EVALUATION OF THE BENEFITS OF TRAFFIC SURVEILLANCE AND CONTROL ON THE GULF FREEWAY

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PREFACE

The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the Bureau of Public Roads.

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SUMMARY

Freeway surveillance and control have been used to improve traffic operation on and near the Gulf Freeway in Houston, Texas. Several research reports previously issued by the Texas Transportation Institute have investigated the nature and types of surveillance and control and have documented their effects on the Gulf Freeway. This report gives an economic evaluation of the loss of time resulting from freeway obstructions and an evaluation of the benefits of freeway surveillance and control. These economic evaluations serve two purposes: (1) the costs of obstructions can be used to evaluate the savings which are possible by reducing the number of such obstructions, and (2) the benefit calculations can be used in evaluations of the desirability of investments for freeway surveillance and control.

In the report, three types of comparisons are made "within" a year of operation with freeway controls. Each of these three includes comparisons of peak-period travel times during an obstructed freeway condition with peak-period travel times for a freeway condition that is less obstructed. The purpose of the comparisons is to give the time cost of the obstructed condition relative to the less obstructed condition. The freeway is divided into three

subsystems and the travel time comparisons are made for only one of these, the Griggs-Broadway Subsystem. It was estimated, however, that the total time costs of obstructions for all three subsystems might be as high as 2.24 times as much as that for the Griggs-Broadway Subsystem alone, since total peak-period travel time for all three subsystems was 2.24 times as much as that of the Broadway-Griggs Subsystem.

During control, total travel time per peak period (7:00 A.M. - 8:00 A.M.) in the Broadway-Griggs Subsystem was higher on days with accidents on the inbound freeway, as compared to non-accident days, by approximately 245 vehicle hours if the pavement was wet or damp, and by approximately 87 vehicle hours if the pavement was dry. Using a weighted-average value of time of $2.92 per vehicle hour as the value of time, the value of the increased travel time due to accidents is approximately $700 per peak period with wet pavement and $250 per peak period with dry pavement.

On days with obstructions other than accidents on the inbound freeway, peak-period total travel time for the Broadway-Griggs Subsystem was higher, when compared to days with no obstructions, by 55 vehicle hours when the pavement was wet or damp and by 41 vehicle hours when the pavement was dry. These obstructions other than accidents on the inbound freeway include vehicle stalls on or near the inbound freeway, accidents at ramps or on frontage roads, and unusual pedestrian activity near the freeway.

On days with accidents on the inbound freeway, as compared to days with no obstructions of any type, peak period total travel time in the Broadway-Griggs Subsystem was higher by 268 vehicle hours with wet pavement and by 99 vehicle hours with dry pavement.

In addition to these "within control" comparisons, an entire year of non-holiday weekdays with control is compared with a conceptual year without control. Some information for the conceptual year without control is taken from operation in the years before control and part is estimated using this before-control information together with information gathered with control. Travel time, for the 252 non-holiday weekdays, on the inbound Gulf during the 7:00 A.M. - 8:00 A.M. peak period is estimated to have decreased by approximately 79,600 vehicle hours due to control. Travel time on the inbound frontage roads for the 252 days is estimated to have increased by approximately 2,800 vehicle hours due to control. Evaluated at $2.92 per vehicle hour, the net decrease in travel times due to control amounts to an annual savings of about $224,000. In the year with control the number of accidents occurring between 7:00 A.M. and 9:00 A.M. on the inbound freeway were 57 as compared to 121 in the year before control.

The number of accidents on the ramps and service roads were exactly the same, 15 accidents, in the year with control as in the year before control. The overall reduction of 64 accidents, evaluated at $600 per accident, amounts to an annual savings due to control of $38,000.

The annual peak-period savings in travel time and accidents due to control is evaluated at about $262,000.

In addition to the reductions in travel times and accidents on and near the inbound freeway, there probably were other benefits which may be attributed to control. Vehicle operating costs were probably reduced because the number of speed changes and the amount of stop-and-go operation were reduced. The amount of discomfort due to speed changes and congestion was reduced. By decreasing the amount of freeway congestion and the number of speed changes, control may have decreased the number of stalls on the inbound freeway and thus would have reduced the extra travel time associated therewith. Since the number of stalls is not known for the before-control period, this possible benefit cannot be evaluated. It is known that during control there were 48 non-accident days on which stalls occurred on or near the inbound freeway.

The measurement of the benefits of control covered only the peak-period inbound freeway and frontage roads. It should be noted that control may have saved time for vehicles immediately before and after the peak period. Also, control of the inbound freeway probably improved operations on the outbound freeway. For example, the decreased number of accidents on the inbound freeway led to fewer distractions for outbound traffic. Surveillance of accidents has shown that congestion on the outbound lanes occurs near the location of an inbound accident; no attempt has been made to quantify these effects on the outbound traffic.

