no freeway stages completed. The impacts are similar for both commercial and industrial development but with lower magnitudes, 16.7 and 10.3 percentage point increases, respectively. The impact of freeway construction on multiple residential land use is much smaller and less statistically significant with an overall increase of only 2.3 percentage points compared to areas with no freeway construction stage completed.

3. The results obtained indicate that stage constructing a freeway costs more in vehicle user costs than in benefits gained from delaying construction expenditures. Also, the delay of main lane freeway construction has a greater impact on user costs than delaying service road construction.

4. Freeway staging decisions should not be made exclusively on the basis of budget constraints. Other factors, such as land use impacts and vehicle user impacts, need to be considered. This type of information and trade-off should be explicitly incorporated into the decision-making process of project selection and construction timetable.

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REFERENCES

1. M.K. Chui, J.L. Memmott, and J.L. Buffington. Economic Effects of Stage Construction of the Northwest and Southwest Freeways in Houston, Texas. Research Report 225-26. Texas Transportation Institute, The Texas A&M University System, College Station, Aug. 1982.
2. Texas Department of Highways and Public Transportation. Guide to the Highway Economic Evaluation Model. Austin, Tex., Feb. 1976.
3. J. Kmenta. Elements of Econometrics. MacMillan Publishing Co., Inc., New York, 1971.
4. J.L. Memmott and J.L. Buffington. The Evaluation of High Occupancy Vehicle Projects in the HEEM. Research Report 225-24, Texas Transportation Institute, The Texas A&M University System, College Station, Jan. 1982.
5. J.L. Memmott and J.L. Buffington. Predicting Traffic Volume Growth Rates Resulting from Changes in Highway Capacity and Land Development. Research Report 225-23, Texas Transportation Institute, The Texas A&M University System, College Station, Jan. 1981.

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