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Characteristics of Passenger Car Travel on Toll Roads and Comparable Free Roads

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Among the factors important to an accurate analysis of the benefits accruing to passenger car users through highway improvements are (a) average over-all rates of fuel consumption and speed by type of road, (b) the effects on passenger car operation of traffic impedances, (c) relative attractiveness of the different types of highway improvement benefits to motorists, and (d) the value to motorists of time saving and increased driving comfort. Data useful to passenger car benefit studies in connection with each of these factors were obtained in 1959 during the operation of a passenger car over 14,000 mi on primary highways in 17 States. These data included rates of fuel consumption, over-all speeds, speed changes identified by cause, and records of all traffic impedances.

The study route included, in addition to many miles where the only service was provided by free roads, 14 sections of toll route where drivers traveling between two particular points have a choice between use of a toll route or an alternate free route. At each of these comparison sections vehicle data were collected for trips on both the toll and free routes. In addition, roadside interview stations were operated on each of the alternate routes to determine the percent of local drivers choosing the toll route in preference to the free route and the reasons given by drivers for electing to use whichever route they were interviewed on.

The average over-all rates of fuel consumption and speed on major existing highways and on toll routes are presented in tabular form, with the variation in the over-all rates of fuel consumption and speed as affected by the frequency of driveways and crossroads shown by bar diagrams. The effects of traffic impedances on passenger car operation, the proportion of passenger car users electing to use the toll route at each of the 14 toll route comparison sections, and the relative attractiveness to users of the types of benefit realized on both the toll routes and free routes are given in a series of tables.

Finally, the data collected at the toll route comparison sections were subjected to a separate analysis to obtain estimates of the value to motorists of the time saving and increased driving comfort achieved through highway improvements.

●AN ACCURATE determination of the benefits accruing to passenger car users through highway improvements of various kinds is of paramount importance in highway user benefit studies. The number of passenger cars on the roads and streets and the volume of passenger car travel accumulated each year makes the aggregate benefits from highway improvement for this type of vehicle greater than the combined total for all other types of vehicle.

Among the important factors in passenger car benefit studies are (a) fuel and time consumption both on thoroughfares having numerous traffic signals, access points, and sharp curves, and on divided highways with no traffic signals and fully controlled access, (b) the effect of traffic signals, access points, and curvature on highway vehicle operation, (c) the relative importance to motorists of the various types of benefit accruing through highway improvements, and (d) estimates of the value to the motorists of the time saving and increased driving comfort accruing to users through highway improvements. These items are concerned both with the over-all effects of certain types of highway improvement on passenger car operations and with the values drivers place on improved travel conditions. Numerous other factors having important effects on passenger car user benefits, such as the relationship between highway design characteristics and accident rates, the effect of surface conditions and vehicle speeds on vehicle maintenance costs, and the value of reduced travel distance, are not included in this study.

Fuel and time consumption in passenger car operation is affected by several highway factors: (a) length, (b) relation of capacity to average daily traffic, (c) frequency of sharp curves, intersections-at-grade and driveway entrances, (d) surface type, and (e) gradients. Data are currently available on the fuel and time consumption of passenger cars as affected by each of these factors and several studies have been made on the over-all fuel and time consumption of passenger cars operating over limited distances under a particular set of highway conditions (1, 2). However, for benefit studies of large-scale improvement projects more information is needed on over-all average speeds and average fuel consumption rates for operation on typical present day highways and on highways constructed to the highest design standards. Predictions of the time and fuel benefits to arise through a general highway improvement program can be made by summing the savings for each item of improvement such as elimination of intersections-at-grade and addition of traffic lanes. However, time and fuel savings computed in this manner should be compared with the difference in over-all fuel and time consumption of highways of the general type as that involved in a particular analysis, and highways built to high standards, to guard against inadvertently inflating benefits by counting the same items of benefit more than once. Moreover, average over-all values of time and fuel consumption for operation on roads which have intersections-at-grade, access points, and sharp curves, and for operation on divided highways with full control of access can often be used to make preliminary estimates of the fuel and time savings to result from a major highway improvement project.

Traffic impedances such as traffic lights, access points, and sharp curves, affect vehicle operation by forcing drivers to make undesired stops and slowdowns. These speed changes not only increase fuel and time consumption but are annoying to drivers. As an aid to estimating the extent of the benefits to accrue to motorists through highway improvements that eliminate these impedances, information should be available on the frequency of the different types of impedances, the average speed changes caused by each impedance and, in the case of stops for traffic signals and stop signs, the average duration of the stopped delays.

An aspect of user benefit analysis of significance in connection with passenger car benefit studies is the relative preference of users for the various types of benefit arising through highway improvement. Information on the relative attractiveness to motorists of reduced travel cost, time saving, greater safety, and increased driving comfort can be of material assistance in the computation of benefits by providing a guide to the kinds of improvement most desired by users and to the relative advantages, from the users point of view, of the types of benefit realized from these improvements.

A knowledge of motorists' evaluation of two of the benefits brought about by highway improvements, time saving and increased driving comfort, is of paramount importance in passenger car benefit studies. Many highway improvements, particularly those on a large scale in rural areas, bring about higher average operating speeds. Because for the normal range of passenger car speeds in rural areas operating costs for fuel, oil and maintenance increase with increased speed, these improvements frequently result in increased operating costs (3). Consequently most of the benefits accruing to passenger car users through highway improvement are those associated with time saving, increased driving comfort, and safety. The benefits to users resulting from reductions in accident rates through road improvements are subject to continuing study and research. The monetary values to users of time saving and increased driving comfort have an importance in benefit analyses at least as great as accident cost saving and warrant thorough investigation.

FIELD STUDY

The four factors previously discussed were investigated during the summer of 1959 by operating a passenger car a distance of 14,000 mi on primary highways in 17 States and collecting a variety of data relative to passenger car operation and highway travel characteristics. Included as portions of the study route were 14 locations where a major free route and a toll road are in position to serve the same traffic. At each of these locations several comparison runs were made on both the free road and the toll road. At the time of these test runs origin-and-destination interview stations were operated on each route to determine the relative use of the roads and to record trip purpose and driver preference data.

Study Vehicle

The vehicle used for the study was a 1959 six-cylinder 4-door standard station wagon of popular make equipped with automatic drive. It was necessary to use the station wagon rather than a sedan or other type of passenger car to provide sufficient interior space to carry the bulky equipment for recording study data described later. Although the vehicle was new and had been operated only 3,380 mi at the beginning of the study, it was placed on a dynamometer and its engine performance given a special check immediately preceding the study. All engine defects discovered at this time, however minor, were corrected. During the 2-month study period while the vehicle covered over 14,000 mi of travel, all recommendations of the manufacturer in regard to vehicle care and maintenance were strictly adhered to.

The vehicle weight and cross-section dimensions were carefully determined. The gross weight of the vehicle, when loaded with the data collecting equipment and carrying both the vehicle operator and the observer, was 4,900 lb. The frontal cross-section of the vehicle itself was 6 ft wide by 5 ft high, the same as for a passenger car of the same make, but the total cross-section was increased by an open-top wooden box affixed to the roof of the vehicle to support and protect a gasoline-powered generator, needed to provide electrical power to operate the data collecting equipment located inside the station wagon. This box added 1⅛ ft to the vehicle height for almost the full width of its roof. The full cross-section of the vehicle when equipped for collecting data was 6 ft wide by 6⅛ ft high.

Equipment for Measuring and Recording Data

The data collecting equipment (described in detail in the following paragraphs) consisted of an electronic device for measuring distance and speed data, an automatic printer for recording distance, speed and time data, a code box for manually adding code numbers to the printer record tape, a fuelmeter, and several hand counters.

The items of electronic equipment were interconnected as a unit called the traffic impedance analyzer (Fig. 1). The instrument for measuring distance and speed was actuated by a flexible cable connection to the cable of the vehicle's speedometer. The output information from this instrument was directed as a series of electrical impulses into the automatic printer through appropriate electrical connections. The printer recorded once each second on a strip of paper tape, the travel distance in miles and hundredths of a mile from a fixed point, usually the beginning point of a study run, the vehicle speed in miles per hour (to the nearest mile), and the elapsed time in seconds since leaving the initial point of the study run.

A manual code box with 20 push buttons arranged in two columns of 10 buttons each enabled the observer to record any number from 0 through 9 in each of two columns of the printer tape, changing the numbers each second if necessary. A typical sample of the printer tape is shown in Figure 2. A recent article (4) contains a full description of the traffic impedance analyzer and an explanation of the operation of its component parts.

Vehicle fuel consumption data were obtained using a bellows-type fuelmeter connected to the gasoline line of the vehicle between the fuel pump and the carburetor. The instrument was mounted on the front seat of the vehicle beside the driver so as to be easily read by the observer who sat on the rear seat. The fuelmeter, which gave fuel consumption readings to the nearest 1/60th of a gallon, was read and the data recorded by the observer at each study check point as described in the section on "test procedure." Fuel consumption data as obtained by reading the fuelmeter were continuously checked for accuracy during the study by comparing the difference in fuel readings between successive additions to the fuel tank with the quantity of fuel put into the tank as measured by the gasoline station fuel pumps.

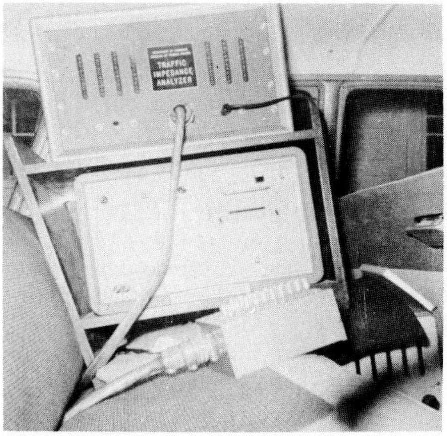

Figure 1. Traffic impedance analyzer.

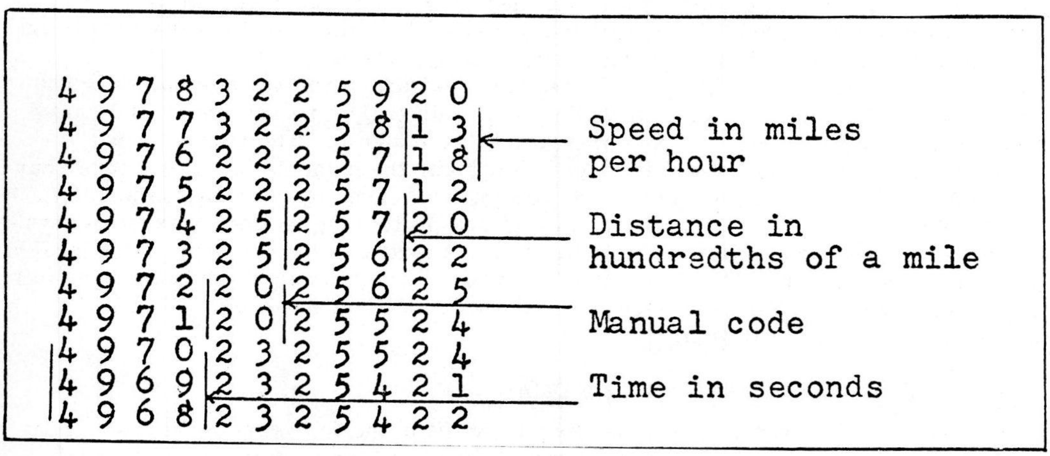

Figure 2. A typical recording sample from the traffic impedance analyzer.

Study Route

The study route ran north from Washington, D.C., by way of Elizabeth, N.J., to Syracuse, N.Y. From Syracuse it ran east to Boston, Mass., and thence north to

Portland Me. From Portland the route ran westward through Syracuse, Buffalo, N.Y., Toledo, Ohio, Elkhart, Ind., Springfield, Ill., and Hannibal, Mo., to Wichita, Kans. From Wichita the route ran south through Tulsa and Oklahoma City, Okla., to Ft. Worth, Tex. From Ft. Worth the route ran eastward through New Orleans, La., and along the Gulf coast to Tallahassee, Fla., then southward to West Palm Beach, Fla. From West Palm Beach the route ran northward through Daytona Beach, Fla., Jacksonville, Fla., Savannah, Ga., and Richmond, Va., to Washington, D.C. The termini of each of the sections of the study route, together with route numbers, are given in Table 1 in the order in which the data were obtained except that all toll road comparison sections are given first (Fig. 3).

TABLE 1

ROUTE NUMBERS AND TERMINAL POINTS OF STUDY SECTIONS USED FOR INVESTIGATION OF PASSENGER CAR OPERATING CHARACTERISTICS

Section No.	Initial Point	End Point	Route	Toll Route (toll route comparison sections only)	Remarks
1	Elizabeth, N J	Delaware Memorial Br	US 1 and US 130	New Jersey Tnpk	3 trips each route
18	Trenton, N.J.	Delaware Memorial Br.	US 130	New Jersey Tnpk	3 trips each route
19	Camden, N.J.	Delaware Memorial Br.	US 130	New Jersey Tnpk.	3 trips each route
2	Syracuse, N.Y.	Utica, N.Y.	NY 5	New York Thruway	3 trips each route
3	Syracuse, N.Y.	Harriman, N Y.	US 81, US 11, US 17	New York Thruway	3 trips each route
4	Portsmouth, N.H.	Massachusetts line	US 1	New Hampshire Tnpk.	3 trips each route
51	Portland, Me.	Kittery, Me.	US 1	Maine Tnpk	3 trips each route
6	Toledo, Ohio	Indiana line	US 20	Ohio Tnpk	3 trips each route
7	Elkhart, Ind	Ohio line	US 20	Indiana E -W. Toll Rd.	3 trips each route
8	Wichita, Kan.	Wellington, Kan	US 81	Kansas Tnpk.	3 trips each route
9	Wichita, Kan.	Topeka, Kan.	US 81, US 50, US 75	Kansas Tnpk.	3 trips each route
10	Tulsa, Okla.	Oklahoma City, Okla	US 66	Turner Tnpk.	3 trips each route
20	Tulsa, Okla.	Miami, Okla.	US 66	Will Rogers Tnpk.	3 trips each route
11	West Palm Beach, Fla.	Ft. Pierce, Fla.	US 1	Sunshine State Pkwy.	3 trips each route
30	Braman, Okla.	Tulsa, Okla	US 177, US 77, US 75	-	Free road only
31	North city limit Oklahoma City, Okla	South city limit Oklahoma City, Okla.	US 77	-	Through Oklahoma City
32	Moore, Okla.	Ardmore, Okla	US 77	-	Free road only
33	Ft. Worth, Tex.	Dallas, Tex.	US 80	-	Free road only
34	Ft. Worth, Tex.	Dallas, Tex.	Dallas-Ft. Worth Tnpk	-	Toll road only
35	Center of Dallas, Tex.	E. city limit, Dallas, Tex.	US 80	-	Through Dallas
36	West city limit Shreveport, La.	East city limit Shreveport, La.	US 80 and US 71	-	Through Shreveport
37	Shreveport, La.	Baton Rouge, La.	US 71 and US 190	-	Free road only
38	North city limit Baton Rouge, La.	South city limit Baton Rouge, La.	US 61	-	Through Baton Rouge
39	Gonzalez, La.	New Orleans, La.	US 61	-	Free road only
40	Downtown New Orleans, La.	Residential area New Orleans, La.	US 90	-	Through New Orleans
41	New Orleans, La.	Biloxi, Miss.	US 90	-	Free road only
42	West city limit Biloxi, Miss.	East city limit Biloxi, Miss	US 90	-	Through Biloxi
43	Biloxi, Miss.	Mobile, Ala.	US 90	-	Free road only
44	West city limit Mobile, Ala.	East city limit Mobile, Ala.	US 90	-	Through Mobile
45	Mobile, Ala.	Chipley, Fla	US 90	-	Free road only
46	Ft. Pierce, Fla.	Daytona Beach, Fla	US 1	-	Free road only
47	South city limit Daytona Beach, Fla.	North city limit Daytona Beach, Fla.	US 1	-	Through Daytona Beach
48	South city limit Jacksonville, Fla.	North city limit Jacksonville, Fla.	US 1 and US 17	-	Through Jacksonville
49	Jacksonville, Fla.	Woodbine, Ga.	US 17	-	Free road only
50	Center of Savannah, Ga.	North city limit Savannah, Ga.	US 17	-	Through Savannah
51	Hardeeville, S.C.	Walterboro, S.C	US 17 and US 17A	-	Free road only
52	Walterboro, S.C.	Summerton, S.C.	US 15	-	Free road only
53	Manning, S.C.	Florence, S.C	US 301	-	Free road only
54	Rowland, N.C.	St. Paul, N.C.	US 301	-	Free road only
55	South city limit Fayetteville, N.C.	North city limit Fayetteville, N.C	US 301 and US 401	-	Through Fayetteville
56	South city limit Raleigh, N.C.	North city limit Raleigh, N.C.	US 401	-	Through Raleigh
57	Raleigh, N.C.	Norlina, N.C.	US 1	-	Free road only
58	South Hill, Va.	Petersburg, Va.	US 1	-	Free road only
59	South city limit Petersburg, Va.	North city limit Richmond, Va.	US 1	-	Free road only
60	North city limit Richmond, Va.	South city limit Petersburg, Va.	Richmond, Petersburg Tnpk.	-	Toll road only

Test Procedure

The test vehicle was operated on each section of the route for which data were collected from one end of the section to the other in a manner as closely typical of the passenger cars in the traffic stream as possible. This was done by having the vehicle float with the traffic; that is, operate so as to be passed by about the same number of vehicles as it overtook and passed.

During each test run the traffic impedance analyzer automatically recorded on the printer tape speed, distance, and time data each second. The observer, continuously alert to traffic conditions and highway elements affecting vehicle speed, made use of the manual code box to record on the printer tape opposite each speed change a code number to identify the highway factor or traffic event causing the speed change. The code used is given in Table 2. The left column of code numbers identified highway and traffic factors such as number of lanes or whether a highway is divided or not, whereas

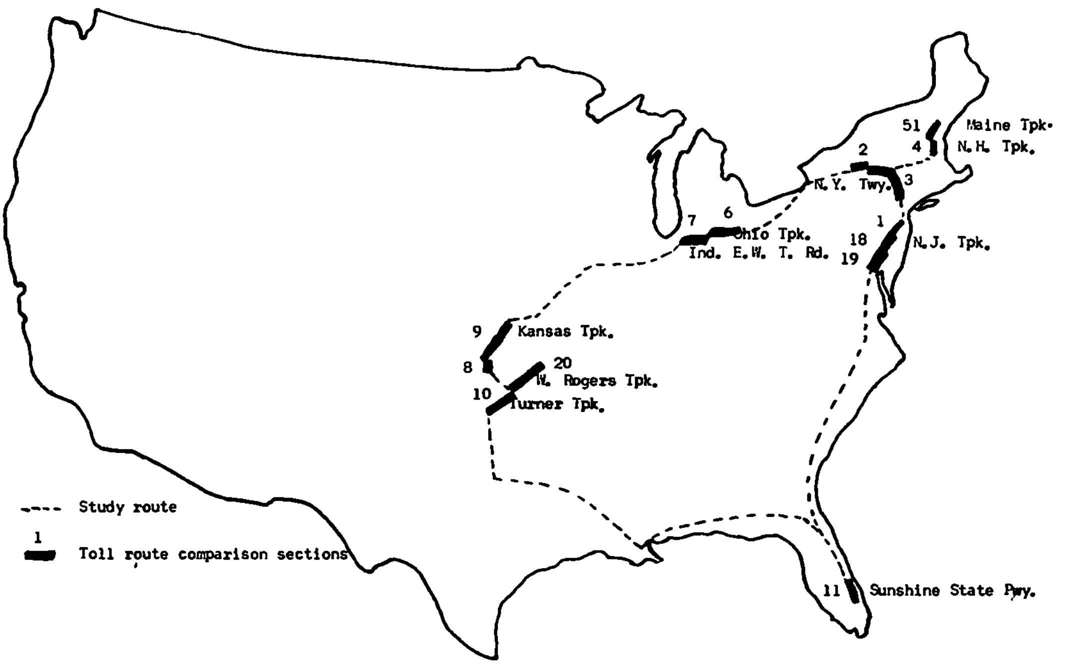

Figure 3. Study route showing 14 road comparison sections.

the code numbers in the right column identified traffic events such as a vehicle suddenly entering from a side road and causing the test vehicle to reduce speed.