I

INTRODUCTION

During the past few years freeway surveillance and control have been used to improve traffic operation on and near the inbound Gulf Freeway in Houston, Texas. (See Figures 1 and 2 for illustrations of the Gulf Freeway System.) Studies by the Texas Transportation Institute quantified the problem of congestion on the inbound freeway and determined traffic speeds, traffic densities, demand and capacity at bottlenecks, etc. The information collected in these studies was used as the basis for control procedures which included the metering and closing of some entrance ramps on the inbound freeway. The surveillance and control procedures principally were meant to improve traffic operation during the peak period of operation (7:00 a.m. to 8:00 a.m.). Previous studies have recorded how surveillance and control affected traffic operation.[1] Among the effects of surveillance and control were:

1. Volume of traffic on the inbound freeway increased during the peak period.
2. Travel time per vehicle decreased.
3. The variation in speed of travel decreased.

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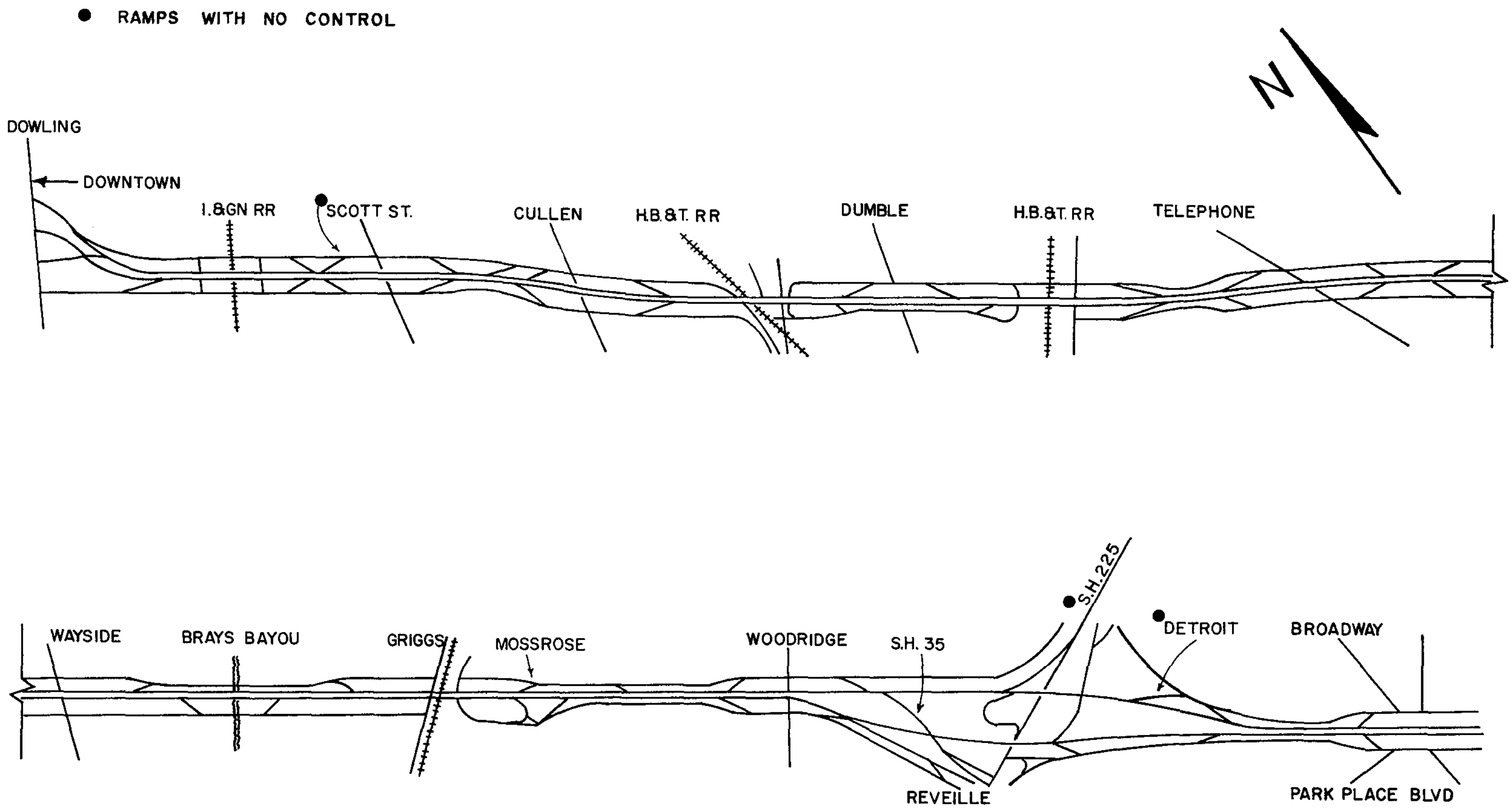
[1]A list of these publications appears at the end of this report.