The observer manually recorded on a separate data sheet clock time, vehicle odometer readings, fuelmeter readings and fuel temperatures at each of several check points on each test run. The check points were places where the character of the highway changed abruptly. For example, each point where a highway entered or left an urban area, even though it was only a small town, was a check point. Check points were located in this manner to make possible an analysis of the data by type of highway and character of traffic conditions. Check points were recorded on the printer tape using code number 1 in the right hand code column. Because all check points were selected in advance of the test runs, it was a relatively simple matter to go over the printer tape after completion of each run and write on the tape a complete identification of each check point. The clock time and vehicle odometer readings recorded for each check point constituted a check on the operation of the electronic measuring and recording equipment.

TABLE 2

TRAFFIC IMPEDANCE ANALYZER CODE USED IN INVESTIGATION OF PASSENGER CAR OPERATING CHARACTERISTICS, 1959

Button No.	Code: Left Column	Code: Right Column
1.	2- or 3-lane rural free-moving traffic.	Check point.
2.	2-lane rural, trailing another vehicle—unable to pass.	Traffic signal.
3.	4- or more-lane rural without access control.	Stop sign or flashing red signal, if stopped, otherwise trailing truck.
4.	4- or more-lane rural, divided with access control.	Sharp curve or turn if slowed down, railroad crossing if stopped.
5.	2- or 3-lane urban, free-moving traffic.	Residential driveway where entering or leaving vehicle affected test vehicle.
6.	4- or more-lane urban, free-moving traffic.	Commercial driveway where entering or leaving vehicle affected test vehicle.
7.	2- or 3-lane urban congested traffic conditions.	Overtaking and passing maneuver by test vehicle.
8.	4- or more-lane urban congested, traffic conditions.	Effect of school bus in rural areas, or double-parked vehicles in urban areas
9.	2-, 3- or 4-lane urban, one-way, free-moving traffic conditions.	Vehicle turning into highway from crossroad affecting test vehicle.
0.	2-, 3- or 4-lane urban, one-way, congested traffic conditions.	Blank.

The number of access points were recorded for each study section because of their effect on traffic operations and vehicle fuel consumption. A separate count was made for crossroads and cross streets, residential driveways, and commercial driveways. Thus, all points of access to a section of highway over which test data were collected were counted from check point to check point with hand counters and recorded on the data sheet. Each intersecting highway or street was counted as one crossroad regardless of whether it crossed the study route or terminated at it. All residential driveways on both sides of the route on divided as well as undivided highways were included in the total count of residential access points. Similarly, all entrances and exits to commercial establishments on both sides of the route were counted for the count of commercial access points. Where a commercial entrance was very wide, each 40 ft of width was counted as one access point. The observer counted commercial and residential driveways with two hand counters while the vehicle operator counted crossroads with a third hand counter.

On each of 14 sections of the study route designated as toll route comparison sections, users desiring to travel from one end of the section to the other had a choice between using a major non-toll highway built to standards associated with roads of uncontrolled access and a toll road built to conform with the highest design standards (Table 1). At each of these sections a special study was carried out to obtain directly comparable data of passenger car operations on the toll roads and the alternate free routes. In most cases, the toll road routes included short sections of free route at each end to connect the toll routes to the free routes at the common end points.

At each toll route comparison section three test runs were made on the free road from the designated initial point to the end point. The comparable toll road trips were made as return trips on the toll road for each free road trip. Special runs made on the New York Thruway where the severest terrain conditions were found, demonstrated that there was no significant difference in toll road data by direction of travel. The operation of the vehicle on test runs and the kinds of data collected on each run were the same for all test runs except that on the toll road the electronic recording equipment was operated for only one test run at each comparison section. It was not considered necessary to operate the traffic impedance analyzer to record speed changes for more then one toll road run because of the inherent uniformity of speeds encountered in toll road operations.

Roadside Interview Stations

Roadside interview stations were operated on both the toll road and the alternate free route at each toll route comparison section to obtain information both on the relative use of the two routes and on the factors affecting user selection of one route in preference to the other. The drivers of all passenger cars operating in the direction from the initial point to end point of each comparison section during a 1-day interview period (8 a.m. to 8 p.m.) were stopped at each interview station and asked the following questions:

1. What is the origin of this trip? (If the origin reported was the city in which the initial point of the comparison section was located, the driver was asked to give the street address.)
2. What is the destination of this trip?
3. What is the purpose of this trip?
4. Why are you using this route rather than the alternate toll/free route?

The two interview stations for each comparison section were operated by the highway department of the State in which the particular section was located during the week that the test runs were being made.

ANALYSIS

Four separate analyses were made: (a) a comparison of average over-all speeds and rates of fuel consumption of a 4,900-lb passenger vehicle for operation on highways with the highest design standard (toll roads) vs operation on major thoroughfares without access control and without many of the other modern design features; (b) determination of the effect of traffic signals, access points, and sharp curves on passenger car operation on major thoroughfares; (c) an analysis of the relative use of toll and free routes; and (d) an investigation of the average motorist's evaluation of the time saving and improved driving comfort resulting from highway improvement.

Fuel and Time Consumption

The over-all average speed in miles per hour and the average rate of fuel consumption in miles per gallon were determined for the distance between each successive check point of each section of the study route. These were computed using the elapsed time, fuel consumption, and distance recorded for the movement between the check points. The speeds and rates of fuel consumption computed for all portions of highway having the same general travel characteristics were then grouped together and the average values found for each group. The average speeds and rates of fuel consumption on primary routes in rural areas, urban downtown areas, urban areas outside the downtown area, and in small towns are given in Table 3.

TABLE 3

AVERAGE OVER-ALL SPEEDS AND RATES OF FUEL CONSUMPTION OF A STATION WAGON OF 4,900-LB GROSS WEIGHT ON PRIMARY ROUTES BY TYPE OF ROUTE AND NUMBER OF TRAFFIC LANES

Type of Route	Average Over-all Speeds (mph)		Average Over-all Rate of Fuel Consumption (mpg)	
	2 Lanes	4 Lanes	2 Lanes	4 Lanes
Routes with controlled access: Rural divided highways	-	60.1	-	11.1
Routes without controlled access: Rural roads (exclusive of small towns)	49.7	47.8	12.5	12.5
Main urban routes: Downtown areas of large cities	23.0	24.3	12.5	14.3
Outside downtown areas of large cities	24.9	31.1	14.3	14.3
Small towns	29.6	27.2	14.3	14.3

The results presented in Table 3 demonstrate the general over-all effects on vehicle speeds and rates of fuel consumption of improvements which would result only in an increase in the number of traffic lanes from two to four and those which bring about the upgrading of the typical primary highway of uncontrolled access to the level of routes designed to the highest standards (toll road). This table shows that the speeds and rates of fuel consumption on rural routes are about the same for both 2-lane and 4-lane roads but both are higher on toll routes compared to free routes for the typical traffic volumes using the routes. The slightly lower average over-all speed shown for 4-lane rural roads with no control of access as compared to 2-lane rural roads was undoubtedly due to the much higher traffic volumes encountered on the 4-lane roads.

On free routes in urban areas except small towns the average speeds are greater on roads of 4 lanes than on 2-lane roads, but the fuel consumption rates are about the same. In small towns the average over-all speed is higher for 2-lane roads than it is for 4-lane roads. This result is explained by the greater frequency of traffic signal stops on 4-lane routes than on 2-lane routes in small towns (see item 7 of Table 4). These values indicate generally the speeds and rates of fuel consumption on 2- and 4-lane roads but are inconclusive for direct computation of user benefits because they do not differentiate according to traffic volumes. They are useful, however, as over-all checks on time and fuel benefits computed by other means.

The variation in the average over-all speeds and fuel consumption rates of passenger cars as related to the frequency of driveways and nonsignalized intersections (crossroads) on primary 2-lane rural roads is shown by bar diagrams in Figure 4. This figure may be used to estimate the effects on passenger car time and fuel consumption to result through improvements which reduce the frequency of access points on primary 2-lane rural roads for the ranges of average daily traffic volumes typical of such roads.

Figure 4 shows that where there are fewer than two crossroads per mile both the

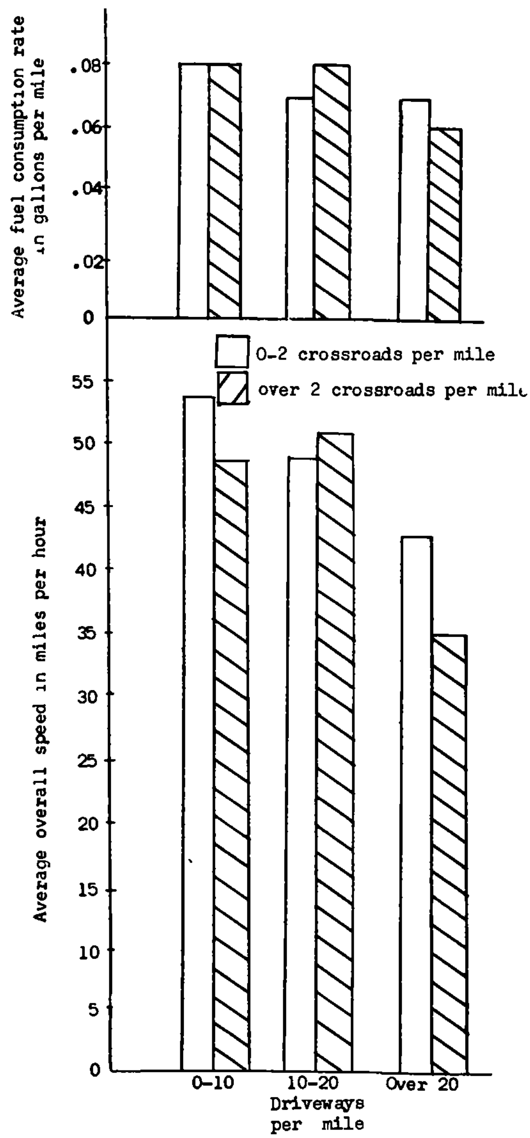

Figure 4. Average over-all speeds and fuel consumption rates on primary 2-lane rural roads as affected by the frequency of driveways and crossroads.

average over-all speed and the average rate of fuel consumption decrease with an increase in the frequency of driveways from less than 10 to between 10 and 20 driveways per mile but only the average over-all speed continues to decrease when the frequency of driveways is increased to more than 20 per mile. When the number of crossroads per mile exceeds two, average over-all speeds remain about the same for an increase in driveway frequency from less than 10 to between 10 and 20 per mile. The slight increase in speed shown in Figure 4 for this increase in driveway frequency reflects the fact that in mountainous terrain where there are likely to be few farm entrances because of poor farming conditions, road grades adversely affect vehicle speeds, whereas in flat or rolling terrain, where there is usually a greater frequency of farms, road grades are more conducive to higher over-all speeds. However, average over-all speed drops abruptly for a driveway frequency in excess of 20 per mile.

Little change in rate of fuel consumption results when there are more than two crossroads per mile for an increase in driveway frequency from less than 10 driveways per mile to between 10 and 20 driveways per mile but an increase in driveway frequency to more than 20 per mile results in an appreciable reduction in fuel consumption. The reduced fuel consumption associated with the increase in number of access points is due to the decreased speeds brought about by the increased frequency of driveways.

Traffic Signals, Access Points and Sharp Curves

Certain of the effects of traffic signals, access points, and sharp curves on passenger car operation and the frequency of occurrence of these impedances were computed using data collected with the traffic impedance analyzer. These are presented in Table 4 differentiated according to whether the impedances were in rural or urban areas. One important effect of a traffic impedance is to cause changes in vehicle speeds. The average number of speed change units given in Table 4 for each of the three impedances, is the average for each impedance of the arithmetic sum of all speed changes associated with the movement of a vehicle past the impedance, each speed change unit being a change in speed of 1 mph. For example, if a vehicle approaching a traffic signal at 50 mph slows to 25 mph, increases speed to 30 mph, and then slows to a stop followed later by an increase in speed back to 50 mph, the total number of speed change units would be (50-25) plus (30-25) plus (30-0) plus (50-0) or 110 units of speed change. All single speed changes of 3 mph or less were ignored. The percent of traffic signals at which the study vehicle was stopped and the average duration of traffic signal stops as well as the percent of commercial and residential driveways at which the study vehicle was slowed by vehicles entering or leaving the traffic stream are included in Table 4 as important impedance effects for benefit studies.

TABLE 4

EFFECT OF TRAFFIC SIGNALS, ACCESS POINTS, AND SHARP CURVES ON OPERATION OF PASSENGER CARS, AND FREQUENCY OF THESE TRAFFIC IMPEDANCES ON MAJOR THOROUGHFARES OF THE UNITED STATES

Item	Urban Area	Rural Area
1. Percent of traffic lights at which study vehicle was stopped	43	30
2. Average stopped delay at traffic signals	0.29 min	0.21 min
3. Average number of speed change units per traffic signal stop[a]	60	90
4. Average percent of driveways (both residential and commercial) at which study vehicle was slowed by entering or leaving vehicles	0.5	0.8
5. Average number of speed change units per access point at which a through vehicle is slowed by an entering or leaving vehicle[a]	20	20
6. Average number of speed change units per sharp curve[a]	15	15
7. Average number of traffic signals per mile	1.96	0.05 (2-lane) 0.20 (4-lane)
8. Average number of residential access points per mile	16.0	5.8
9. Average number of commercial access points per mile	34.2	5.2
10. Average total number of driveways per mile	50.2	11.0
11. Average number of crossroads per mile	10.6	1.9

[a]The number of speed change units for any impedance is the arithmetic sum of speed changes associated with the impedance.

The information presented in Table 4 relative to the effects of driveway access points on vehicle operation is useful for estimating the user benefits to result from the elimination of private driveways. Item 4 shows that the percent of driveways at which the study vehicle was slowed by vehicles entering or leaving the highway at driveways was 0.5 percent (1 in 200) in urban areas and 0.8 percent (1 in 125) in rural areas. Item 10 shows the average number of driveway access points per mile on the free routes studied to be 50.2 in urban areas and 11.0 in rural areas. The average distances traveled by the study vehicle between driveways at which an entering or leaving vehicle caused a slowdown were computed using these values and were found to be 4 mi in urban areas and 11 mi in rural areas.

The values given in items 1 and 2 of Table 4 are useful for predicting the benefits to accrue to highway users through the elimination of a signalized intersection-at-grade. The average percent of through vehicles stopped by each traffic light on primary roads is 43 percent in urban areas and 30 percent in rural areas with the average stopped delay 0.29 min and 0.21 min in urban and rural areas, respectively. The amount of saving in fuel and time consumption to accrue to users through the elimination of slowdowns due to driveway entrances and stops due to traffic signals can be computed using these data together with data on the fuel and time consumed by highway vehicles for stop-and-go and slowdown operations (1). The usefulness to benefit studies of the speed change data given in Table 4 is described in a later section of this paper in connection with the value to users of improved driving comfort.

Relative Use of Toll Routes and Alternate Free Routes

The data obtained at the roadside interview stations at both the toll and free routes of each of the 14 toll route comparison sections were analyzed to determine the relative use of high-type roads on which a toll is levied and alternate free routes built to lower design standards. Because the interview data included trip purposes and driver responses to the interview question regarding drivers' reasons for selecting whichever route they were interviewed on, it was possible to extend the analysis to show the relative importance of many of the factors influencing driver choice of route.

In computing the percent of the drivers electing to use the toll road at each comparison section as given in Table 5, only drivers going the full length of the comparison section whose trips originated at the initial point of the particular section were included. Drivers whose trips originated beyond the origin city were excluded because it was felt that these drivers were not local people and not sufficiently aware of the travel characteristics of the comparable routes to make a rational choice. Drivers whose trips originated or ended at intermediate points were excluded because, in most cases, they would have to go an appreciable distance out of their way to make use of the alternate route.

Table 5 also shows for each toll route comparison section the breakdown of the toll road user responses to the interview inquiry as to why they elected to use the toll road instead of the free road. The reasons given by all drivers responding to this inquiry are included, whether or not their trip originated at the initial point of the comparison.

TABLE 5

RELATIVE USE OF TOLL ROAD AND COMPARABLE FREE ROAD AT TOLL ROAD COMPARISON SECTIONS, AND DRIVER REASONS FOR USE OF TOLL ROAD

Toll Road Comparison Section No	Initial and End Points[a]	No of Passenger Cars Originating at Initial Point				No. of Drivers Responding to Inquiry	Driver Reasons for Using Toll Road[b]									
		Toll Road	Free Road	Total	Percent Using Toll Road		Time Saving		Greater Safety		Less Costly		Greater Comfort and Convenience		All Other Reasons	
							No	%	No	%	No.	%	No.	%	No.	%
1	Elizabeth, N J to Delaware Mem Br	9	5	14	64	94	62	66	3	3	1	1	'7	18	11	12
18	Trenton, N J to Delaware Mem Br	65	15	80	81	65	54	83	1	2	0	0	6	^	4	6
19	Camden, N J to Delaware Mem Br.	234	883	1,117	21	321	228	71	15	5	0	0	64	20	14	4
2	Syracuse, N.Y. to Utica, N.Y.	199	368	567	35	281	237	84	13	5	0	0	12	4	19	7
3	Syracuse, N Y. to Harriman, N. Y	51	28	79	65	84	60	71	3	4	0	0	18	21	3	4
4	Portsmouth, N.H. to Mass line	317	159	476	67	3,260	2,665	82	51	1	5	Neg	355	11	184	6
51	Portland, Me. to Kittery, Me	241	155	396	60	689	535	78	23	3	0	0	102	15	29	4
6	Toledo, Ohio to Indiana line	150	142	292	51	4,214	3,416	81	207	5	88	2	0	0	503	12
7	Elkhart, Ind. to Ohio line	31	9	40	78	154	122	79	8	5	0	0	12	8	12	8
8	Wichita, Kans. to Wellington, Kans	210	110	320	66	Data	analysis	incomplete			Data	analysis	incomplete			
9	Wichita, Kans to Topeka, Kans.	112	14	126	90	Data	analysis	incomplete			Data	analysis	incomplete			
10	Tulsa, Okla. to Oklahoma City	512	72	584	88	Data	analysis	incomplete			Data	analysis	incomplete			
20	Tulsa, Okla. to Miami, Okla.	144	31	175	82	Data	analysis	incomplete			Data	analysis	incomplete			
11	W. Palm Beach, Fla. to Ft. Pierce, Fla.	63	185	248	25	126	96	76	9	7	0	0	18	14	3	3
All		2,338	2,176	4,514	53	9,288	747	580	333	4	94	1	604	7	782	8

[a]See Table 1 for other data on toll road comparison sections
[b]Includes all passenger cars on toll roads regardless of trip origin

The breakdown of avowed reasons for using toll roads given in Table 5 for the 14 toll route comparison sections shows that between 71 and 84 percent of the toll road users elect to use the toll route rather than the free route to save time, 1 to 7 percent for reasons of safety, less than 1 percent to save money, up to 21 percent for improved driving comfort, and up to 12 percent for other reasons. Time saving is the most important single factor inducing drivers to travel on toll roads, with improved driving comfort second in importance. Less than 7 percent of those electing to use the toll road did so for safety reasons. These data indicate that from the passenger car users' point of view the highway improvements which bring about the greatest benefits are those which reduce time consumption and improve driving comfort.

Table 6 shows for the toll routes and free routes of all toll road comparison sections the breakdown of users according to the reasons given by the drivers for electing to use the route they were interviewed on for each of five categories of trip purposes: work, shop, vacation, recreation or social other than vacation, and all others. These values are given both in absolute numbers and as percentages of the total sample in each trip purpose category. All passenger car users moving in one direction on both the toll and free routes during a 12-hr interview period on each of the 10 toll road comparison sections for which data analyses are complete are represented in Table 6. Data analysis is incomplete for toll road comparison sections 8, 9, 10 and 20 (Table 5).

Two items of information of significance in passenger car user benefit studies are brought out in Table 6: the relative importance of the factors inducing passenger car users to elect to use a free road when a toll route is available, and the effect of trip purpose on the relative importance to passenger car users of the factors inducing them to use either toll routes or free routes. The relative importance of the factors inducing passenger car users to use a toll road when a free road is available was given in Table 5 and discussed in connection with that table.

An average of 21 percent of free road users indicated that they decided to travel on the free road to save time, 13 percent to save money, 19 percent for greater driving comfort, and 47 percent for other reasons. A negligible number of free road users thought travel by the free route was safer. The most common reasons given by free road users for using the free route are those included in the category of all other reasons and include less driving monotony, desire to shop or visit at points on the free route, see a particular view, and mechanical difficulty with the vehicle. The percentage of passenger car users who used the free road to save time and the percentage who used the free road to enjoy greater driving comfort are about equal in magnitude and second in importance only to the aggregate of reasons included in the category of all other reasons. Only a small percentage of free road users were influenced to use the free road to save money. It appears that on the free roads as on

TABLE 6

DISTRIBUTION BY TRIP PURPOSE OF DRIVER REASONS FOR USING EITHER THE TOLL ROUTE OR A COMPARABLE FREE ROUTE AT LOCATIONS WHERE A CHOICE EXISTS

Trip Purpose	Type of Route	Time Saving		Greater Safety		Less Costly		Comfort and Conven		All Other Reasons		Total[a]	
		No	%	No.	%	No	%	No.	%	No.	%	No	%
Work	Toll	2,018	83	72	3	57	2	120	5	173	7	2,440	100
	Free	740	75	0	0	485	16	589	20	1,181	39	2,995	100
Shop	Toll	98	83	5	4	1	1	7	6	7	6	118	100
	Free	181	31	0	0	51	9	137	23	221	37	590	100
Vacation	Toll	3,876	81	185	4	24	Neg	282	6	417	9	4,784	100
	Free	330	12	2	Neg	282	10	441	15	1,809	63	2,864	100
Other social or recreation	Toll	997	78	45	3	7	Neg.	137	11	100	8	1,286	100
	Free	363	24	1	Neg.	161	11	364	24	608	41	1,497	100
Other	Toll	486	73	26	4	5	1	58	9	85	13	660	100
	Free	203	32	0	0	88	14	119	19	217	35	627	100
Total	Toll	7,475	80	333	4	94	1	604	7	782	8	9,288	100
	Free	1,817	21	3	Neg	1,067	13	1,650	19	4,036	47	8,573	100
Grand total	Both	9,252	52	336	2	1,161	6	2,254	13	4,818	27	17,861	100

[a]Includes all passenger car users moving in one direction during a 12-hr interview period at each of the 10 toll road comparison sections for which data analysis is complete (Table 5)

toll roads, when only factors associated with the highway itself are considered, time saving and improved driving comfort are of greatest importance to the passenger car user. The percentage of passenger car users on the free routes that use the free route for reasons of greater comfort and convenience is appreciably higher than the percentage of toll road users that use the toll route for this reason. The explanation for this is probably the greater frequency and wider choice of restaurants, motels, and gasoline service stations on the free routes.

The effect of trip purpose on the relative importance to passenger car users of the factors causing them to select either the toll route or the free route is also given in Table 6. For the toll road users the relative importance of the various reasons for using the toll road is about the same regardless of trip purpose except that the toll road users traveling to or from work or on shopping excursions are influenced more by time saving and less than by comfort and convenience than are other users. For free road users the relative importance of the reasons for using the free route are nearly the same for all trip purposes except that most users on vacation use the free road for reasons other than time saving, safety, cost outlay, or driving comfort. Only a relatively small percentage of free road users on vacation use the free road either to save time or for greater driving comfort. In general these data indicate that there is no appreciable over-all difference in the importance to users of the various types of benefit by trip purpose.

Motorist's Evaluation of Time Saving and Increased Driving Comfort

The data collected at the roadside interview stations by the several State highway departments and by operation of the test vehicle on the toll roads and alternate free routes at the toll route comparison sections were analyzed at the Office of Research of the Bureau of Public Roads to obtain estimates of the value to motorists of the time saving and the greater driving comfort experienced when operating on the toll road. Drivers do not, in general, consciously assign a separate value to each of these benefits. However, because both are effective in influencing driver selection of route, each has a certain amount of attractiveness to users which may be measured in monetary terms.

The analysis was based on the theory that through travelers using toll roads, where a free alternate route is available, pay a premium to do so because they expect to benefit by an amount at least equal to the toll charge. The benefits received would be one or more of the following types of benefit: reduced operating costs, time saving, increased driving comfort and reduced accident costs. The value of two of these benefits can be estimated: operating cost saving, on the basis of the fuel consumption difference on the two routes, and accident cost savings, on the basis of published accident rate and accident cost reports. The problem is to arrive at a value of the two benefits, time saving and increased driver comfort, on the basis of estimated values of the other two benefits, and a known toll charge presumably paid to obtain these benefits.

A difficulty which complicated the problem of evaluating time saving and driver comfort benefits was selection of a suitable unit with which to measure driving comfort. A minute of time could be used to measure time saving but there was no similar unit for measuring improvement of driving comfort. However, it is generally recognized that uniformity of driving speed is a characteristic of good driving conditions. Most of the highway factors that cause driver annoyance, such as traffic lights and sharp curves, cause vehicles to change speed, frequently causing them to reduce speed to a full stop. These considerations lead to the selection of the speed change unit of 1 mph, previously described in connection with Table 3, as the unit of driving discomfort. Each speed change unit eliminated through highway improvement is therefore a unit of driving comfort improvement. In determining the number of units of speed change for a highway, only variations in speed where the speed change is more than 3 mph are included because variations of 3 mph plus or minus are typical of normal driving under the best conditions. Using speed change units as a measure of driving discomfort, the driving discomfort of a section of highway is the arithmetic sum of all speed changes on that section of road, neglecting all single speed changes of 3 mph or less. The unit value of improved driving comfort is taken in this analysis to be the value to users of each speed change unit of 1 mph saved through highway improvement.

The data obtained at each of the 14 toll route comparison sections are summarized in a convenient form in Tables 7 and 8 for the analysis of the motorist's evaluation of time saving and increased driving comfort. In both tables each toll route comparison section is identified by number and by the initial and end points. Inasmuch as at each comparison section a series of trips were made on both the free route and toll route, all trip data are given in Tables 7 and 8 as differences between the values for a free route trip and a toll route trip. For this purpose each free route trip was paired with

TABLE 7

TRIP LENGTHS AND RELATIVE USE OF TOLL AND FREE ROUTES, AND SAVINGS IN TIME CONSUMPTION AND SPEED CHANGE UNITS FOR OPERATION ON TOLL ROUTES FOR 14 TOLL ROUTE COMPARISON SECTIONS

Toll Route Comparison Section No	Initial and End Points[a]	No of Traffic Lanes of Free Route	Trip Length: Toll Route Miles	Trip Length: Alternate Free Route Miles	Percentage of Drivers Electing to Use Toll Road[b] (P)	Saving in Time Consumption and Number of Speed Change Units for Toll Route Trips Compared to Free Route Trips by Comparison Trip Pairs[c]: Comparison Trip Pairs	Time Saving Minutes (ΔT)	Saving in Speed Change Units[d] (ΔD)
1	Elizabeth, N.J to Delaware Memorial Br.	4	103.8	107.2	64	A	61	3,410
						B	47	3,430
						C	69	4,290
18	Trentor N.J. to Delaware Memorial Br.	4	55.8	58.7	81	A	34	1,795
						B	30	2,140
						C	28	2,055
19	Camden, N.J. to Delaware Memorial Br.	4	29 2	29 4	21	A	13	595
						B	7	355
						C	5	420
2	Syracuse, N.Y to Utica, N.Y.	2	53.5	50.4	35	A	15	945
						B	16	1,540
						C	28	2,020
3	Syracuse, N.Y. to Harriman, N.Y.	2	240.1	216.7	65	A	62	4,580
						B	60	4,970
4	Portsmouth, N.H. to Mass. line	2	16.0	16.1	67	A	4	110
						B	7	420
						C	5	145
51	Portland, Me. to Kittery, Me.	2	49.8	48.3	60	A	26	1,915
						B	22	1,190
						C	31	1,280
6	Toledo, Ohio to Ind. line	2	68 9	67.8	51	A	11	410
						B	9	310
7	Elkhart, Ind to Ohio line	2	69.3	62.9	78	A	0	975
						B	2	865
						C	3	745
8	Wichita, Kans to Well , Kans	2	27.2	26 2	66	A	5	50
						B	5	35
						C	4	50
9	Witchita, Kans. to Topeka, Kans.	2	134.8	165.6	90	A	53	1,390
						B	51	945
10	Tulsa, Okla. to Oklahoma City, Okla.	2	86.2	98.6	88	A	38	2,040
						B	35	1,960
						C	39	2,475
20	Tulsa, Okla. to Miami, Okla	2	74.3	80.3	82	A	19	915
						B	16	705
						C	23	830
11	West Palm Beach, Fla. to Ft. Pierce, Fla.	4	65.0	57.4	25	A	2	425
						B	0	475

[a]See Table 1 for other data on toll route comparison sections.
[b]Based on drivers whose trips originated at initial point of comparison section.
[c]A comparison trip pairs consists of one toll route trip and one free route trip. Time saving and saving in speed change units are for full trip length.
[d]A speed change unit is 1 mph change, plus or minus, for all speed changes in excess of 3 mph.

a toll route trip and the value of the differences in time consumption, speed change units and fuel cost as well as total cost differences are given for these comparison trip pairs. At each comparison section there are at least two comparison trip pairs and at many sections there are three. These are identified by the letters A, B and C.

Table 7 presents data on the number of traffic lanes on the free routes, the trip lengths, both of the toll and free routes, the percentage of drivers electing to use the toll route, and the differences in time consumption and number of speed change units for the two trips of each comparison trip pair. The percentage of drivers electing to travel by toll route was determined using only the drivers on the compared routes whose trip origins were at the initial points of the compared sections. ΔT and ΔD are the savings in time and speed change units, respectively, for a toll route trip compared to a free route trip.

The cost differences for operating over the routes of each comparison section are given in Table 8 for each comparison trip pair. These cost differences are the toll charge for toll road operation, R, the reduction in accident cost expectancy for operation on the toll route, ΔA, and the additional fuel cost for operation on the toll route, ΔF. The total additional cost for operation on the toll route as compared to operation on the free route for each comparison pair, ΔM, found by use of the formula $\Delta M = R + \Delta F - \Delta A$ is also given in Table 8.

TABLE 8

COST DIFFERENCES FOR OPERATION ON TOLL ROUTE AS COMPARED TO OPERATION ON ALTERNATE FREE ROUTE FOR 14 TOLL ROUTE COMPARISON SECTIONS

Toll Route Comparison Section No	Initial and End Points[a]	Toll Charge, R (cents)	Reduction in Accident Cost Expectancy on Toll Route[b], ΔA (cents)	Comparison Trip Pairs[c]	Additional Fuel Cost for Operation on Toll Route[c], ΔF (cents)	Total Additional Cost for Operation on Toll Route[d], ΔM (cents)
1	Elizabeth, N.J. to Del. Mem Br.	130	11 0	A	-1.5	117.5
				B	6.9	125.9
				C	0.9	119.9
18	Trenton, N.J. to Del. Mem Br	60	6.1	A	-6.9	47.0
				B	1.2	55.1
				C	1.5	55.4
19	Camden, N J. to Del. Mem. Br	30	3.0	A	-2.7	24.3
				B	1.8	28 8
				C	2.7	29.7
2	Syracuse, N.Y. to Utica, N.Y.	75	4 8	A	11.7	81.9
				B	8.4	78.6
				C	15.3	85.5
3	Syracuse, N.Y to Harriman, N.Y	370	19.5	A	105.3	455.8
				B	99.0	449.5
4	Portsmouth, N.H. to Massachusetts line	20	1 6	A	1.8	20.2
				B	5.1	23.5
				C	2.4	20.8
51	Portland, Me. to Kittery, Me.	100	4 7	A	21.6	116.9
				B	16.5	111.8
				C	18.0	113.3
6	Toledo, Ohio to Indiana line	90	6 7	A	3.6	86.9
				B	12.6	95.9
7	Elkhart, Ind. to Ohio line	85	5.7	A	38.4	117 7
				B	33.0	112.3
				C	45.0	124.3
8	Wichita, Kans. to Wellington, Kansas	30	2.5	A	14.7	42.2
				B	12.9	40 4
				C	6.0	33.5
9	Wichita, Kans to Topeka, Kans.	245	19.0	A	50.1	276 1
				B	30.6	256.6
10	Tulsa, Okla. to to Okla. City., Okla.	140	10.8	A	-7.5	121.7
				B	-12.3	116.9
				C	-1.5	127.7
20	Tulsa, Okla Miami, Okla.	120	8.4	A	24.6	136 2
				B	19.8	131.4
				C	23.4	135.0
11	West Palm Beach, Fla , to Ft Pierce, Fla	100	5 1	A	52.5	147 4
				B	52 2	147.1

[a]See Table 1 for other data on toll route comparison sections.
[b]Based on unit accident cost expectancy as follows: $0.07 per vehicle-mi on toll routes and $0.17 per vehicle-mi on routes without access control.
[c]A comparison trip pair consists of one toll route and one free trip.
[d]$\Delta M = R + \Delta F - \Delta A$

The saving in accident cost expectancy for operation on the toll route given in Table 8 is the difference in the average cost of accidents for a passenger car traversing the full length of each comparison section over the toll route as compared to operation over the free route. The accident expectancy cost of a passenger car on each route is the product of the route length in miles given in Table 7, the average accident rate of all types of accidents per vehicle-mile, and the average cost of a passenger car accident. The average accident rates used in these computations were 151 accidents per 100,000,000 vehicle-miles on toll roads and 332 accidents per 100,000,000 vehicle-miles on roads with no access control as presented in House Document No. 93 of the 86th Congress, First Session (5). The average cost of a passenger car accident on primary rural routes with no control of access is $521 per accident as determined from a study of accident costs in Massachusetts in 1953 (6). Unpublished data from the Massachusetts Accident Study show that the average cost of a passenger car accident (all accidents) on both primary and secondary rural highways is $402 per accident. If the types of accidents that very seldom occur on toll roads (head-on collision, head-on side-swipe collision, and collisions with bicycles and scooters) are eliminated, the average cost of a passenger car accident on rural routes is $369. Assuming that the saving in average passenger accident cost achieved through the elimination of these accident types, $33 ($402-$369), is the same on primary routes as on primary and secondary routes together, the average cost of an accident on toll routes is $488 ($521-$33).

The motorists at the initial points of each comparison section who wish to travel the full distance from the initial point to the end point of a comparison section are faced with the choice between two alternatives: (a) to use the toll road and pay the extra cost, ΔM, but save an amount of time, ΔT, and a number of speed change units (driving comfrot), ΔD; or (b) to use the free road and put up with the additional time consumption and speed changes but saving total cost difference, ΔM. The percentage of drivers who elect to use the toll road at each location is P, given in Table 7.

The first step in the analysis of the data of Tables 7 and 8 to obtain an estimate of the value the average motorist places on the saving of 1 min of trip time, t, and the value the average motorist places on the saving of one unit of speed change, s, was establishment of a relationship between these unknowns and the study data, ΔM, ΔT, ΔD and r, where r equals P/(100-P). Equations defining a model of the relationship between these variables have been presented by Cherniack (7). The following simple equation is an adaptation of Cherniack's work appropriate to this analysis as developed by G. P. St. Clair, Director of the Bureau of Public Roads' Highway Cost Allocation Study: $+\Delta M = -u \log r - t(\Delta T) - S(\Delta D)$. St. Clair's derivation of this equation is presented in the Appendix.

The values of t and s were arrived at by substituting the values of ΔM, ΔT, and ΔD and r, where r = P/(100-P), from Tables 7 and 8 in a series of equations of the foregoing form and solving by multiple regression. Only data for runs at study locations where the free routes are 2-lane roads were included in the equations. It was considered best not to include data for both 2- and 4-lane free roads in the equation for one multiple regression solution because of the differences in travel characteristics on the two types of road. Of particular concern was the fact that passing maneuvers measured by the amount of speed change represent a greater annoyance to drivers on 2-lane roads than they do on 4-lane roads. The data used in the multiple regression solution are those determined for the 27 comparison trip pairs of the 10 comparison sections where the free routes are 2-lane roads (Table 7).

The computations of the values of t and s by multiple regression analysis were made by Nathan Lieder, statistician for the Office of Research of the Bureau of Public Roads. The values of t and s together with the confidence limits on the 95 percent level of accuracy were found to be the following:

t = 2.365 cents per minute plus or minus 0.59 cent.

s = 0.048 cent per speed change unit plus or minus 0.062 cent.

The estimate of the motorist's evaluation of a minute of time saved rounded to the hundredth of a cent is 2.37 cents on the basis of the data collected for this study. This estimate of the value of time agrees fairly well with the estimate recommended by the American Association of State Highway Officials, 2.58 cents per minute (3).

The estimate of the value to motorists of the elimination of one speed change unit (a 1-mph change in speed) rounded to the hundredth of a cent is 0.05 cent. The variance of this estimate, plus or minus 0.06 cent, is very high, however, and appears to indicate that driver discomfort is not fully measured by speed change units. Certain anomalies in the data and general observations of the field crew of this study also indicate that driver discomfort is greater than shown by number of speed change units. For example, one obviously annoying traffic condition is for a motorist to have to trail a slow-moving vehicle for many miles on a 2-lane road before finding an opportunity to pass. The trailing driver, forced to travel at a slow but uniform speed, is annoyed because his speed is controlled by another driver and because he knows that to gain relief he must pass on a 2-lane road, which in itself is annoying. However, this distress is not reflected in speed change units. It is probable that to arrive at a better estimate of the value to drivers of the elimination of driving discomfort as measured by speed change units, some adjustment must be made to account for annoyances that are not reflected in speed changes.