GULF FREEWAY
HOUSTON, TEXAS
FIGURE 1



GULF FREEWAY STUDY SYSTEM

FIGURE 2

4. The number of accidents occurring near the inbound freeway between 7:00 a.m. and 9:00 a.m. decreased.

This report uses information from these previous reports together with some new information to develop dollar estimates of the time cost of obstructions and of the benefits of surveillance and control.

II

STUDY PROCEDURES

This section gives an explanation of the methods of comparison used in the study, the data employed, the "types of days" selected for different comparisons, and the economic coefficients derived for the assignment of dollar values.

Method of Comparisons

Dollar estimates of the cost of obstructions and the benefits of control are developed in the last three sections of the report. These dollar estimates are based on two methods of comparison. In two sections, estimates of the time cost of obstructions, during control, are given. Days are classified into different types, according to pavement condition (wet or dry) and freeway operating condition (presence of different types of obstructions). For the same pavement condition, travel times on days with obstructions of different types are compared to travel times on "less-obstructed" days to derive estimates of the "time lost" due to obstructions.

A dollar value is assigned to an "average" hour of time and the value of time lost due to obstructions is then estimated. All of the comparisons made in these two sections are among days with control.

In the final section of the report the total annual benefits of control are discussed. The value of time saved by control and of the reduction in accidents due to control are estimated. Whereas comparisons in the preceding sections were on a day basis, the comparison in the final section is on a year basis. A year with control is compared with a conceptual year without control. The benefits which are attributed to control are those that occur during the peak period on non-holiday weekdays.

Explanation of Data

Data used in comparisons in the report are types of days, average travel times, and number of accidents. Part of the data was developed specifically for this study from the "with control" year, which includes non-holiday weekdays from September 27, 1965 through September 23, 1966. This year with control included 252 non-holiday weekdays. Complete information, for all 252 days, was available on pavement condition and freeway operating condition. Information on travel times was available for 164 of these 252 days. Other data on travel times, volume of peak-period traffic, and accidents rates were developed in previous Gulf Freeway project studies and references are given below to these studies.

All information on travel times used pertain to the peak period of operation on and near the inbound Gulf Freeway. Total travel times are estimated for three subsystems of the inbound Gulf Freeway; these are the Broadway-Griggs Subsystem, the Griggs-South HB and T Railroad Subsystem, and the South HB and T Railroad-Calhoun-Pease Subsystem. Total travel time in a subsystem is estimated by taking the integral of the time function between 7:00 a.m. and 8:00 a.m., where the number of vehicles in the subsystem is a known function of time (3, 6).* Travel time per vehicle in a subsystem is estimated by dividing total travel time in the subsystem during the peak period by the number (adjusted) of vehicles using the subsystem during the peak period.

Types of Days

From September 27, 1965 through September 23, 1966, there were 260 weekdays, of which eight were holidays. Of the total 252 non-holiday weekdays, complete information on travel times in the Broadway-Griggs Subsystem was available for 164 days.

The distributions of the total 252 analysis days of the year with control and the 164 of these 252 days for which

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*Numbers in parentheses refer to references in the bibliography.

complete information was available on travel times in the Broadway-Griggs Subsystem are given in Tables 1 and 2. In these two tables the number of days are shown according to the "pavement condition" and the "freeway operating condition."

The pavement condition is classified as "dry" or "wet." These terms are more-or-less self-explanatory. It might be mentioned, however, that the "wet" days include days during which it was raining or had been raining in the freeway area and also days during which heavy fog had made the pavement damp.

Days are classified into three types according to "freeway operating condition." These day types are "accident on inbound freeway," "other obstruction," and "no obstruction." Accident-on-inbound-freeway days include those days on which there was at least one accident on the inbound freeway and includes some days having other obstructions such as stalls, in addition to an accident. Another type of day, "non-accident day," is used in some comparisons and it combines all days which are "other obstruction" with those which are "no obstruction.