It is evident, therefore, that further investigation is needed both to obtain more data on speed changes on toll route comparison sections and to incorporate into the analysis of the value to motorists of relief from driving annoyance, other measures of annoyance in addition to speed change units. In connection with the latter, further analysis is planned to exploit field data on the trailing operations of the study vehicle on 2-lane roads which were collected for this study but not contained in this report.

The analysis gives an accurate distribution between the items of time saving and reduced driving annoyances of the average passenger car user's evaluation of the sum of these two benefits. The value to passenger car users of a minute of time saving (2.37 cents) is also accurate because the average number of units of time saving (minutes) can be directly measured. The relatively high value arrived at for each unit of speed change saving (0.048 cent) is due to the allocation of the travel discomfort benefit value among only the number of speed change units saved when it probably should be allocated among the number of speed change units saved plus an unknown number of other discomfort units saved. To the extent that the amount of driving discomfort not measured by number of speed change units is in any way related to the number of speed change units, the product of 0.048 cent and the number of speed change units saved through highway improvement is a reasonable estimate of the value of the improved driving comfort benefit arising through the improvement. This estimate of the user's evaluation of each 1-mph speed reduction may be used to approximate driving comfort benefits arising through improvements which reduce the number of speed change units on roads similar to those for which study data were obtained, primary rural roads without control of access.

In Table 4 the average number of speed change units associated with three impedances, a traffic signal stop, an access point where a through vehicle is slowed by an entering or leaving vehicle, and a sharp curve, are given for operation in rural areas. Multiplying these values by the estimate of the average motorist's evaluation of the elimination of one speed change unit, 0.048 cent, gives the following estimates of the comfort and convenience benefit users receive through the given highway improvements: elimination of a traffic signal stop in rural areas, 4.32 cents; elimination of a sharp curve, 0.72 cent; and elimination of a slowdown to a through vehicle at an access point, 0.96 cent.

SUMMARY

Several types of data useful in analyses of the benefits accruing to passenger car users through highway improvement were developed in this study. Among these were average over-all rates of fuel consumption and speed for operation on existing major routes of 2 lanes and 4 lanes in both urban and rural areas and for operation on toll roads. These data showed that there is little difference between over-all speeds on

2- and 4-lane roads except on main urban routes of large cities outside of the downtown areas where over-all speeds on the 4-lane routes were approximately 25 percent greater than on the 2-lane routes. The greatest difference in average over-all operating speed observed was between that for operation on rural 4-lane divided controlled-access routes, 60.1 mph, and that for operation on 2- or 4-lane rural routes without control of access, between 47 and 50 mph. The fuel consumption rate on the rural 4-lane divided, controlled-access routes is about 12 percent greater than on the rural routes without control of access which, in turn, is about 15 percent greater than on urban routes. These differences in fuel consumption rates reflect the overriding effect of speed on rate of fuel consumption. For the typical traffic volumes carried by existing thoroughfares having no access control, there is little difference either in speeds or in fuel consumption rates for operation on 4-lane routes as compared to operation on 2-lane routes.

Certain of the effects of traffic signals, access points (driveways and crossroads without signal protection), and sharp curves on passenger car operation, together with the average frequencies of these impedances on major routes of the United States, are included in this report. The average passenger car driver is required to stop at 43 percent of the traffic lights in urban areas and at 30 percent of the traffic lights in rural areas and, when stopped at traffic lights, suffers an average stopped delay of 0.29 min in urban areas and 0.21 min in rural areas. Also the average driver is slowed by vehicles entering or leaving driveways at 0.5 percent of the driveways in urban areas and at 0.8 percent of the driveways in rural areas. These data, together with data on speed changes and on the average frequencies of impedances, can be very useful in user benefit computations by providing a means of estimating the effects on traffic operations of highway improvements which eliminate individual impedances or groups of impedances.

The relative use of toll routes and alternate free routes by drivers familiar with both routes, and the reasons given by drivers on the compared routes for using either the toll route or the free route are given to show the relative attractiveness to passenger car users of the different types of benefits arising from highway improvements. The type of benefit most important to motorists was found to be time saving with an average of 80 percent of the passenger car drivers on toll roads and 21 percent of the passenger car drivers on free roads stating they selected their travel route on the basis of time saving. The second most important reason given by passenger car users for selecting their route was greater comfort and convenience or less driving strain The highway benefits of least importance in governing passenger car user's selection of route were found to be greater safety and lower travel costs. Only 13 percent of the free road users indicated that they were influenced not to use the toll road because of the cost factor.

The toll road, free road comparison data were analyzed to arrive at an estimate of the average passenger car user's evaluation of time saving of 2.37 cents per minute of travel time saved and an estimate of his evaluation of an improvement in driving conditions (measured in units of speed change reduction) of 0.048 cents per 1-mph reduction in speed change. The estimate of the value of time saving is of a higher order of accuracy than that for the value of a speed change reduction largely because there are factors affecting driving comfort which are not reflected in speed changes. Because driving comfort was measured only by speed change reduction, the value of each unit of speed change reduction is somewhat high for general use. However it may be used to estimate driving comfort benefits arising through improvements which reduce the number of speed change units on roads similar to those for which study data were obtained, primary rural roads without controlled access.

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Appendix

The following is a derivation of a simple equation relating time saving, saving in speed change units, and cost difference for operation on a toll road rather than a free road, and the percent of traffic using the toll road to user evaluations of a minute of time saving and a 1-mph reduction in amount of speed change.

Assume that the number of daily round trips that will be made from a given origin, O, to a given destination, D, for a given purpose can be represented by the following equation:

$$V_{OD} = \left[q\right]\left[V_O\right]\left[I_{Da}\right]\left[F(C)\right] \qquad (1)$$

in which

q = a coefficient related to the propensity to make trips. This value is immaterial for present purposes.
V_O = number of vehicles domiciled in zone of origin.
I_{Da} = coefficient of attractiveness of the destination zone, D, for trips of the given purpose, a. Then if the purpose is home-to-work, this coefficient would be related to the number of employed persons in zone D.
F(C) = a function of the average cost of trip, C.

The number of trips for all purposes is given by the equation:

$$V_{OD} = \left[q\right]\left[V_O\right]\left[F(C)\right]\left[\Sigma I_n\right]$$

in which

$\Sigma I_n = I_a + I_b + I_c + \ldots\ldots\ldots I_n$, the sum of all trip purpose coefficients.

Let the following represent the cost function:

$$F(C) = 10^{-hC} \qquad (2)$$

in which

h is a coefficient to account for the unknown effect of travel cost on driver trip decisions.

This equation can be simplified by putting h = 1, but this presumably would reduce its generality and force it to conform to a curve that the data might not fit. Furthermore, h = 1 lacks generality, because if base e had been used, it would produce a different function.

In general this function behaves more or less as would be wished. If C is limited to positive values, as it should be, the function has its greatest value, one, when C =

0; and thus the number of trips varies inversely with the cost. It is not a perfect function but it has the virtue of simplicity.

The equation, therefore, takes the form:

$$V_{OD} = \left[q\right] \left[V_o\right] \left[\Sigma I_n\right]\left[10^{-hC}\right] \qquad (3)$$

Alternative routes: Eq. 3 may be taken as applicable to all trips made from O to D, the cost, C, being taken as the average cost of the trip, OD. There is, however, the problem of the distribution of the trips, V_{OD}, among two or more alternative routes having different trip costs. The equation will presumably hold for any one alternative, in relation to numbers of trips to other destinations. To assume that it holds for the distribution of trips to the same destination among alternative routes, it is necessary to say that the distribution of motorists subjective appraisals of certain cost elements (values of time and driving comfort) is such that the distribution of trips among alternative routes between the same termini obeys the same cost function.

If the subscript OD is reduced to O or D, according to the point of origin, and the subscripts 1 and 2 are used for two alternative routes between O and D, for trips from O to D the following may be written:

$$V_{O1} = (q)\,(V_O)\,(\Sigma I_D)\,10^{-hC_1}$$

$$V_{O2} = (q)\,(V_O)\,(\Sigma I_D)\,10^{-hC_2}$$

$$r_O = \frac{V_{O1}}{V_{O2}} \quad \frac{10^{-hC_1}}{10^{-hC_2}} = 10^{-h(C_1 - C_2)}$$

It becomes at once obvious that the result would be exactly the same for the trips originating at D:

$$r = r_O = r_D = 10^{-h(C_1-C_2)}$$

$$\log r = -h(C_1 - C_2)$$

$$\log r = -h(\Delta C)$$

$$\log r = -h(\Delta M + t\,\Delta T + s\,\Delta D)$$

in which

ΔM = the net sum of measured cost differences: operating cost, accident cost, expectancy and toll charge,

ΔT = time difference,

t = unit value of a minute of time saved,

ΔD = difference in speed change units,

s = unit value of a speed change unit eliminated,

r = P/(100-P), and

P = percentage of sum of travelers on the two alternate routes who elected to use the toll road.

The signs of the terms must be watched. If the free route is designated as route 1, then ΔM is likely to be negative and ΔT and ΔD are likely to be positive because measured costs are less on the free route, whereas, time and driving comfort costs are generally greater.

Let $u = \frac{1}{h}$,

then

$$u \log r = -\Delta M - t\Delta T - s\Delta D.$$

$$\Delta M = -u \log r - t\Delta T - s\Delta D. \qquad (4)$$

Economy Studies for Highways

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Much time and effort is devoted to collecting data and preparing estimates for highway economy studies, while the actual economic analysis is accomplished quickly. And yet if comparisons are made improperly or if certain basic assumptions are inappropriate, the decisions stemming from the analysis may be in error. The aim of this paper is to adapt certain general principles of engineering economy into the somewhat specialized circumstances of the highway framework.

Results of economy studies for highways might be stated in terms of annual costs or savings, excess of benefits over costs, benefit-cost ratio, or rate of return on investment. Properly employed and interpreted, all of these methods give correct results; improperly used, they can lead to wrong decisions. The first part of this paper illustrates, by example, the proper procedures for comparing multiple alternatives by each method and indicates some of the pitfalls to be avoided in using each of them.

Much of the raw data for economy studies for highways are based on predictions of events 20, 30, or even more years in the future. An examination of past happenings over such periods of time coupled with any consideration of today's rapid rate of change, clearly demonstrates the uncertainty of such long-range forecasts. If economy studies are made at zero interest rate, the effect is to give predictions at all future dates equal weight. As the interest rate for economy studies is increased, the effect of happenings in the more distant future is discounted. In other words, studies made at low interest rates are highly sensitive to variations in estimates of future events; studies made at higher interest rates are less sensitive to such changes. The second section of this paper examines the "sensitivity" of economy studies to assumptions regarding estimated lives, salvage values, and expected growth or decline of benefits. Findings are presented by means of examples and graphs.

THE primary purpose of this paper is to throw light on two subjects; first, the interpretation of computed benefit-cost ratios and computed rates of return on investment in proposed public works projects where more than two alternatives are to be considered; and second, the sensitivity of economy studies to assumptions regarding such factors as interest rate, assumed life, salvage value, and growth factors. It may be viewed as an expansion of the discussion of certain matters presented more concisely in other writings, particularly in parts of five papers presented at meetings of the Highway Research Board and in certain chapters of three books (1, 2, 3, 4, 5, 6, 7, 8).

Economy studies to compare alternate highway locations and designs may be divided into two aspects, as follows:

A. Estimation of first costs, lives, salvage values, and maintenance costs of the various alternatives. Estimation of the consequences of the different locations and designs to highway users and other members of the general public, with a conversion of these consequences into year-by-year monetary figures insofar as practicable.

B. Analysis of the foregoing estimates in a way that will guide a recommendation for a choice among the alternatives. This analysis may be based on any one of a number of different techniques such as comparative equivalent uniform annual costs, comparative present worths, excess of annual "benefits" over annual "costs," benefit-cost ratios, or prospective rates of return on investment. To compute equivalent annual costs, present worths, annual benefits, annual costs, and benefit-cost ratios, it is necessary to choose some one interest rate that will be used in all calculations; the operational effect of selecting any particular interest rate is to base decisions among alternatives on the assumption that the rate selected is the minimum rate of return that is sufficiently attractive to justify a proposed investment, all things considered. If the rate-of-return technique is employed, some minimum attractive rate of return must be selected as a criterion for decisions among alternatives, even though this rate is not employed in the calculations.

This paper does not discuss any of the problems of estimation mentioned under (A) although it is widely recognized that many of these problems of estimation are troublesome and controversial. Rather, it deals with the interpretation of the different types of analysis mentioned in (B). Emphasis is laid on the interrelationships of the various techniques mentioned, particularly the rate-of-return and benefit-cost ratio techniques. In the view of the authors, the subjects treated in the main body of this paper are non-controversial. However, the highway literature demonstrates a widespread failure to understand these matters on the part of many persons who are responsible for recommending choices or making choices among alternatives in the field of public works. In part, this impression has been obtained from examining nearly 100 recent reports (1958 and 1959) comparing alternate highway locations in the United States (4). In part, also, the impression comes from conversations and correspondence with persons engaged in the economic analysis of public works. The objective, then, is to present a statement of certain basic principles in a compact form that makes these principles readily available to highway analysts and other persons concerned with decisions among alternatives in the public works field.

I. Interpretation of Results from Multiple Alternatives

This subject is developed by means of a single hypothetical example involving the economic analysis of a number of different proposals for the location and design of a section of highway. In some respects, the example is simpler than many actual cases; for example, it is assumed that all of the elements of the highway investment will last throughout the 30-yr study period and will have zero salvage value at the end of that period. Moreover, it is assumed that for each location and design the decrease in relevant annual costs to highway users and others which results from the improvement will be uniform throughout the 30 yr. The foregoing simplifications are intended to make it easier for the reader to concentrate his attention on principles involved in the comparison of multiple alternatives. The second section of this paper examines the sensitivity of conclusions of economy studies comparing such highway alternatives to differences in estimated lives and salvage values, to different assumed lengths of study period, and to the difference between the expectation of growing or declining benefits.

Seven percent has been selected as the minimum attractive rate of return or interest rate used in the example. In the past analysts have generally used lower interest rates than this for economic comparisons of highway alternatives. One purpose of using seven percent here rather than, say, three percent is that the higher rate is advantageous in discussing the sensitivity of the conclusions of highway economy studies to the estimates on which they are based.

Moreover, the present writers believe that the interest rates in common use in such studies (0 percent to about 3½ percent) are unjustifiably low. One of the writers has presented the case for higher rates at some length (3). The writers are not alone in their view that the commonly used interest rates are too low (7).

Although the example is a simplified one in a number of respects, it is complicated in the sense of involving a fair number of alternatives. One of the purposes of this report is to stress certain points—not always clearly understood by analysts—relating to the possible misinterpretation of benefit-cost ratios and prospective rates of return in comparisons of more than two alternatives. Certain aspects of the relationships among different methods of analysis can be brought out to better advantage by an example that contains a considerable number of alternatives.

Hypothetical Example of Alternatives in Highway Location and Design

A certain section of highway is now in location A. A number of proposed designs at new locations and proposed improvements at the present location are to be compared with a continuation of the present condition at A. For purposes of analysis, continuing the present condition is designated as A-1.

Three possible new designs in the present location are referred to as A-2, A-3, and A-4, respectively. Two new locations B and C are also considered for this section of highway. There are five designs to be analyzed at location B and four at location C. These 13 proposals, A-1 to A-4, B-1 to B-5, and C-1 to C-4, are mutually exclusive in the sense that only one proposal will be selected. Of course the various designs at each location contain a number of common elements.

Costs to Highway Agency

Table 1 gives the investments and the estimated annual maintenance costs for the various locations. It also gives estimates of the annual costs to highway users and other members of the public; the estimates for each alternative include all such costs that it is believed will be influenced by the decision among the various locations and designs.

The various alternatives at each of the three locations may be thought of as differing primarily in the frequency and elaborateness of interchange structures in a modern highway facility. Because the example is simplified by assuming that the entire investment has a 30-yr life with zero terminal salvage value, the usual breakdown of the total investment into its various components (for example, right-of-way, grading, pavement, structures) is not shown.

Consequences of Proposed Improvement

In decision making regarding proposed investments in public works, it is relevant to consider the expected consequences to the entire public, not merely consequences to the public agencies that will build and maintain the works. In the classic phrase of the U.S. Flood Control Act of 1936, an analyst should consider consequences "to whomsoever they may accrue." For many proposed works, one segment of the public will be affected favorably whereas another segment will be affected unfavorably. Both the favorable and the unfavorable consequences ought to be considered in the decision making regarding the proposed works. For consequences to be commensurable with proposed investments, they need to be expressed in terms of money amounts.

Many of the obvious consequences of highway investments consist of costs of various kinds to highway users. If the volume and type of traffic is estimated for each alternative, the highway user costs influenced by the choice among the alternatives can also be estimated. As this paper will not include a discussion of the issues involved in estimating such costs, they have merely been stated as a total figure in Col. 4, Table 1. The reader may view this total as including estimated vehicle operating costs, costs of commercial time, accident costs, and any other highway-user costs that he deems to be relevant and that can be estimated in a satisfactory way. He may also view the total as including any expected net nonuser consequences that can be expressed in terms of money.

The writers recognize that, in many cases, some consequences of decisions among highway alternatives cannot be expressed in terms of money. Furthermore, these "irreducibles," "to whomsoever they may accrue," are relevant to the decision. In these situations, the "dollar" answers from the economy study do not dictate the final choice; on the other hand they provide a money figure against which the irreducibles can be weighed and thereby narrow the area of uncertainty with which the decision-maker is faced.

TABLE 1

ESTIMATES FOR CERTAIN MUTUALLY EXCLUSIVE HIGHWAY ALTERNATIVES

Alternative	First Cost ($1,000)	Annual Maint. Cost ($1,000)	Annual Costs to Highway Users and Others ($1,000)
A-1	0	60	2,200
A-2	1,500	35	1,920
A-3	2,000	30	1,860
A-4	3,500	40	1,810
B-1	3,000	30	1,790
B-2	4,000	20	1,690
B-3	5,000	30	1,580
B-4	6,000	40	1,510
B-5	7,000	45	1,480
C-1	5,500	40	1,620
C-2	8,000	30	1,470
C-3	9,000	40	1,400
C-4	11,000	50	1,340

Determining Minimum Equivalent Uniform Annual Cost

Under the authors' assumptions, the annual highway maintenance costs and the annual costs to highway users and others (Cols. 3 and 4, Table 1) are assumed to be uniform throughout the 30-yr study period. In contrast, the estimated investments occur in a lump sum at the start of the 30-yr period. It is explained in texts on engineering economy and on the mathematics of investment that such an initial outlay may be converted into an equivalent uniform annual figure for n years if it is multiplied by a factor $\frac{i(1 + i)^n}{(1 + i)^n - 1}$ in which i is the appropriate interest rate. In the literature of engineering economy this factor is called the capital recovery factor, sometimes abbreviated to CRF. For the assumed interest rate of seven percent and the estimated life of 30 yr, the capital recovery factor is $\frac{0.07(1.07)^{30}}{(1.07)^{30} - 1} = 0.08059$.

Assuming zero salvage value, the product of an investment and the appropriate capital recovery factor is referred to as the annual cost of capital recovery, sometimes abbreviated to CR. For example, for project A-3, CR = $2,000,000(0.08059) = $161,000. In some of the literature of engineering economy, this product is referred to as "interest plus amortization" or as "investment charges."

Table 2 gives the three sets of annual costs "to whomsoever they may accrue" influenced by the choice among the proposed highway locations and designs; namely, capital recovery costs, maintenance costs, and costs to highway users and other members of the general public. The total of these costs is given for each alternative. It is evident that with the seven percent interest rate that has been used in computing investment charges, the equivalent uniform annual costs are minimized by the selection of project B-3. This project saves $247,000 a year as compared to the continuation of the present condition (represented by A-1). It also is evident that all of the other proposals except C-4 involve a saving as compared to continuing the present condition.

The interpretation of Table 2 is discussed further after the comparison of these alternatives by a number of other methods has been presented.

TABLE 2

EQUIVALENT UNIFORM ANNUAL COSTS FOR CERTAIN HIGHWAY ALTERNATIVES

Alternative	Capital Recovery of Init. Investment at 7% ($1,000)	Mainte nance ($1,000)	Costs to Highway Users and Others ($1,000)	Total ($1,000)	Annual Saving as Compared to Continuing Present Condition ($1,000)
A-1	0	60	2,200	2,260	-
A-2	121	35	1,920	2,076	184
A-3	161	30	1,860	2,051	209
A-4	282	40	1,810	2,132	128
B-1	242	30	1,790	2,062	198
B-2	322	20	1,690	2,032	228
B-3	403	30	1,580	2,013	247
B-4	484	40	1,510	2,034	226
B-5	564	45	1,480	2,089	171
C-1	443	40	1,620	2,103	157
C-2	645	30	1,470	2,145	115
C-3	725	40	1,400	2,165	95
C-4	886	50	1,340	2,276	-16

Determining Maximum Excess of Benefits Over Costs

In Table 2 all annual costs "to whomsover they may accrue" are lumped together combining the investment charges and maintenance costs on the highway with the annual costs to highway users and others. Another possible way of looking at the analysis is to define "benefits" as the prospective reduction in estimated future costs to highway users and others as compared to such estimated costs if the present condition is to be continued. Benefits so defined are then to be compared in some manner with the highway costs (for example, with the sum of highway investment charges and highway maintenance costs). There are several different methods of using benefits and costs, so defined, to reach a choice among the alternatives submitted for consideration. One simple method is to compute the excess of benefits over costs for each alternative and to select the alternative giving the maximum excess of benefits over costs. This method is given in Table 3, which shows B-3 as the project to be selected by this criterion.

Col. 6, Table 2 gives the net annual advantage of each alternative as compared to A-1, which is a continuation of the present condition. Col. 5, Table 3 also gives net annual advantage as compared to A-1. Of course the figures in two final columns are identical and the same project, B-3, is selected by the two methods. It will be obvious to the reader that there are no real differences between the decision rules for project selection implied in Tables 2 and 3; the difference between the two methods of analysis is entirely in terminology.

Computation of Benefit-Cost Ratios for Each Proposed Location and Design as Compared to a Continuation of the Present Condition

The most common technique for economic analysis of proposed public works project is by means of the benefit-cost ratio. (This ratio is also called the "benefit quotient," the "benefit ratio," and—somewhat illogically—the "cost-benefit ratio.") Table 4 gives the calculation of this ratio for each proposal to change the highway from its present condition. Because each comparison is between some new proposal (for example, A-2, B-2, C-2) and the present condition, the "costs" used as the denominator of the fraction are the highway costs in excess of the $60,000 figure (all maintenance) anticipated with alternative A-1.

Analysts do not always understand the limitations of a set of benefit-cost ratios such as those given in Col. 4, Table 4. Some persons, inspecting these ratios, might conclude that A-2 is the best alternative because it has the largest benefit-cost ratio. Other persons might select C-3 as the plan that, considering all the plans having benefit-cost ratios of at least 1.00; yields the highest total benefits. Neither group of persons would be correct.

As a matter of fact, the benefit-cost ratios in Col. 4, Table 4 do not provide a sufficient basis for a choice among the alternatives. All of these ratios merely compare a particular proposed location and design with an assumed continuation of the present condition; none of the ratios provides a basis for comparing the alternatives with one another.

Computation and Analysis of Incremental Benefit-Cost Ratios

Obviously no sound conclusion can be reached unless there is a criterion for comparing the many alternatives with each other. If the benefit-cost-ratio technique is to be employed in the economic analysis, it is necessary to compute ratios of increments of benefits to increments of costs. Table 5 gives a convenient organization of calculations for this purpose.

TABLE 3

EXCESS OF ANNUAL BENEFITS OVER ANNUAL HIGHWAY COSTS FOR CERTAIN HIGHWAY ALTERNATIVES

Alternative	Annual Benefits ($1,000)	Annual Highway Costs ($1,000)	Benefits Minus Costs ($1,000)	Improvement in Benefits Minus Costs as Compared to A-1[a], ($1,000)
A-1	0	60	- 60	-
A-2	280	156	+124	184
A-3	340	191	+149	209
A-4	390	322	+ 68	128
B-1	410	272	+138	198
B-2	510	342	+168	228
B-3	620	433	+187	247
B-4	690	524	+166	226
B-5	720	609	+111	171
C-1	580	483	+ 97	157
C-2	730	675	+ 55	115
C-3	800	765	+ 35	95
C-4	860	936	- 76	- 16

[a]Continuing the present condition.

The criterion here illustrated for the analysis of benefit-cost ratios is the same one implied in the decision favoring B-3 when annual costs were minimized in Table 2 and when the excess of benefits over costs were maximized in Table 3. This criterion is that no avoidable increment of cost is justified unless this increment of cost causes an increment of benefits at least as great as the increment of costs. It follows that for any acceptable project, the incremental benefit-cost ratio should be at least 1.00 as compared to all projects having lower costs (including the continuation of the present condition).

TABLE 4

BENEFIT-COST RATIOS COMPARING CERTAIN MUTUALLY EXCLUSIVE HIGHWAY ALTERNATIVES WITH CONTINUATION OF A PRESENT CONDITION

Alternative	Extra Annual Benefits Above A-1 ($1,000)	Extra Annual Costs Above A-1 ($1,000)	Benefit-Cost Ratio Col. 2/Col. 3
A-2	280	96	2.92
A-3	340	131	2.60
A-4	390	262	1.49
B-1	410	212	1.93
B-2	510	283	1.80
B-3	620	373	1.66
B-4	690	464	1.49
B-5	720	549	1.31
C-1	580	423	1.37
C-2	730	615	1.19
C-3	800	705	1.13
C-4	860	876	0.98

It is desirable that analysts understand clearly the interpretation of the type of analysis given in Table 5. Why does this type of analysis lead to a selection of project B-3, the same project that was selected when annual costs were minimized in Table 2 and when the excess of benefits over costs were maximized in Table 3?

Project A-2, the project having the lowest cost of the 12 proposed improvements, is clearly superior to A-1, the continuation of the present condition; an increment of annual benefits of $280,000 is caused by an increment of annual costs of only $96,000. Because of the superiority of A-2, to A-1, a comparison of the remaining 11 proposals with A-1 has no relevance in choosing among the 13 original alternatives.

A comparison of A-3 with A-2 favors A-3; $60,000 additional annual benefits are gained through only $35,000 of annual costs; the incremental benefit-cost ratio is 1.71. Project A-2 is therefore eliminated from the subsequent analysis.

Neither B-1 nor A-4 is attractive as compared to A-3 because their incremental benefit-cost ratios compared to A-3 are less than unity. It should be noted that A-4 should be compared with A-3, not with B-1, because B-1 has been eliminated by its 0.86 incremental benefit-cost ratio as compared to A-3.

A continuation of the analysis shows B-2 superior to A-3, and B-3 superior to A-2. None of the remaining 6 projects is attractive as compared to B-3 because for all of these projects, the incremental benefit-cost ratio compared to B-3 is less than unity. Therefore, Table 5 leads to the selection of B-3 as the most desirable location and design.

Stated a little differently, it is evident that in comparing B-3 with any project having lower costs, the prospective increment of benefits from B-3 is more than the prospective increment of costs. It is also evident that for all of the projects having higher costs than B-3, the prospective increment of benefits as compared to B-3 is less than the prospective increment of costs as compared to B-3.

Computation of Prospective Rate of Return on Investment as Compared to a Continuation of a Present Condition

Table 6 gives a method of computing rate of return on investment applicable to the

TABLE 5

INCREMENTAL BENEFIT-COST RATIOS COMPARING MUTUALLY EXCLUSIVE HIGHWAY ALTERNATIVES WITH ONE ANOTHER[a]

Projects Compared	Increment of Annual Benefits ($1,000)	Increment of Annual Costs ($1,000)	Incremental Benefit-Cost Ratio	Decision in Favor of
A-2 over A-1	280	96	2.92	A-2
A-3 over A-2	60	35	1.71	A-3
B-1 over A-3	70	81	0.86	A-3
A-4 over A-3	50	131	0.38	A-3
B-2 over A-3	170	152	1.12	B-2
B-3 over B-2	110	90	1.22	B-3
C-1 over B-3	- 40	50	Negative	B-3
B-4 over B-3	70	91	0.77	B-3
B-5 over B-3	100	176	0.57	B-3
C-2 over B-3	110	242	0.45	B-3
C-3 over B-3	180	332	0.54	B-3
C-4 over B-3	240	503	0.48	B-3

[a]Projects examined in order of increasing annual costs.

simple assumptions of our example. For convenience, the projects are listed in increasing order of investment. Col. 2 gives the reduced annual disbursements for each proposal as compared to A-1, the continuation of the present condition. Col. 4 is ob-

TABLE 6

PROSPECTIVE RATES OF RETURN ON TOTAL INVESTMENT IN CERTAIN HIGHWAY ALTERNATIVES AS COMPARED TO CONTINUATION OF A PRESENT CONDITION

Alternative	Reduction in Total of Annual Maintenance Costs and Annual Costs to Highway Users and Others as Compared to A-1[a] ($1,000)	Investment ($1,000)	Capital Recovery Factor for 30 Yr, Col. 2/Col. 3	Rate of Return on Investment as Compared to A-1[a] (%)
A-2	305	1,500	0.203	20.2
A-3	370	2,000	0.185	18.4
B-1	440	3,000	0.147	14.4
A-4	410	3,500	0.117	11.2
B-2	550	4,000	0.138	13.5
B-3	650	5,000	0.130	12.6
C-1	600	5,500	0.109	10.3
B-4	710	6,000	0.118	11.2
B-5	735	7,000	0.105	9.9
C-2	760	8,000	0.095	8.7
C-3	820	9,000	0.091	8.3
C-4	870	11,000	0.079	6.8

[a]Continuing the present condition.

tained by dividing the figure from col. 2 by the investment shown in col. 3. Under the special conditions of uniform annual savings and zero terminal salvage values, this quotient is the capital recovery factor corresponding to the estimated life (30 yr in the example). The interest rate or rate of return that will be earned on the investment can be determined by interpolation in a table of capital recovery factors or may be read from a graph such as Figure 1. (Because of the relatively long life and the relatively high rates of return, many of these rates of return are almost as large as the corresponding capital recovery factors.)

The possible misinterpretations of prospective rates of return as compared to a continuation of a present condition are similar to those of benefit-cost ratios as compared to continuing a present condition. One analyst might select project A-2 as the one yielding the highest prospective rate of return, 20.2 percent. Another might conclude that with a stipulated minimum attractive rate of return of seven percent, the only project ruled out by Table 6 is project C-4 that yields only 6.8 percent; therefore C-3 might be selected with its 8.3 percent rate of return as the highest investment

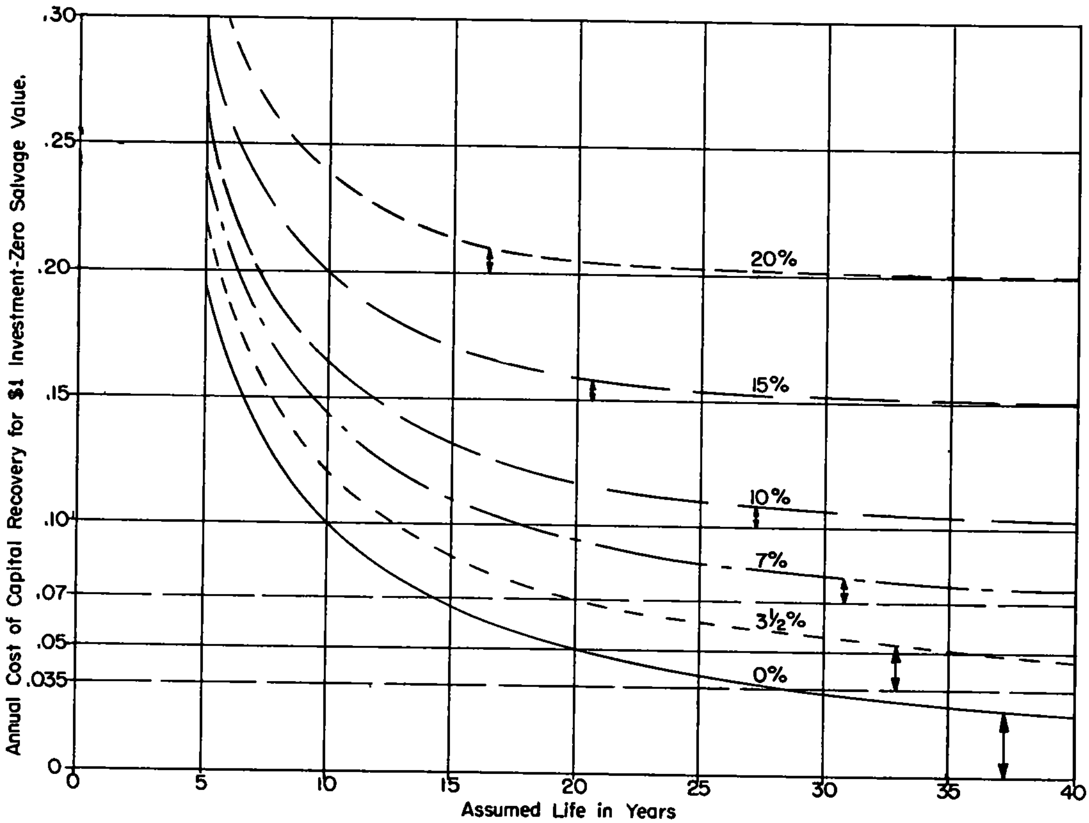

Figure 1. Capital recovery factors for various lives and selected interest rates.

that meets the stipulated standard of attractiveness. However, neither the selection of A-2 nor C-3 is consistent with the stipulated criterion for selection; namely, the minimum attractive rate of return of 7 percent.

The difficulty here is essentially the same one encountered in interpreting Table 4, which gave benefit-cost ratios as compared to continuation of a present condition. Prospective rates of return for a number of alternatives as compared to continuing a present condition do not provide an adequate basis for comparing these alternatives with one another.

Calculation and Interpretation of Prospective Rates of Return on Increments of Investment

Table 7 illustrates a convenient organization of calculation of rates of return on increments of investment under the simple assumptions of zero salvage values and uniform annual differences in disbursements for the various alternatives. The transition from computed capital recovery factors to rates of return is made in the same manner that was explained in the discussion of Table 6. Projects are considered in order of increasing investment, just as in Table 6.

Tables 6 and 7 differ from Tables 2 to 5 in that no interest rate (such as 7 percent) is assumed in making the calculations. Nevertheless, an interest rate or minimum attractive rate of return needs to be selected as a basis for making decisions among the alternatives. The decisions indicated in col. 6, Table 7 are based on a stipulated minimum attractive rate of return of 7 percent. Because 7 percent was used in the analysis minimizing annual costs (Table 2), in the analysis maximizing the excess of benefits over costs (Table 3), and in the analysis based on benefit-cost ratios (Tables 4 and 5 considered together), it might be reasonably expected that Table 7 will give the same conclusion reached by the other three methods of analysis. As a matter of fact, in Table 7 project B-3 is selected, the same project that was picked by the other three methods of analysis.

Comparison of Multiple Alternatives in Terms of Return on Total Annual Expenditures

So far, this paper has demonstrated that, properly employed, economy studies by any one of several methods will show which among various alternative solutions is the

TABLE 7

RATES OF RETURN ON INCREMENTS OF INVESTMENT CALCULATED TO COMPARE CERTAIN MUTUALLY EXCLUSIVE HIGHWAY ALTERNATIVES WITH ONE ANOTHER. PROJECTS ARE EXAMINED IN ORDER OF INCREASING INVESTMENTS. MINIMUM ATTRACTIVE RATE OF RETURN IS STIPULATED TO BE SEVEN PERCENT

Projects Compared	Increment of Reduction in Annual Disbursements ($1,000)	Increment of Investment ($1,000)	Capital Recovery Factor	Rate of Return on Increment of Investment (%)	Decision In Favor of
A-2 over A-1	305	1,500	0.203	20.2	A-2
A-3 over A-2	65	500	0.130	12.6	A-3
B-1 over A-3	70	1,000	0.070	5.7	A-3
A-4 over A-3	40	1,500	0.027	Neg.	A-3
B-2 over A-3	180	2,000	0.090	8.1	B-2
B-3 over B-2	100	1,000	0.100	9.3	B-3
B-4 over B-3	60	1,000	0.060	4.3	B-3
B-5 over B-3	85	2,000	0.0425	1.6	B-3
C-2 over B-3	110	3,000	0.0367	0.6	B-3
C-3 over B-3	170	4,000	0.0422	1.6	B-3
C-4 over B-3	220	6,000	0.0367	0.6	B-3

proper choice under a stated set of conditions. The reasoning underlying these methods of analysis can be further clarified by reworking the same example again, this time in the context of the return that the hypothetical highway agency will receive on a fixed total of expenditures, including various levels of expenditure for the subject project. The presumption underlying this approach, which is true for highway agencies operating on fixed annual income, is that if funds are devoted to a given project, some other desirable use of the money must be foregone.

Additions to the data supplied earlier are as follows:

1. Total funds available to the highway agency for all purposes during the year of the study, $20, 000, 000.
2. Rate of return on all other investments or expenditures that the highway agency will make is 7 percent.

Table 8 gives computations to determine three different bases of comparing the alternative ways of investing the entire $20, 000, 000 annual budget. These bases are excess of benefits over costs (col. 9) benefit-cost ratio (col. 10) and rate of return on investment (col. 12). In each instance, the selection of alternative B-3 shows as the most advantageous, just as it did in the previous examples. As would be expected, the excess of benefits over costs found by the method of Table 8 agrees with that given in Table 3, except for the last place difference resulting from rounding of figures. A similar comparisons of benefit-cost ratios or rates of return is not possible.

Because added computation is required, this method is not appropriate for routine use. However, the writers have found it to be an extremely valuable illustrative tool and recommend it for that purpose.

In the examples developed so far in this paper, the study period has been set at 30 yr. It has been assumed that this was the expected life of every highway element and of the traffic using the road. More commonly the practice is to assign different lives to the various roadway elements and to make traffic estimates for yet another period of years. The authors have deliberately avoided these complexities. In the first place, they would encumber the example with added complexity and obscure the main issue. Second, there may be good reason to challenge comparisons that mix long roadway life and short traffic estimates. This topic needs further exploration.