Economic Coefficients

To derive a value of time for an average vehicle operating on the Gulf Freeway during the 7:00 a.m. - 8:00 a.m. peak

TABLE 1

TOTAL NUMBER OF ANALYSIS DAYS FOR BROADWAY-GRIGGS SUBSYSTEM, BY PAVEMENT AND FREEWAY OPERATING CONDITIONS

Pavement Condition	Freeway Operating Condition			All Freeway Operating Conditions
	Accident On Inbound Freeway	Other Obstruction	No Obstruction	
	Number of Days			
Wet	10	15	29	54
Dry	32	63	103	198
All Pavement Conditions	42	78	132	252

TABLE 2

NUMBER OF NON-HOLIDAY WEEKDAYS
FOR WHICH COMPLETE INFORMATION ON
GRIGGS-BROADWAY-SUBSYSTEM
TRAVEL TIMES WAS AVAILABLE DURING
THE CONTROL PERIOD,
BY PAVEMENT AND FREEWAY
OPERATING CONDITIONS

Pavement Condition	Freeway Operating Condition			All Freeway Operating Conditions
	Accident On Inbound Freeway	Other Obstruction	No Obstruction	
	Number of Days			
Wet	7	10	17	34
Dry	21	38	71	130
All Pavement Conditions	28	48	88	164

period, a five-day count of different types of vehicles was made and the proportions of vehicles of different types given by these counts were used with values of time from two recent studies to derive a composite value of time. Since the precise amount of time saved by different vehicle types is not known, it is assumed that the proportion of total time saved by vehicles of a particular type is the same as the proportion of such vehicles as given by the five-day count.

For purposes of vehicle counts, vehicles are divided into four types, each of which is assigned a different value of time. Thi first type, "Autos and Pick-ups," includes all automobiles, pick-ups apparently used for the same purpose as automobiles, campers, and compact, non-commercial panels. "Delivery Vehicles" includes panel trucks not included in the first vehicle type, stake-bed pick-ups, light, two-axle, four-tire trucks, pick-ups apparently used commercially (with load or tools), pick-ups with trailers, and school buses. "Trucks" includes single-unit trucks with dual tires and truck-trailer combinations. "Commercial Buses" includes buses identified as commercial and other full-size buses.

A value of time of $2.82 per vehicle hour is used for the first type of vehicles, "Autos and Pick-ups." This is based upon a recent Stanford Research Institute study (5) which recommends $2.82 per passenger per hour as a value of

TABLE 3

DERIVATION OF AVERAGE VALUE OF TIME PER VEHICLE HOUR

Types of Vehicles	Proportion of Vehicles of This Type[1/]		Value of Time Per Vehicle Hour		
Autos, Pick-ups	.9445	X	$2.82[2/]	=	2.6635
Delivery Vehicles	.0371	X	3.68[3/]	=	.1365
Trucks	.0165	X	6.56[3/]	=	.1082
Buses	.0019	X	7.43[3/]	=	.0142
	Value of Time Per Vehicle Hour			=	2.92

1/ Based on a five-day survey, made during control on the Gulf Freeway, of peak-period inbound traffic.

2/ Based on Stanford Research Institute, The Value of Time for Passenger Cars, Vol. I by Dan G. Haney et al. and Vol. II by Thomas C. Thomas (Menlo Park, California: Stanford Research Institute, May, 1967).

3/ Based on William G. Adkins, Allan W. Ward, and William F. McFarland, Values of Time Savings of Commercial Vehicles, National Cooperative Highway Research Program Report 33 (Washington, D. C.: Highway Research Board, 1967).

time. This value of $2.82 is used as the value of time *per vehicle hour* in this study although such is a "conservative" estimate since the average number of passengers per vehicle is more than one. The values of time for the other three types of vehicles are taken from a recent Texas Transportation Institute study (1). Table 3 gives the derivation of the "average" value of time, $2.92 per vehicle hour, which is used in this paper.

Since no information was readily available on the cost of motor vehicle accidents occurring on and near the inbound Gulf Freeway, it is assumed that $600 is the cost per accident of property damage, medical expenses, and loss of output due to injury and death. The use of $600 per accident is based on a National Safety Council memorandum (2).

III

TIME COST OF OBSTRUCTIONS FOR THE BROADWAY-GRIGGS SUBSYSTEM

This section estimates the cost of accidents and other obstructions during the peak periods during the year of freeway surveillance and control.

The average travel time per vehicle during control varied with weather and freeway operating conditions. Travel times were highest when there was wet pavement and rain and when there was an obstruction such as a major accident or a prolonged stall.

In general, the effect of obstructions, such as accidents and stalls, on travel times depended on the pavement condition and the location, time of occurrence, and duration of the obstruction. It did not appear that the type of pavement condition affected the likelihood of an accident or other obstruction, but lack of a large number of observations precludes definite statements regarding the effects of weather on the frequency of obstructions.

Three types of comparisons were made in the study. Each comparison considers only travel times in the Broadway-Griggs Subsystem. (In the next section, a method of estimating travel times for all three subsystems is briefly outlined.) In each of the three types of comparisons an obstructed condition (occurring during control) is compared to a less obstructed condition (also occurring during control).

Table 4 gives the average number of vehicles using the Broadway-Griggs Subsystem during the peak period (7:00 a.m. - 8:00 a.m.) during control, for different pavement and freeway operating conditions. Table 5 gives the average travel time per vehicle, in hours, in the Broadway-Griggs Subsystem, of those vehicles using this subsystem during the peak period during control.