TABLE 8

COMPARISON OF ALTERNATIVE HIGHWAY INVESTMENTS IN TERMS OF TOTAL ANNUAL EXPENDITURES OF A HYPOTHETICAL HIGHWAY AGENCY

Alternative (1)	Total Annual Funds Available to Agency ($1,000) (2)	Expenditure on Subject Project ($1,000) (3)	Reduction in Total Annual Maintenance Costs and Annual Costs to Highway Users for Subject Project ($1,000) (4)	Funds Remaining for Investing in Other Projects at 7% (2) - (3) ($1,000) (5)	Annual Income from Other Projects (CRF - 7% - 30) = 0 08059 (5) x (CRF - 7% - 30) ($1,000) (6)	Total Annual Benefits (4) + (6) ($1,000) (7)	Cost of Capital Recovery on Total Annual Funds Invested (2) x (CRF - 7% - 30) ($1,000) (8)	Excess of Benefits Over Costs (7) - (8) ($1,000) (9)	Benefit-Cost Ratio (7) ÷ (8) (10)	Capital Recovery Factor i = ? n = 30 yr (7) ÷ (2) (11)	Rate of Return on Investment (%) (12)
A-1	20,000	0	0	20,000	1,612	1,612	1,612	0	1 00	0 0806	7 0
A-2	20,000	1,500	105	18,500	1,491	1,796	1,612	184	1 11	0 08980	8 1
A-3	20,000	2,000	370	18,000	1,451	1,821	1,612	209	1 12	0 09105	8 3
A-4	20,000	3,500	410	16,500	1,330	1,740	1,612	128	1 08	0 08700	7 8
B-1	20,000	3,000	440	17,000	1,370	1,810	1,612	198	1 12	0 09050	8 2
B-2	20,000	4,000	550	16,000	1,289	1,839	1,612	227	1 14	0 09195	8 4
B-3	20,000	5,000	650	15,000	1,209	1,859	1,612	247	1 15	0 09295	8 5
B-4	20,000	6,000	710	14,000	1,128	1,838	1,612	226	1 14	0 09190	8 4
B-5	20,000	7,000	735	13,000	1,048	1,783	1,612	171	1 11	0 08915	8 0
C-1	20,000	5,500	600	14,500	1,169	1,769	1,612	157	1 10	0 08845	8 0
C-2	20,000	8,000	760	12,000	967	1,727	1,612	115	1 07	0 08635	7 7
C-3	20,000	9,000	820	11,000	886	1,706	1,612	94	1 06	0 0853	7 6
C-4	20,000	11,000	870	9,000	725	1,595	1,612	- 17	0 99	0 07975	6 9

II. Sensitivity Aspects

With all economy study procedures except "rate of return on investment," an interest rate must be adopted before the analysis can be undertaken. For all procedures, including rate of return, assumptions for the useful life of each element of the highway and its salvage value at the end of that life must be made. Estimates of traffic, extended into the future in terms of growth or decline for a reasonable number of years must be converted into annual amounts of cost or saving. All such assumptions influence the final result of economy studies to a greater or lesser degree. The "sensitivity" of the results to such assumptions is the subject of the remainder of this paper.

Sensitivity of Economy-Study Results to Assumed Interest Rate

The selection of an interest rate or minimum attractive rate of return lies at the very heart of every economic analysis. The greatest exactness and care in preparing estimates and forecasts can be meaningless if the interest rate is inappropriate for the conditions under which the decision is made. The authors previously have presented their arguments for relatively high interest rates (1, 3, 6) as have others (7) and these will not be repeated here. It is deemed worthwhile, however, to demonstrate the effect of interest rates on the illustrative example presented earlier in the paper.

Table 9 represents a recomputation of the example at four different interest rates; namely, 0 percent, 3½ percent, 7 percent, and 10 percent. These computations demonstrate that for each interest rate a different alternative appears to be most favorable. Lower and lower interest rates favor heavier and heavier capital investments. For example, the use of 0 percent interest as compared to 7 percent argues for alternative C-3 at an added capital investment of $4,000,000 over B-3; and 3½ percent as compared to 7 percent justifies B-4 at an extra $1,000,000 first cost.

The principle illustrated by Table 9 can be stated another way, as follows: Suppose a highway agency must choose among numerous projects, all of which show a rate of return of 7 percent. It employs 0 percent for its economy studies. It then will invest $4,000,000 in this project that would be better employed elsewhere. Thus the improper choice of interest rate has defeated the purpose for which the economy study was made.

Sensitivity of Economy Studies to Assumed Life of the Project

In an economy study employing some form of annual cost comparison, capital or investment costs are spread uniformly over each year of the assumed life of the highway element. Where salvage value is not considered, this uniform annual charge for principal and interest is found by multiplying the first cost of the element by the capital recovery factor (CRF). Tables of capital recovery factors appear in textbooks of engineering economy and finance and in some books on highway engineering (5, 6, 7). Those for interest rates of 0 percent, 3½ percent, 7 percent, 10 percent, 15 percent and 20 percent and for lives appropriate for highway economy studies are plotted in Figure 1.

As assumed life increases, the capital recovery factor approaches the interest rate as an asymptote (Fig. 1). At high interest rates, this approach occurs rapidly, as the interest rate decreases, the speed of approach slows. It follows, then, that economy studies made at higher interest rates are relatively insensitive to changes in assumed life; at low or zero interest rates, this sensitivity is high. For example, at 7 percent, the increase in the annual cost of capital recovery when the assumed life is shortened from 30 to 20 yr is 17 percent; at zero interest rate the increase is 50 percent (Fig. 1). This is another evidence that higher interest rates discount the effect of happenings in the more distant future where uncertainties of prediction are greatest.

Sensitivity of Economy Studies to Assumed Salvage Values

The salvage value of a highway is its residual dollar worth at the end of the economy study period. One method for recognizing salvage value is to determine the present sum

TABLE 9

SENSITIVITY OF DECISIONS AMONG ALTERNATIVES TO THE CHOSEN MINIMUM ATTRACTIVE RATE OF RETURN[a]

Alternative	Estimated First Cost ($1,000)	Capital Recovery of Initial Investment at 0% (1)	3½% (2)	7% (3)	10% (4)	Maintenance ($1,000) (5)	Cost to Highway Users and Others ($1,000) (6)	0 Percent: Total (1)+(5)+(6) ($1,000) (7)	0 Percent: Annual Savings as Compared to Present ($1,000) (8)	3½ Percent: Total (2)+(5)+(6) ($1,000) (9)	3½ Percent: Annual Savings as Compared to Present ($1,000) (10)	7 Percent: Total (3)+(5)+(6) ($1,000) (11)	7 Percent: Annual Savings as Compared to Present ($1,000) (12)	10 Percent: Total (4)+(5)+(6) ($1,000) (13)	10 Percent: Annual Savings as Compared to Present ($1,000) (14)
A-1	0	0	0	0	0	60	2,200	2,260	0	2,260	0	2,260	0	2,260	0
A-2	1,500	50	82	121	159	35	1,920	2,005	255	2,037	223	2,076	184	2,114	146
A-3	2,000	67	109	161	212	30	1,860	1,957	303	1,999	261	2,051	209	2,102	158[b]
A-4	3,500	117	190	282	371	40	1,810	1,967	293	2,040	220	2,132	128	2,221	39
B-1	3,000	100	163	242	318	30	1,790	1,920	340	1,983	277	2,062	198	2,138	122
B-2	4,000	133	217	322	424	20	1,690	1,843	417	1,927	333	2,032	228	2,134	126
B-3	5,000	167	272	403	530	30	1,580	1,777	483	1,882	378	2,013	247[b]	2,140	120
B-4	6,000	200	326	484	636	40	1,510	1,750	510	1,876	384[b]	2,034	226	2,186	74
B-5	7,000	233	381	564	743	45	1,480	1,758	502	1,906	354	2,089	171	2,268	- 8
C-1	5,500	183	299	443	583	40	1,620	1,843	417	1,959	301	2,103	157	2,243	17
C-2	8,000	267	435	645	849	30	1,470	1,767	493	1,935	325	2,145	115	2,349	- 89
C-3	9,000	300	489	725	955	40	1,400	1,740	520[b]	1,929	331	2,165	95	2,395	-135
C-4	11,000	367	598	886	1,167	50	1,340	1,757	503	1,988	272	2,276	16	2,557	-297

[a]Life = 30 yr; terminal salvage value = 0
[b]Most desirable project at given rate of return

that, invested at compound interest, will produce an amount equal to the salvage value at the salvage date. By subtracting this present sum from the original investment, salvage value is fully recognized in the economy study.

Conversion of salvage value to its present worth is accomplished by multiplying it by the single payment present worth factor given in compound interest tables. An identical answer results when the salvage value is divided by the single payment compound amount factor. Figure 2 offers, for interest rates of 0, 3½, 7, and 10 percent and periods of 20 and 30 yr, a convenient graphical method for converting percent salvage value to percent present worth. To illustrate, assume a salvage value of 50 percent of first cost, interest at 7 percent, and a study period of 20 yr. Then the present worth of the 50 percent salvage value is 13 percent (see dotted lines—Fig. 2). Full credit for the 50 percent salvage value will be taken if the first cost of the item is reduced to 87 percent of its actual value.

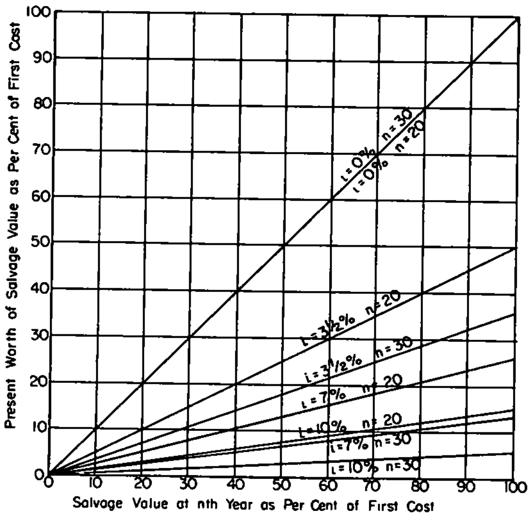

Figure 2. Relationship between salvage value at end of study period and present worth of salvage value.

Figure 2 provides a convenient means for appraising the "sensitivity" of economy studies to assumptions regarding salvage value. It can be seen that for any stated life, as interest rate increases, the percentage present worth of salvage value decreases. Thus, studies made at zero or very low interest rates are sensitive to assumptions regarding salvage value; as the interest rate increases, this sensitivity decreases. Likewise, at interest rates other than zero, the importance of salvage value decreases as the assumed life increases.

It has been suggested by Winfrey (7), among others, that "salvage values should be kept low, especially for pavements and other elements difficult to use in future reconstruction." Furthermore, at realistic interest rates and relatively long lives, the present worth of salvage value is small. Coupling these notions offers a strong argument in favor of neglecting salvage value in highway economy studies. As a specific example, Figure 2 shows that for the combination of a 10 percent salvage value, 20-yr life, and i of 7 percent, the difference between including and excluding salvage value is only 2½ percent, which is considerably less than the expected error in other estimates.

Sensitivity to Assumed Rate of Growth of Annual Costs or Savings

Savings to highway users constitute one of the major justifications of highway improvement. To determine these user savings, estimates must be made of the savings accruing to an individual vehicle of each classification, such as passenger cars and various types of commercial vehicles. There is also a traffic projection to indicate, for each year of the study period, the number of vehicles on which the estimated individual savings will occur. For an economy study, the savings each year are determined by summing the products of unit savings times annual traffic for each vehicle class. If annual savings differ from year to year, they must be converted to a uniform equivalent annual sum by means of compound interest tables or charts.

At present, projections of future traffic commonly assume substantial increases over the study period; in many instances traffic 20 or 30 yr hence is set at double or treble existing levels. Under such circumstances, it is important that the analyst be aware of the effect of these assumptions on the results of his economy study. Furthermore, he needs to understand the interplay between these assumptions and the interest rate at which the analysis is made.

Figure 3 presents, for certain assumptions appropriate for highway economy studies, the relationship among length of study period, interest rate, traffic growth, and the resulting equivalent annual cost or savings. Data for Figure 3 are based on the following formula:

$$\text{Equivalent uniform annual cost or saving} = a + \frac{g}{i} - \frac{ng}{i}(\text{CRF} - i)$$

in which

a = annual cost or savings for the first year of the study period;
g = the constant dollar increase or decrease each year (for example, the increase in the second year over the first, the third over the second, etc.); and
n = the number of years (or interest periods) in the study.

In using this formula or graphs based on it, it must be recognized that "a" represents the first year's cost or saving and not that for the present or "zero" year. This distinction is important in studies where the basic assumption is, for example, that "present costs or savings double or triple in (say) 20 years." In such instances, correct use of formula or graph requires (a) increasing or decreasing the present annual cost or savings by g to determine a and (b) correcting the ratio from "last year" over "present year" into "last year" over "first year." Derivation of this gradient formula and a table of solutions are given elsewhere (6). Another formula and somewhat different results obtain if growth is computed in terms of a uniform percentage (geometric) annual increase. Only the arithmetic increase procedure is considered in this paper.

The use of Figure 3 can be illustrated by several examples. First, consider the case where annual costs or savings remain constant through the study period. Then the ratio of last year to first year is 1.00 and no conversion is needed. Figure 3 shows that, at a ratio of 1.00, equivalent uniform annual cost or savings equals 100 percent of the first year's cost or saving. Next, consider the case where the ratio of last to first year's cost or savings is 3.0. At zero percent interest and either 20- or 30-yr life, equivalent uniform annual cost or savings equal 200 percent of the first year's cost or savings. This is, of course, the average of the two. Phrased differently, the estimated annual cost or saving 20 or 30 yr hence carries equal weight to estimates for the first year. A third instance is for a ratio of 3.0, a study period of 30 yr, but with interest at 7 percent. In this instance, the equivalent uniform annual cost or savings is 1.67 times the first year's cost or savings. In this case, the effect of including interest at 7 percent has been to discount the effect of the higher savings or costs of the later years by reducing the percentage form 200 to 167. Stated differently, this and other comparisons that can be made by means of the graph indicate that studies made at higher interest rates are less sensitive to assumptions of future happenings than those made at lower or zero interest.

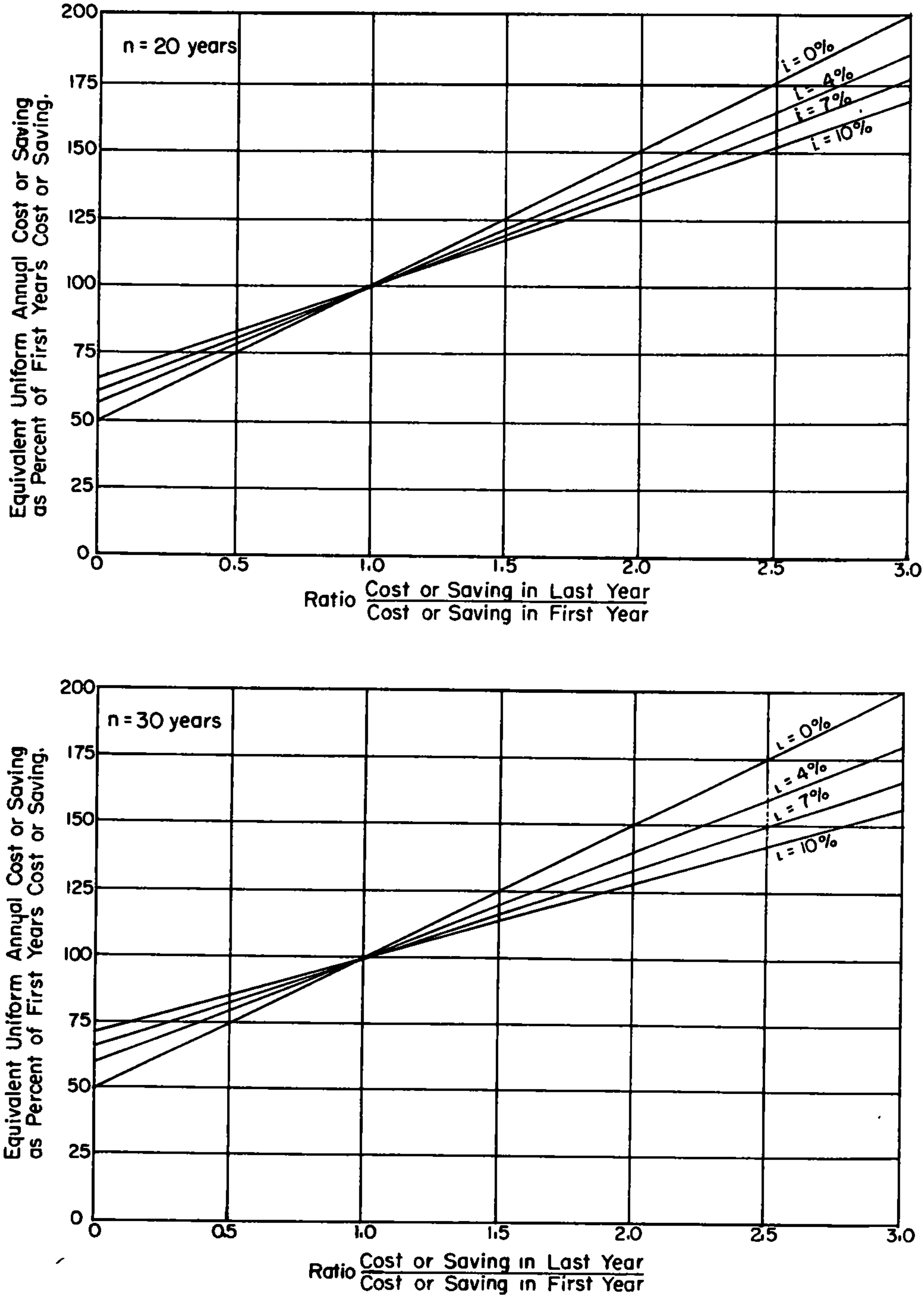

Figure 3. Relationship between growth factors and equivalent uniform annual cost or saving.

It is important that the analyst realizes how greatly his selection of growth rates influences the results of the economy study. Figure 3 provides a quick means for doing so. For example, for 20-yr life and 7 percent interest, and last year over first year ratios of 2.00 and 3.00, the percentages for equivalent annual cost or savings are 138 and 177 as contrasted with 150 and 200 at 0 percent interest. These represent significant differences that should be considered carefully. One possibility is to make two analyses, one based on a pessimistic estimate of growth and the other on an optimistic one. With this approach, the range of variation in consequences of the improvement can be gaged.

Summary of Sensitivity Aspects of Economy Studies

The foregoing discussion has indicated that economy study results show varying degrees of sensitivity to assumptions regarding service life, salvage values, and assumed rate of growth. In all instances, higher interest rates reduce the sensitivity of the conclusions of a study to these assumptions. This paper offers graphs and suggests methods by which the economic analyst can appraise the effects of changes in his assumptions on the final result.

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Economic Evaluation of Traffic Networks

GEORGE HAIKALIS and HYMAN JOSEPH, Chicago Area Transportation Study

Economic analysis of a traffic network requires estimation of the total travel costs to the users and the total capital requirements to provide the system. The paper describes a method for determining these costs of a network by use of electronic data processing machines.

The three components of travel costs (operating, accident and time costs) are related to average daily speed on each link in the network. Speeds are based on type of route, capacities, daily traffic flow (as given by a traffic assignment), and relative location.

Examples of Chicago area data and results are given. Selection of the least cost plan of several alternatives is made.