TABLE 4

AVERAGE NUMBER OF VEHICLES USING THE BROADWAY-GRIGGS SUBSYSTEM DURING CONTROL IN THE 7:00 A.M. - 8:00 A.M. PEAK PERIOD, BY PAVEMENT AND FREEWAY OPERATING CONDITIONS

Pavement Condition	Freeway Operating Condition				All Freeway Operating Conditions
	Accident On Inbound Freeway	No Accident on Inbound Freeway			
		Other Obstruction	No Obstruction	All Non-Accident	
	Number of Vehicles				
Wet	5,111	5,382	5,475	5,440	5,373
Dry	5,602	5,746	5,837	5,805	5,773
All Weather Conditions	5,480	5,670	5,767	5,733	5,690

TABLE 5

AVERAGE NUMBER OF HOURS OF TRAVEL PER VEHICLE, IN THE BROADWAY-GRIGGS SUBSYSTEM, DURING CONTROL IN THE 7:00 A.M. - 8:00 A.M. PEAK PERIOD, BY PAVEMENT AND FREEWAY OPERATING CONDITIONS

Pavement Condition	Freeway Operating Conditions				All Freeway Operating Conditions
	Accident On Inbound Freeway	No Accident on Inbound Freeway			
		Other Obstruction	No Obstruction	All Non-Accident	
	Average Travel Times				
Wet	.165	.126	.116	.120	.129
Dry	.099	.089	.082	.084	.087
All Weather Conditions	.114	.096	.088	.091	.095

Table 6 shows the differences in travel time per peak period for three different types of comparisons. The column in Table 6 entitled "Travel Time Difference Per Vehicle (Vehicle Hours)" gives the difference in hours per vehicle for one condition relative to another condition. The values from which these differences are derived are given in Table 5. For example, Table 5 gives the travel time per vehicle for days on which there was an accident on the inbound freeway as .165 hours with wet pavement. For non-accident days the travel time per vehicle, with wet pavement, is .120 hours, Thus, the difference shown in Table 6 for the "Accident vs. Non-accident" type of comparison for wet pavement days is .045 hours (.165 hours minus .120 hours).

The column in Table 5 entitled "Traffic Volume Per Peak Period (Vehicles)" is the larger of the average volumes, per peak period, of the two types of days compared. For example, with wet pavement, the "accident" volume is 5,111 vehicles per hour and the "non-accident" volume is 5,440 vehicles per hour (Table 4); in Table 6, the volume given for the "Accident vs. non-accident" comparison is 5,440 vehicles per hour, the larger of the two volumes for the types of days compared. The reasoning which led to the use of the larger of the two volumes is as follows: if there were no accidents on the freeway an average of 5,440 vehicles would use the Broadway-

TABLE 6

DEVELOPMENT OF BROADWAY-GRIGGS SUBSYSTEM
TOTAL TIME DIFFERENCES PER PEAK PERIOD,
BY WET AND DRY PAVEMENT CONDITIONS
FOR DIFFERENT TYPES OF COMPARISON

Type of Comparison	Pavement Condition	Travel Time Difference Per Vehicle (Vehicle Hours)	Traffic Volume Per Peak Period (Vehicles)	Total Time Difference Per Peak Period (Vehicle Hours)	Cost of Time Difference (Dollars)
Accident Vs. Non-Accident	Wet	.045	5,440	244.8	715
	Dry	.015	5,805	87.1	254
Accident Vs. No Obstruction	Wet	.049	5,475	268.3	783
	Dry	.017	5,837	99.2	290
Other Obstruction Vs. No Obstruction	Wet	.010	5,475	54.8	160
	Dry	.007	5,837	40.9	119

Griggs Subsystem during the peak period on days with wet pavement and each of these vehicles would have an average travel time in the subsystem of .165 hours; with an accident on the inbound freeway, the volume would be only 5,111 vehicles per peak period, with each vehicle having a travel time of .120 hours.

Since the volume changes, total hours of travel times do not seem to be the quantities to compare. Thus, it was decided to assume that 5,111 vehicles had travel times increased by .045 hours each, due to an accident and that an additional 329 vehicles, which would have used the subsystem during the peak period had there been no accident, also had their travel time per vehicle increased by .045 hours. More specifically, the assumption is that the 329 vehicles which did not use the freeway due to accident effects used an alternate route which added .045 hours to the travel time of each. (The diversion of traffic stopped when an equilibrium between freeway and non-freeway travel time was reached.) Using this reasoning the "time lost per vehicle" due to some "unfavorable condition" is weighted by the number of vehicles which would have used the freeway in the absence of the unfavorable condition to derive the total time lost per peak period due to the unfavorable condition.

Using the above reasoning, hours of time lost per peak period due to some conditions as compared to other conditions were developed and are given in Table 6. For example, during the peak period, on days with wet pavement, travel time for 5,440 vehicles was estimated to have increased by 244.8 hours in the Broadway-Griggs subsystem on accident days).

Using $2.92 per vehicle hour as the value of time, the values of time lost per peak period due to obstructions were developed and are given in the last column of Table 6.

The annual value of time lost on non-holiday weekdays in the Broadway-Griggs Subsystem due to accidents can be estimated since it is known that of the 252 analysis days there were 42 accident days, ten of which had wet pavement and 32 of which had dry pavement.

If, instead of having these 42 accident days, the year had included 42 days with travel times like the average non-accident day, then travel time in the Broadway-Griggs Subsystem would have been about 2,448 vehicle hours less on the ten days with wet pavement and 2,787 vehicle hours less on the 32 days with dry pavement (total of 5,235 vehicle hours). At $2.92 per hour these 42 accident days cost about $15,000 of extra vehicle travel time. This amounts to about $700 on wet pavement days and about $250 on dry pavement days, or an average of about $360 per day (average pavement condition).

IV

TIME COST OF OBSTRUCTIONS FOR THE INBOUND FREEWAY

The preceding section estimated the time lost in the Broadway-Griggs Subsystem due to obstructions in three different types of comparisons. Due to the large amount of time it takes to estimate travel times in a subsystem, complete information (on 164 days) was developed for the Broadway-Griggs Subsystem only. Observations have shown, however, that during control total travel time for all three subsystems of the inbound freeway is about 2.24 times as much as the travel time in the Broadway-Griggs Subsystem. If it is assumed that a proportionate amount of time is lost in each subsystem, then the total time lost, due to obstructions, in all three subsystems would be 2.24 times the amounts given in the preceding section for the Broadway-Griggs Subsystem.

V

CONCEPTUALIZED BENEFITS OF CONTROL

Control improved freeway conditions in several ways that might be assigned dollar values. Information suggests that control (1) reduced the number of accidents on and near the inbound freeway, (2) reduced travel times on the inbound freeway, (3) increased travel times on the inbound frontage roads, (4) reduced vehicle operating costs on the inbound freeway, and (5) increased vehicle operating costs on the inbound frontage roads. Control also probably reduced the discomfort of driving on the freeway by allowing more uniform speed of travel as there were fewer speed changes, including fewer stops. In turn, control also may have reduced the number of vehicle stalls on the freeway through speed change reductions.

In the following discussion, each of the above benefits is discussed more fully. Dollar estimates of the benefits of reduced travel times and reduced number of accidents are given, but none of the other benefits are estimated in dollar terms. The estimate of the dollar value of reduced travel times should be regarded only as an estimate based upon incomplete information and thus subject to error.

Estimates of the annual dollar value of time and accident savings due to control are made by making several assumptions regarding travel times and accident rates. Using known information, estimates are made to develop the total time and accident cost of the year with control and also of what that year might have been without control. Then the year with control is compared to the year that "might have been" without control.

Travel Time on Inbound Freeway

Time savings due to control result mainly in two ways, through reducing the number of accident days and through decreasing congestion on non-accident days. In deriving estimates of total travel time for 252 non-holiday weekdays, days are divided into four types, classified according to the pavement condition and according to whether there was an accident on the freeway. The "inputs" used in deriving total travel time are travel time per vehicle on days of different types, number of vehicles on days of different types, and number of days of different types in the year with control and in a year without control. Each of these inputs is discussed more fully below.

The number of days of different types for the year with control is given in a previous section in Table 1. The number of days of different types for a year without control is estimated by considering the accident rates in the year before control and by assuming that weather conditions for the year without control are approximately the same as were the weather conditions in the year with control.

In the year previous to the year with control there were 121 accidents on the inbound Gulf Freeway between 7:00 a.m. and 9:00 a.m. (4). In the year with control, between 7:00 a.m. and 9:00 a.m., there were 57 accidents on the inbound freeway (4). For determining the effects of accidents on 7:00 a.m. - 8:00 a.m. travel times, days are classified as accident days if one or more accidents occurred on the inbound freeway before 8:00 a.m. During the control year there were 42 such accident days.

Some of the 57 previously mentioned accidents occurred between 8:00 a.m. and 9:00 a.m. Furthermore, some of those that occurred before 8 a.m. were on the same day as other accidents. This accounts for the fact that the number of accident days, as previously defined, is different from the number of accidents as given above. If the ratio of the number of accidents occurring between 7:00 a.m. and 9:00 a.m. to the number of defined accident days is the same without control as with control, an estimate of approximately 89 accident days without control may be assumed; that is, 57 is to 42 as 121 is to 89 (approximately). Of these 89 days, 21 days are assumed to be wet pavement days and 68 are assumed to be dry pavement days (from the relationship found for the year of freeway control).