ECONOMICS AND TRANSPORTATION PLANNING

● ONE of the agencies responsible for the development of a transportation plan for the Chicago area is the Chicago Area Transportation Study. The Study must prepare a plan to guide the investment in transportation facilities—primarily highways—in such a way that the system users receive the greatest return for their investment. Yet the plan must remain consistent with the stated planning objectives and goals of the metropolitan region. With the fulfillment of this responsibility in mind, the method of economic selection of the highway plan was developed at the Study.

In the field of applied technology, few machines or systems have been developed directly from an expression of the stated objectives. Most often, a series of more or less ingeniously created alternatives are offered and these must be objectively compared. Particularly in the field of urban planning, analytic development as a creative device has found little use. The overwhelming complexity of the urban ecosystem has thus far defied mathematical analysis. However, in transportation planning some progress has been made. The theory of the most desirable spacing of the elements of a transportation system (1), developed at the Study, served as an elementary guide in creating a set of presumably near-optimal plans. The several plans developed in this manner were then objectively compared and the most economic plan selected.

Economic Comparison of Plans

Ideally, the economic comparison of alternate plans would involve simulation of the cost elements involved in the highway network over the entire time period of the plan. Obviously, some simplification was required. It was felt that a comparison of costs on a typical weekday in the horizon year of the plans would reveal the optimal plan with little loss of accuracy. The horizon year chosen for the Study's transportation plan is 1980. The typical weekday was found to be the time period for which the most reliable predictions of future travel in an urban area could be made.

The extent of each network tested was limited to that lying within the Chicago area cordon line and referred to as the "Study Area." Figure 1 shows this road network as of 1960. Only arterial streets, expressways, and ramps were included in each 1980 network tested. Local street travel was assumed to be unaffected by changes in the superior facilities network.

The economic comparison, therefore, required a simulation of the pertinent travel costs to the users for a typical weekday in 1980 and an estimate of investment costs for each plan tested. The results of this comparison and the specific cost criteria used in the economic selection of the highway plan are discussed later.

Simulation of User Cost Elements

Basic to an estimate of travel cost to the users of a road network is a simulation of traffic on that network. Much work in this field has been done at the Chicago Area Transportation Study—estimating trip ends, establishing trip interchanges, and assigning these trips to an elaborate coded network. It is possible, with a knowledge of the average daily traffic assigned to a given link in the road network, plus a description of that link—such as its speed limit, traffic carrying ability, signal spacing and provision for access control—to determine the expected daily performance of traffic using that link. The measure of this performance in this study is the "average daily speed."

This speed is considered the basic parameter for all the significant user costs. These groups of costs—time, operating, and accident costs—are each related to average daily speed. Thus, for each link when the average daily speed is determined, the average cost per vehicle-mile for each cost element is also known. The total travel cost for all vehicles using each link is then determined. Costs occurring on the different classes of route types in the various study area sub-regions may be accumulated. And, of course, an over-all total of all user costs in the Study Area is available.

Because of the multiplicity of calculations required, and the nearly 5,000 individual links involved in each plan tested, all computations were handled on the punch card system available at the Study. As the economic analysis was developed, a program was written by M. Schneider of the staff for use of the IBM 704 in conjunction with the traffic assignment program. With the combination of the two programs, it is possible to obtain results of the economic analysis as rapidly as traffic assignments can be made.

DETERMINATION OF EXPECTED NETWORK PERFORMANCE

The need for an estimate of traffic performance on each segment of the road network has been established. The average daily speed of each link is not only difficult to estimate but even difficult to measure. No known speed studies have attempted to measure the average elapsed travel time of all vehicles passing between a pair of points for a period of 24 hr. No emprical data, even if available, could produce useful estimates of 1980 speeds in the road network. For this reason, a theoretical structure for estimating speeds was attempted.

The expected network performance is a function of the physical characteristics of each link in the network and the traffic volume assigned to each link. The physical road structure determines both the traffic carrying ability of the road—capacity—and its maximum performance capabilities at very low volumes—free speed. The insertion of additional traffic volume on a link of given capacity results in time losses to all vehicles using the link. These average time losses per vehicle are called "delay." Thus, a determination of free speed and delay for each link in the network would provide a measure of the performance of the traffic network.

Following is a method of determining free speeds, and a definition of the delay function based on the assigned volume and the measured capacity. The delay function was determined by first finding the average delay for an hour, and generalizing this to an average delay per day.

Free Speeds

The maximum speed that each individual motor vehicle operator selects for a given route segment is defined as the free speed of that operator. Because of the variety of free speeds selected by individuals, there exists a distribution of these free speeds for each route segment. Because of the hazard involved when this distribution is very wide, maximum speed limits have been designated for every route segment.

The free speed of each individual motorist is based primarily on his estimate of the hazard involved on a particular route segment. Expressways and rural highways, with their great sight distances and limited points of access, offer the least hazard and, therefore, permit the highest levels of free speed. Arterial streets in commercial districts offer the greatest hazard even if traffic flow is light because of the presence of pedestrians and intensive curb parking use.

For the Study network, four basic groups of route types were designated and the free speeds determined for each. Arterials, and arterial to expressway ramps, were given free speeds based on the intensity of development adjacent to these routes. Expressways, and expressway to expressway ramps, were given free speeds based on distance from the central area. A fifth route type, junior expressways, appeared in

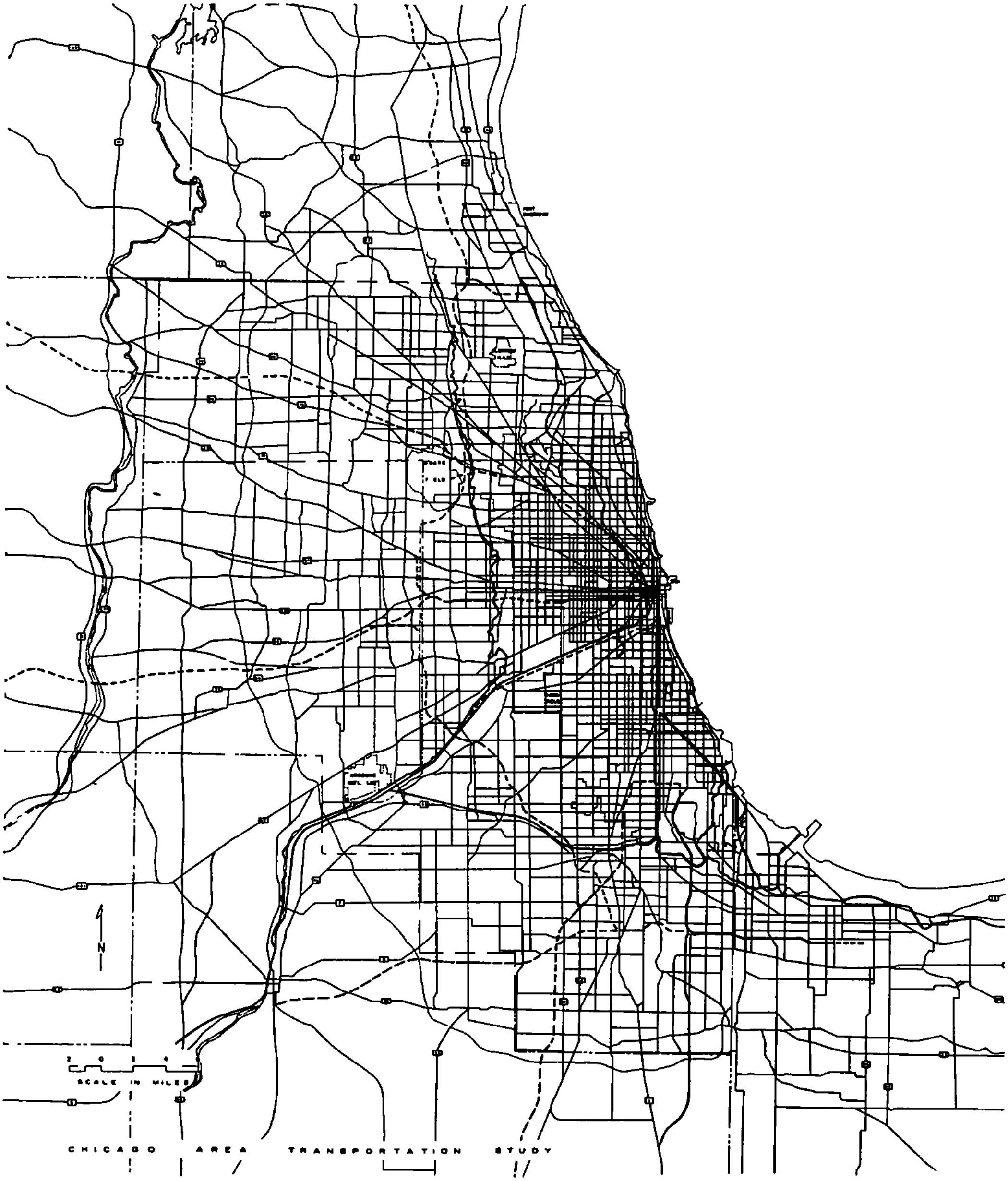

Figure 1. Study area road network.

two of the 1980 plans. These semi-limited-access highways were also given free speeds based on distance from the center. Figure 2 shows the 1956 and 1980 free speeds for arterial route segments based on existing and estimated development intensities of the 582 analysis zones in the Chicago area. Because of the peculiar method of coding arterial to expressway ramps, these route types were given the same free speeds. Table 1 gives the free speeds selected for the other route types. Existing and proposed speed limits on the expressway system were taken into account. The concentric "rings" of the Study Area served as a convenient measure of remoteness from the center (Ring 0).

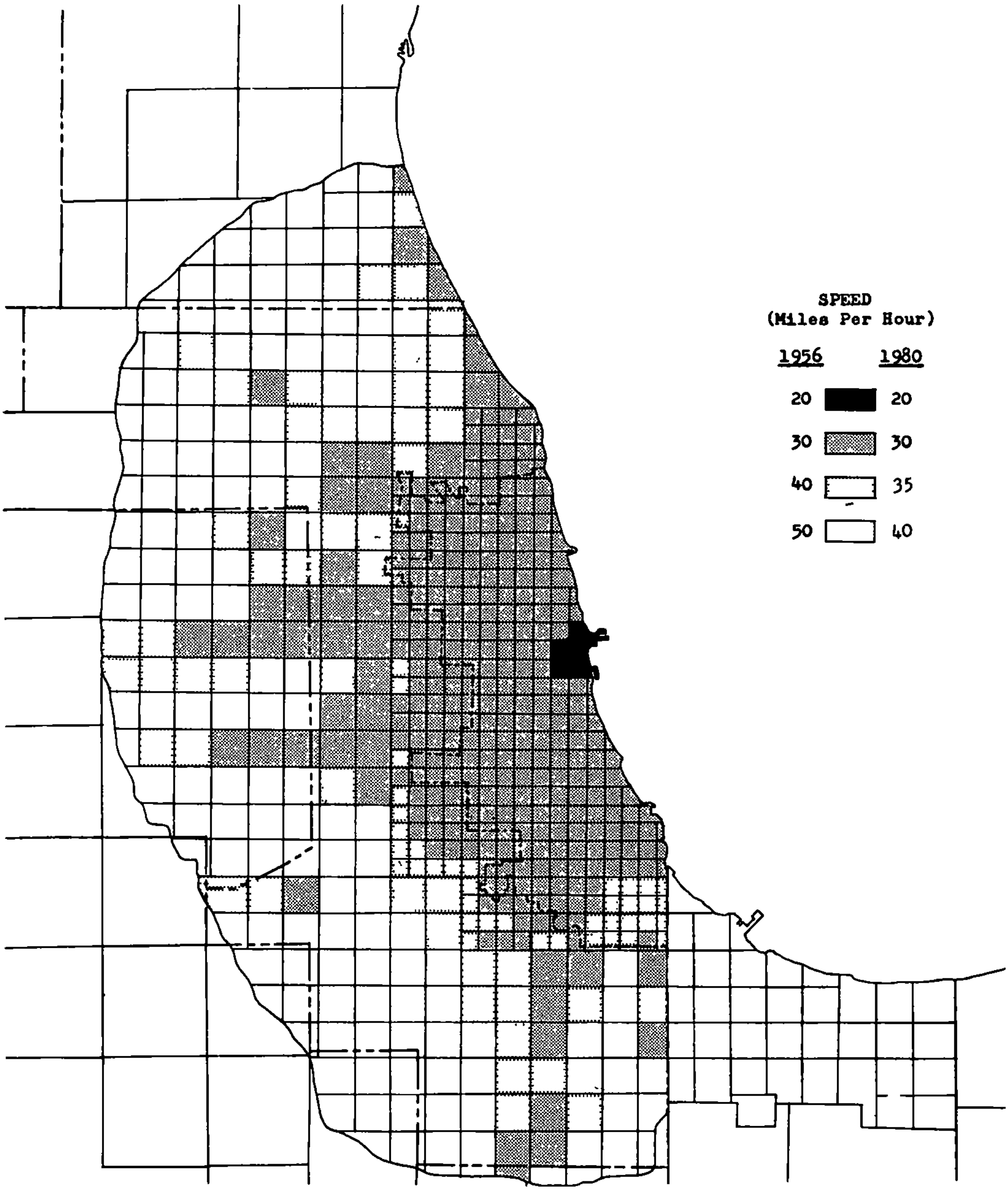

Figure 2. Free speeds—arterials.

TABLE 1

FREE SPEEDS

Ring	Expressway Free Speed 1956	Expressway Free Speed 1980	Junior Expressway And Expway. to Expway. Ramp Free Speed—1980
0	30	35	25
1	40	45	30
2	45	55	35
3	45	55	35
4	45	55	35
5	60	60	40
6	60	60	45
7	60	65	45

Delay at Arterial Intersections

The expected performance on arterial streets was first estimated. The vast majority of the travel in 1956 and about one-half of the travel in 1980 falls on this type of route.

By definition, all arterial street segments coded in the network terminate at intersections with other arterial links. These points of conflict are considered the most important sources of delay and capacity restriction. To simplify the study, all delay was assumed to occur at these intersections. Further, it was assumed that only one such intersection was approached by all the traffic assigned to each coded link. Thus, the greater the spacing of arterial intersections, the less delay per mile, and, therefore, the higher the average speed.

The capacity of each of these intersection approaches was determined as part of the inventory of traffic facilities. Capacity of these approaches in 1980 was estimated. Capacities and volumes used at the Study are given in vehicle equivalents: one light truck equals 1 passenger auto, one medium truck equals 2 autos, and 1 heavy truck equals 3 autos. (All cost items are also in vehicle equivalents. Thus, the time, operating, and accident costs of heavy trucks, for example, are implictly assumed to be three times those of autos.) The hourly capacity of these approaches assumed that each intersection was signalized and that 50 percent of the time the signal favored each approach. Although these assumptions may seem rather gross for 1956, they are not unjustified for 1980 conditions. The hourly capacity was based on the maximum number of autos that could pass through an intersection approach in an hour if each signal cycle were fully loaded (2).

The signal policy for a signalized network can give an indication of traffic performance at very low loads. Ideally, if all signals were traffic actuated, few delays would occur at these low traffic loads. Under these conditions, average speed would be very nearly equal to free speed. Presently, this is not the signal policy. Although it is not inconceivable that this might be made the policy by 1980, it was considered unlikely. The present policy, and one that might be retained for some time, is nominally a progressive system; that is, signals are set for continuous movement along each street, presumably at free speeds. Because of the grid system of arterials in the city, nearly all arterials may be made progressive. Diagonals and a few closely spaced arterials upset this pattern to some degree. In the outlying areas, because of the irregular street pattern and the multiplicity of jurisdictions, only a few routes may be made progressive.

The best approximation of this policy for analytical purposes is the assumption of random arrivals at signals. Thus, at low loads, the average delay each vehicle would expect in waiting for a signal to clear would be one-eighth of the signal cycle. This is because one-half of the vehicles approaching the signal would encounter no delay (assuming 50 percent green time, random arrivals and no delay due to congestion). The other one-half would hit a red signal and wait, on the average, through one-half of the red time (or one-quarter of the total cycle time). If the signal cycle is 60 sec, the average delay would be 7.5 sec. Additional time losses due to acceleration and deceleration would occur. Assuming a speed change rate of 3 mph per sec, and a 30-mph free speed, these losses would amount to 10 sec per vehicle stopped, or 5 sec, average for all vehicles. Thus, an average delay of 12.5 sec per vehicle would occur at signalized intersections under low load conditions.

As the traffic load approaching a signalized intersection increases, average delay increases. The greatest delay occurs when the load waiting at an intersection fails to clear in a cycle. This situation, called signal failure, occurs because of the irregularities in the pattern of arriving traffic. Some cycles receive a greater load than can be handled, while succeeding cycles may have excess capacities that remain unused. The treatment of this problem was undertaken several years ago at the Study (3). The results of this analysis, shown in Figure 3, were obtained using a numerical technique; the curve, hand fitted to these results is

$$d = 0.342e^{6.49\rho} \qquad (1)$$

in which

d = the average delay to each vehicle in seconds; and
ρ = the ratio of hourly volume, v, to maximum hourly capacity, c.

For values of ρ less than 0.541, delay, d, was said to fall not below 11.5 sec according to the analysis. The treatment of this problem analytically, using queuing theory, although not attempted, is suggested as an alternative to the numerical process used.

Thus, with an expression of the expected delay to each vehicle for any given hourly traffic flow approaching a signalized intersection, an estimate of the expected delay for a day may be derived. This is done in a later section of this study.

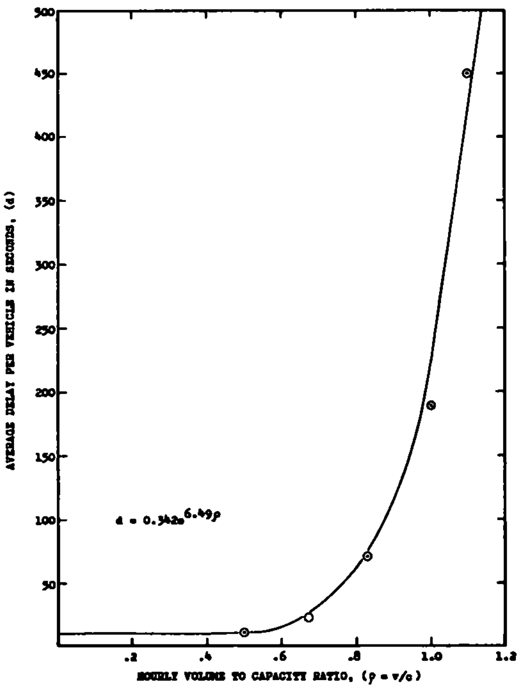

Figure 3. Delay at signalized intersections (curve fitted to values obtained from numerical techniques).