Since 89 of the 252 without control days are assumed to be accident days, this leaves 163 non-accident days in the year without control. Of these 163 non-accident days, 33 are assumed to have had wet pavement and 130 are assumed to have had dry pavement (again in the same ratio as for the control year).

During control on non-accident days for the 7:00 a.m.-8:00 a.m. peak period, an average of 5,440 vehicles used the inbound freeway on wet pavement days (Table 4). In deriving travel time saved by control, it is assumed that, whether the type of day is accident or non-accident, and with control or without control, 5,440 vehicles would like to use the inbound freeway during the peak period on days with wet pavement and 5,800 vehicles would like to use the inbound freeway during the peak period on days with dry pavement.

It is assumed that the average travel times for vehicles on the inbound freeway, for different types of days, without and with control, are those given in the last column (which is the sum of the travel times in the first three columns) of Table 7. (See the note and footnotes to Table 7 for the sources and means of estimation of these travel times.) For example, it is assumed that, without control, on accident days with wet pavement, vehicles would have an average travel time on the inbound freeway of .446 hours per vehicle. The analogous travel time with control is .369 hours per vehicle.

Using this information with assumptions as stated, total travel times for 252 peak periods were estimated for "with control" and "without control," and are given in Table 8. The estimated total travel time without control is 386,176 vehicle hours and with control is 306,598 vehicle hours. At $2.92 per vehicle hour, the value of the 79,578 hours of time saved by control during a year is approximately $232,000.

Travel Time on Inbound Frontage Roads

Studies made in 1964 and 1965 indicated that for days with dry pavement and no obstructions, control increased total travel times on inbound frontage roads by about 11 vehicle hours per peak period; before control, travel time on inbound frontage roads per peak period averaged 190 vehicle hours and after control it averaged 201 vehicle hours. It is assumed that whatever the pavement and freeway operating conditions, the travel time per peak period on the inbound frontage roads is 190 vehicle hours without control and 201 vehicle hours with control. The annual travel time (for 252 non-holiday weekdays) during the peak period on inbound frontage roads is presumed to increase by 2,772 vehicle hours due to control.

Vehicle Operating Costs

Control probably reduced considerably the vehicle operating costs of vehicles using the inbound freeway but may have increased the vehicle operating costs of vehicles using the inbound frontage roads during the peak period.

It has been shown by various researchers that speed changes increase operating costs; and control reduced the number of speed changes made by vehicles operating on the inbound freeway. Vehicle operating costs may have increased for vehicles on frontage roads because these vehicles spent

TABLE 7

TRAVEL TIME PER VEHICLE DURING 7:00 A.M. - 8:00 A.M. PEAK PERIOD ON INBOUND GULF FREEWAY

Control and Type of Day	Inbound Freeway Subsystem (A) Broadway-Griggs	(B) Griggs-S HB & T RR	(C) S HB & T RR Calhoun - Pease	Total Inbound Freeway
	Hours Per Vehicle			
Without Control:				
1. Accident; Wet	.206 4/	.132 4/	.108 4/	.446
2. Accident; Dry	.124 4/	.079 4/	.065 4/	.268
3. Non-Accident; Wet	.150 4/	.096 4/	.079 4/	.325
4. Non-Accident; Dry	.105 1/	.067 1/	.055 1/	.227
With Control:				
1. Accident; Wet	.165 2/	.110 3/	.094 3/	.369
2. Accident; Dry	.099 2/	.066 3/	.057 3/	.222
3. Non-Accident; Wet	.120 2/	.080 3/	.069 3/	.269
4. Non-Accident; Dry	.084 2/	.056 3/	.048 3/	.188

Note: Only the travel times footnoted 1/ and 2/ are based on complete information; all other values are estimated using the procedure of taking proportions of the travel times which are based on complete information.

1/ Based on the "Before Control" vehicle hours of travel given in Table 3, page 28, in Charles Pinnell, Donald R. Drew, William R. McCasland, and Joseph A. Wattleworth, Inbound Gulf Freeway Ramp Control Study II, Research Report Number 24-13 (College Station, Texas: Texas Transportation Institute, July, 1965). These travel times were for days with dry pavement and no obstructions and, therefore, are not strictly comparable to the "Non-Accident, Dry" travel times with control since these latter travel times include some days with obstructions, other than accidents, such as stalls on or near the inbound freeway, unusual pedestrian activity near the freeway, etc. Thus, the travel times given under "Non-Accident, Dry - Without Control" are probably lower than they should be.

2/ Based on information developed in this study from 164 days of freeway operation with control.

TABLE 7 (Cont'd)

3/Estimated by assuning that the travel times with control in the (B) and (C) Subsystems are in the same proportion to the travel time with control in the (A) Subsystem as was the proportion of travel times in (B) and (C) Subsystesm to the travel time in the (A) Subsystem without control as given in the study cited in footnote 1/ above.

4/Estimated by assuming that travel times on days other than "Non-Accident, Dry" bear the same relationship, on days without control, to the travel times on "Non-Accident, Dry" days, as they do with control.

TABLE 8
TRAVEL TIME PER YEAR
DURING 7:00 A.M. - 8:00 A.M. PEAK PERIOD
ON INBOUND GULF FREEWAY

Control and Type of Day	Hours Per Vehicle	Vehicles Per Peak Period	Hours Per Peak Period	Days of This Type Per Year	Total Hours For Days of This Type
ITHOUT CONTROL:					
1. Accident;Wet/Damp	.446	5440	2426	21	50,946
2. Accident; Dry	.268	5800	1554	68	105,672
3. Non-Accident; Wet/Damp	.325	5440	1768	33	58,344
4. Non-Accident; Dry	.227	5800	1317	130	171,210
Total Hours Without Control					386,172
ITH CONTROL:					
1. Accident; Wet/Damp	.369	5440	2007	10	20,070
2. Accident; Dry	.222	5800	1288	32	41,216
3. Non-Accident; Wet/Damp	.269	5440	1463	44	64,372
4. Non-Accident; Dry	.188	5880	1090	166	180,940
Total Hours With Control					306,598

more time waiting at the ramps with control than such vehicles did without control.

Discomfort

By relieving congestion (and thus reducing travel times and speed changes) and reducing the number of accidents, control probably reduced the discomfort of drivers traveling on the freeway. No attempt is made at this time to place a dollar value on this reduction in discomfort.

Vehicle Stalls

By decreasing the amount of freeway congestion and the number of speed changes (especially full stops and stop-and-go operation) control may have decreased the number of stalls on the inbound freeway. It is known that during control, there were 48 non-accident days on which stalls occurred on or near the inbound freeway, but the number of non-accident days, before control, with stalls is not known.

Other Benefits of Control

The preceding discussion of benefits of control has been mainly concerned with benefits occurring during the 7:00 - 8:00 a.m. peak period on the inbound freeway and frontage roads; the one exception is that the numbers of accidents included those occurring between 8:00 a.m. and 9:00 a.m. It should be noted that control probably saved time of vehicles operating immediately before and after the peak period; due to lack of information, no estimate of these benefits is made. Also, the control of the inbound freeway may have improved operations on the outbound freeway; e.g., the decreased number of accidents on the inbound freeway may have led to fewer diversions ("rubber-necking") for outbound traffic.

Partial Estimation of Benefits of Control

Table 9 summarizes part of the information given in the preceding discussion. Control reduced travel time (for a given vehicle volume) on the inbound freeway by 79,574 vehicle hours per year, but increased travel time on the inbound frontage roads by 2,772 vehicle hours; valued at $2.92 per vehicle hour, this amounts to about $232,000 of time saved on the inbound freeway and about $8,000 of time lost on the inbound frontage roads.

Control reduced the number of accidents by 64. At an assumed cost of $600 per accident (as the cost of property damage, medical expenses, work lost due to injury and death), control reduced accident costs by about $38,000 per year of non-holiday weekdays. This $38,000 reduction in accident costs does not include any benefits for improvement in freeway operation due to reducing accidents.

TABLE 9

SUMMARY OF ESTIMATION OF
TOTAL BENEFITS DUE TO CONTROL

	Without Control	With Control	Difference (Without Control Minus With Control)	Savings Per Year Due To Control
Travel Time Per Year On Inbound Freeway	386,172 Vehicle Hours	306,598 Vehicle Hours	79,574 Vehicle Hours	$232,000
Travel Time Per Year on Inbound Frontage Roads	47,880 Vehicle Hours	50,652 Vehicle Hours	-2,772 Vehicle Hours	-$ 8,000
Number of Accidents on Inbound:				
1. Freeway	121	57		
2. Ramps	11	6		
3. Service Roads	5	10		
Total:	137	73	64	$ 38,000
Vehicle Operating Costs Per Year on Inbound Freeway	Not Evaluated	Not Evaluated		Positive
Vehicle Operating Costs Per Year on Inbound Frontage Roads	Not Evaluated	Not Evaluated		Negative But Small
Costs of Discomfort Due to Speed Changes	Not Evaluated	Not Evaluated		Positive
	Total Savings Per Year Due to Control			$262,000+

Although there are indications that control reduced total vehicle operating costs and discomfort of travel and may have reduced number of stalls, no estimation of these savings is attempted.

It is estimated that total benefits for one year of control exceed $262,000.

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