Delay on Expressways

Empirical work done by others has indicated that the average speed of all vehicles using an expressway, even at low traffic volumes, is somewhat less than the posted speed limit. This speed falls as the traffic volume increases. The increase

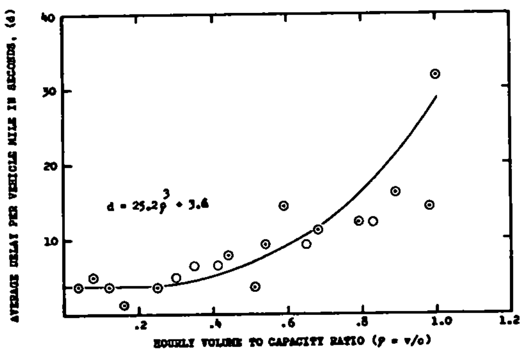

Figure 4. Delay on expressways.

in travel time due to these reduced speeds is defined here as "delay." Figure 4 shows a scatter diagram of average delays derived from data taken in a study of Detroit expressways (4). A curve was hand fitted to these points, expressing the average delay, d, to each vehicle-mile of travel, for various values of ρ, hourly volume to capacity ratio.

$$d = 25.2\rho^3 + 3.6 \qquad (2)$$

This function was assumed to apply to all expressway links, regardless of free speed, even though the particular expressway under study had a 55-mph speed limit.

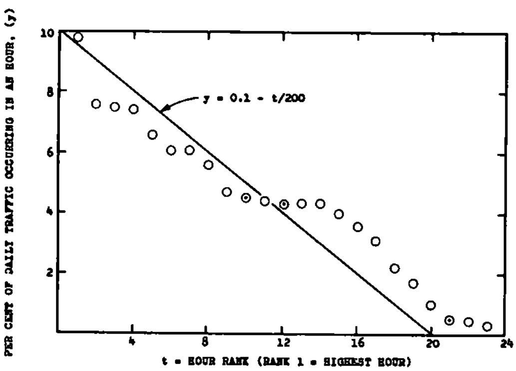

Figure 5. Hourly distribution of traffic.

Estimating Average Delay per Day

The two expressions, Eqs. 1 and 2, give estimates of average expected delay per vehicle for given hourly volumes and capacities. Required, are similar expressions for daily volumes and capacities.

A distribution of the volume of trafffic assigned to a link occurring in each hour of the day must first be designated. Obviously, each link has a separate and unique such distribution. Again a simplification is required. Figure 5 shows the distribution of all internal auto driver trips started in the Chicago area by ranking hour. A straight line was used as an approximation of this distribution.

$$y = 0.1 - t/200 \qquad (3)$$

in which y is the proportion of travel occurring in the 't' highest hour. Note that all travel is assumed to occur in only 20 hr. The diagram is a histogram where y is assumed to be a continuous function of t, for ease of analysis. This function is assumed to be representative of the distribution of hourly traffic flows throughout the day on each link of the network, the area under the curve representing 100 percent of the assigned daily travel.

The hourly traffic flow can be expressed as a proportion of the daily traffic flow,

$$v = y\,V \qquad (4)$$

in which V is the daily assigned volume on the links.

The daily capacity of each link was determined from its measured hourly capacity by assuming a constant peak hour for design purposes. After a study of records of continuous counting stations at both Chicago and Detroit, it was found that the 30th highest hour of two-way traffic flow past a station occurring in a year was about 11 percent of the average weekday flow. It was further observed that this flow was split, 60 percent in the peak direction. Daily capacity was designated for each link by factoring measured hourly maximum capacity by this 'design' peak hour percentage.

$$c = 0.132C \qquad (5)$$

in which c is hourly capacity and C is daily capacity.

The daily capacity of each link was taken into account in the traffic assignments made at the Study. The ratio of daily volume, V, to daily capacity, C, which is designated, Z, was used to alter the travel frictions in each link in the network (5).

The hourly volume to capacity ratio, ρ, may be related to the daily volume to capacity ratio, Z.

$$\rho = \frac{v}{c} = \frac{y\,V}{0.132C} = \frac{yZ}{0.132} \qquad (6)$$

Required is the specific relationship between Z, daily volume to capacity ratio, and D, expected average delay per vehicle for all vehicles using a given link in one day.

Eqs. 1 and 2, shown graphically in Figures 3 and 4, give the expected hourly delay for any imposed hourly volume to capacity ratio. Eq. 3, illustrated in Figure 5, shows the distribution of the hourly volume throughout the day. From this it follows that for a period of time, Δt, beginning at the t highest hour of the day, an hourly proportion of the daily traffic, y, will be occurring. Thus, the total proportion of the daily traffic flow occurring in interval Δt is $y\Delta t$. This infinitesimal proportion of the daily flow on a link will encounter an average delay, d, in seconds per vehicle. The integration of this delay over all values of t produces a daily weighted average of the expected delay to each infinitesimal proportion of the daily flow.

$$D = \int_{t=0}^{t=20} yd \, dt \qquad (7)$$

in which d, hourly delay, is expressed in Eq. 1 for arterials and Eq. 2 for expressways. The substitution of the relationship between y and Z and the expression for d permits the integration of Eq. 7. The result is the functional relationship between D and Z.

Before these substitutions can be made, some consideration of the maximum and minimum values of average hourly (and, consequently, average daily) delay per vehicle must be given. As was mentioned earlier, the minimum delay expected on arterials was mentioned earlier, the minimum delay expected on arterials was set at 11.5 sec per vehicle per link, and for expressways at 3.6 sec per vehicle per mile. Theoretically, the expressions for delay, at high values of volume to capacity, increase rapidly without bound. Although it is true that severe delays do occur at certain critical points in the road network, it is also true that there is a limit to the amount of delay motorists will tolerate. This maximum permitted delay was set at 470 sec for arterial links. This is about the walking time required to cover the average length of arterial link in the network. The maximum delay first occurs at $\rho = 1.108$ and $Z = 1.462$.

The maximum delay on expressways was treated in a slightly different manner. It was felt that when the flow on an expressway in the Chicago area reached maximum capacity, further traffic would be restricted from entering the expressway. Although this is not now the case, certainly by 1980 this would be expected. For this economic analysis, all traffic denied access to the expressway is assumed to travel on arterial streets at 16 mph. This is equal to a delay of 160 sec per mi for each vehicle forced off the expressway system. The average delay for all vehicles, when the hourly volume exceeds the hourly capacity ($\rho \geq 1$), is as follows:

$$d = \frac{160\,(\rho-1) + 28.8}{\rho} \qquad (8)$$

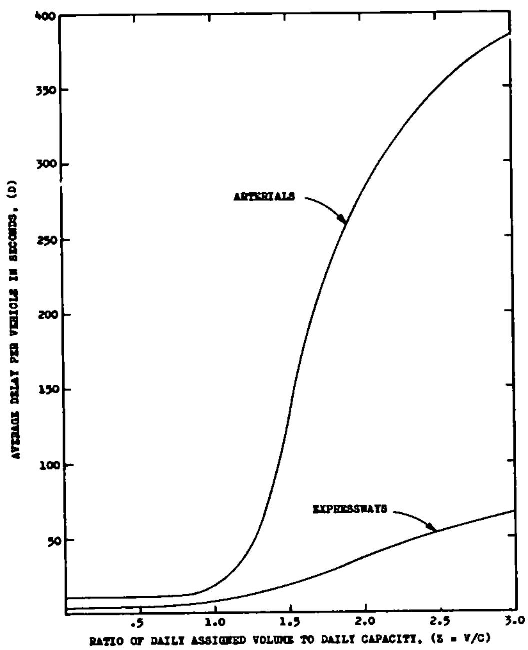

Figure 6. Delay functions for arterials and expressways. (For arterials see Eqs. 9, 10, and 11; for expressways see Eqs. 12 and 13 in text.)

With expressions for hourly delay, hourly distribution, and maximum and minimum delays now defined, the average delay per day may be determined as a function of the assigned volume and the measured capacity of each link. Eq. 7, when integrated, produces the following results.

For arterials:

$$Z \leq 0.714 \qquad D = 11.5 \tag{9}$$

$$0.714 \quad Z \leq 1.462 \qquad D = \frac{0.0282}{Z^2} \quad 124 + e^{4.92Z}(4.92Z-1) \tag{10}$$

$$Z \geq 1.462 \qquad D = 470 - \frac{762}{Z^2} \tag{11}$$

For expressways:

$$Z \leq 1.32 \qquad D = 4.8Z^3 + 3.6 \tag{12}$$

$$Z \geq 1.32 \qquad D = \frac{200}{Z^2} - \frac{345}{Z} + 160 \tag{13}$$

These delay functions are shown in Figure 6.

Use of Delay Functions

The development of the expressions for expected delay on arterials and expressways permits the estimation of a 24-hr average weekday speed on each route segment in the Study network. However, some modification of these expressions is required before they can be used.

The five route types described in the discussion of free speeds must each receive a delay function. It was assumed that arterial to expressway ramps were equivalent to arterial links with respect to performance and delay. This is due to their coding, described earlier; these ramps include a portion of the arterial street segment crossing the expressway. The intermediate type facility—junior expressways—were assumed to contain one through-lane overpass at every other intersection. Thus, they would include one-half as many delay-causing signalized intersections as arterials. The junior expressway delay function was assumed to be exactly one-half of the arterial delay function. Expressway-to-expressway ramps, for simplicity, were said to have the same delay characteristics as junior expressways.

The hourly capacity used in the determination of delay was defined as the maximum possible travel that could be accommodated on a route segment in an hour. Based on an assumed peak hour demand, this hourly capacity was generalized into a maximum possible daily capacity. Earlier work, however, indicated that a lesser value, about 70 percent of this maximum capacity, would be a useful representation for design purposes. This design capacity for a weekday is the capacity specified for each link in the network and the delay relationship must be factored accordingly.

For ease of computation, the delay expressions defined in the previous sections were evaluated for 20 classes of assigned volume to design capacity ratios. Because average speeds could be computed most easily from travel time in hours, these delay functions were evaluated in terms of millihours. Table 2 gives the specific functions used in the economic analysis program.

Values of volume-to-capacity ratio greater than 2.0 are considered as unrealistic, probably the results of concentration of traffic due to the assignment loading process. For this reason, links with higher ratios were given the same delay as links with a 2.0 ratio. A comparison of the values given in Table 2, with the delay functions from which these values were derived, would indicate that for all route types, except expressways, delays are slightly overstated in the table between values of volume to capacity ratio of 0.8 and 1.8. The distortion was due to concern that other causes of delay on these classes of route had been neglected. In particular, between-intersection delay had not been included in the analysis. The change in the delay function, although somewhat arbitrary, resulted in more realistic estimates of average speed.

The delay function was used to estimate the 24-hr average speed of each link in the network. First, a free speed for each link was designated. From this and the length of the link, a "free time" to traverse this link was computed. To this free time a delay time was added—based on the volume-to-capacity ratio of that link. For all route types, except expressways, this delay time was added to each link regardless of its length. For expressways, this delay was first multiplied by the length of the link, because expressway delays are per mile. The total time, free time plus delay time, was computed. This represents the expected elapsed travel time required by any vehicle to traverse each link. Because the volume of traffic on each link is known, the total vehicle hours of travel may be determined for each link. And, of course, the average speed may be computed directly from the elapsed travel time.

TABLE 2

DELAY FUNCTION USED IN THE ECONOMIC ANALYSIS PROGRAM

Ratio of Assigned Volume to Design Capacity	Average Delay to Each Vehicle Using a Coded Link (millihours): Arterials and Arterial to Expway. Ramps	Average Delay to Each Vehicle Using a Coded Link (millihours): Jr. Expressways and Expressway to Expway. Ramps	Delay per Vehicle-Mile of Travel on Each Coded Link—Expressway
0.00-0.09	4	2	1
0.10-0.19	4	2	1
0.20-0.29	4	2	1
0.30-0.39	4	2	1
0.40-0.49	4	2	1
0.50-0.59	4	2	1
0.60-0.69	4	2	1
0.70-0.79	4	2	1
0.80-0.89	5	2	1
0.90-0.99	5	2	1
1.00-1.09	6	3	2
1.10-1.19	6	3	2
1.20-1.29	7	3	2
1.30-1.39	8	4	2
1.40-1.49	9	4	2
1.50-1.59	11	5	3
1.60-1.69	13	6	3
1.70-1.79	15	7	3
1.80-1.89	17	8	4
1.90-1.99	20	10	4
2.00 +	28	14	5

Results of Average Speed Determination

With the average speed of each route segment determined, a comparison between theoretical speeds and actual measured speeds was possible. Unfortunately, little empirical work was available on speed measurement, and this could not produce reliable estimates of daily average speeds. Summaries of the economic analysis speeds by various geographical units indicated that these speeds were not unreasonable. Table 3 gives average speeds on the network by ring, radiating outward from the Chicago Loop (Ring 0).

These results agree with estimates made by others. In particular, Rings 0-4, which lie largely within the City of Chicago, have average speeds not unlike those measured from time to time in other studies. Ring 4 has a low over-all average speed due to the absence of expressway routes in 1956. Average speeds on arterials in 1956 by district, a smaller geographical unit, are shown in Figure 7. Figure 8 shows these same average speeds in a 1980 plan.

TABLE 3

DAILY AVERAGE SPEEDS IN THE STUDY AREA—1956

Ring	Arterials, mph	Expressways, mph	All Route Types, mph
0	8.7	-	9.0
1	15.8	38.2	17.7
2	17.6	41.6	20.3
3	17.2	42.2	18.9
4	17.2	42.4	17.2
5	20.1	55.9	20.9
6	25.2	56.6	26.3
7	32.1	56.7	33.5
CATS Area	20.2	45.0	21.2

With acceptance of the 1956 average speeds as reasonable, estimates of these average speeds for any proposed network in 1980 could be made. Four significantly different 1980 networks were tested by determining the expected performance and cost of each link in each network as was done in the 1956 network. Table 4 gives the average speeds of one such plan, by ring, which can be contrasted to the 1956 network performance summarized in Table 3.

TABLE 4

DAILY AVERAGE SPEEDS IN THE STUDY AREA—1980

Ring	Arterials, mph	Expressways, mph	All Route Types, mph
0	9.0	33.9	10.6
1	15.2	42.6	24.4
2	20.2	50.7	29.8
3	20.7	50.7	29.4
4	19.1	49.7	25.6
5	22.0	54.0	28.1
6	23.6	53.7	30.3
7	28.4	57.8	33.1
CATS Area	23.6	52.7	29.7

The 1980 plan contains a great many more miles of expressway. This results in less congestion and, therefore, higher speed on the arterials in the inner rings. The great growth in traffic and development brings a reduction in arterial speeds in the outlying rings.

Another result of these speed determinations, although not connected with the economic analysis of networks, is its use in suggesting alternative plans to be tested. An examination of the low speed areas may indicate locations for additional expressways. Figure 9 shows the location of the delay, due to congestion in vehicle-hours per square mile of district area, for 1956 travel on the 1956 network. Figure 10 shows this delay if the 1956 travel occurred on one of the 1980 networks. This delay was computed by determining the increase in travel time, on each link in the network, due to the volume-to-capacity ratio being greater than 0.0.

The analysis of the delay due to congestion in a network led to a study of the several components of travel time. This extension of the analysis considered all elements of travel time as delay. The results of the computation of the various elements of this delay are given in Table 5. Only travel on arterial streets in 1956 was studied.

Delay due to signalization was that additional time loss, about 11.5 sec per vehicle per intersection, beyond congestion losses. Delay due to the lack of access control is the additional time required to travel at arterial rather than at expressway speeds. The final delay is the amount of time required if all arterial travel occurred at expressway speeds.

It might be repeated that the major purpose in determining average speeds on each link of each network is to provide the parameter by which travel costs are measured. The determination of travel costs as a function of daily average speed follows.

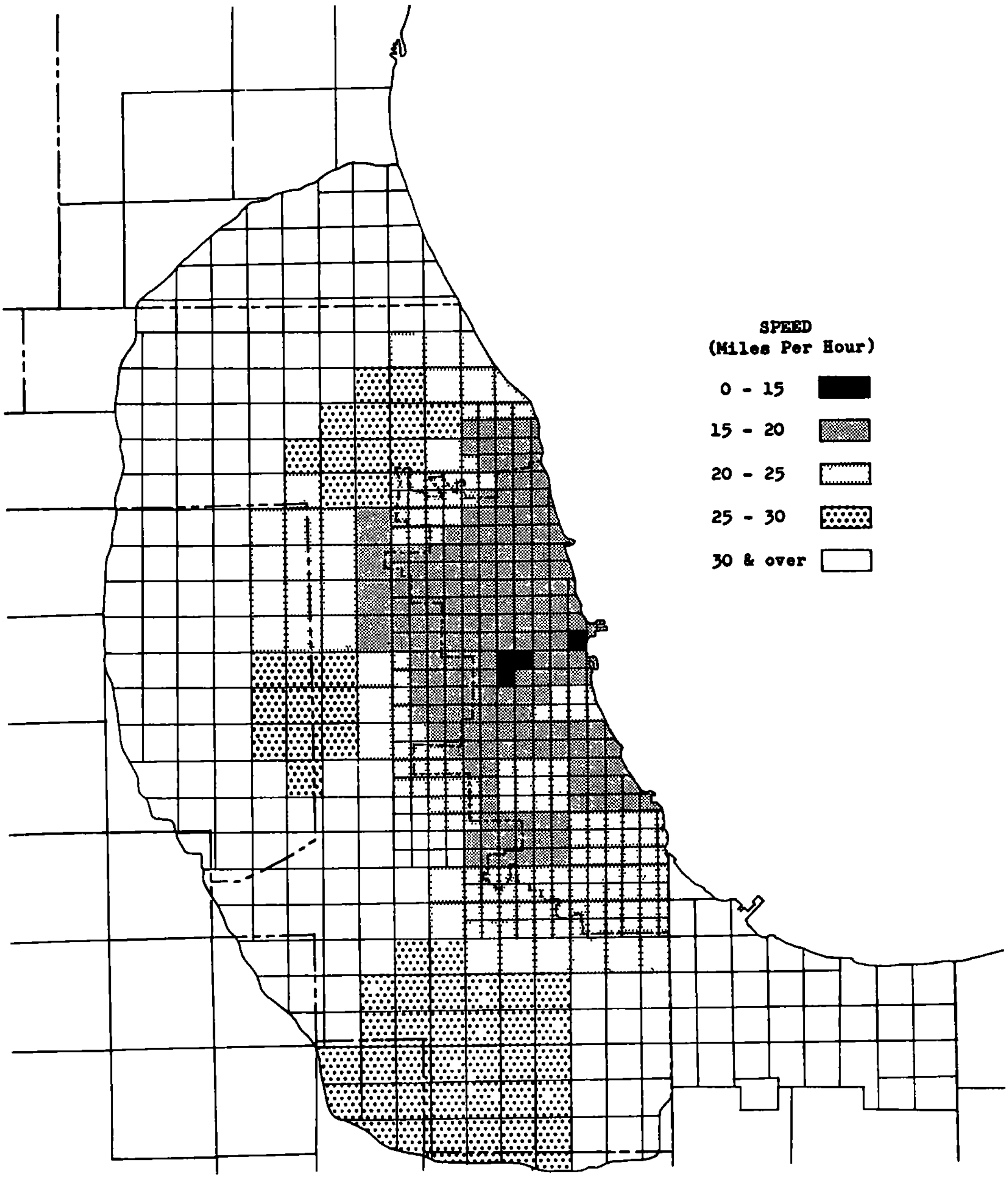

Figure 7. 1956 arterial speeds.

COST PARAMETERS

The savings in travel costs, due to a proposed traffic network, must be compared to the costs of achieving that network to determine if that network is economically justified. Moreover, the best of the economically justified networks must be chosen.

The travel and facility costs are the costs considered relevant for the analysis of a traffic network. Only direct user costs are considered so that double counting may be avoided. A truck may reduce its travel costs by the use of an expressway. The initial effect of this cost saving is to increase the profits of the trucker. In a competitive

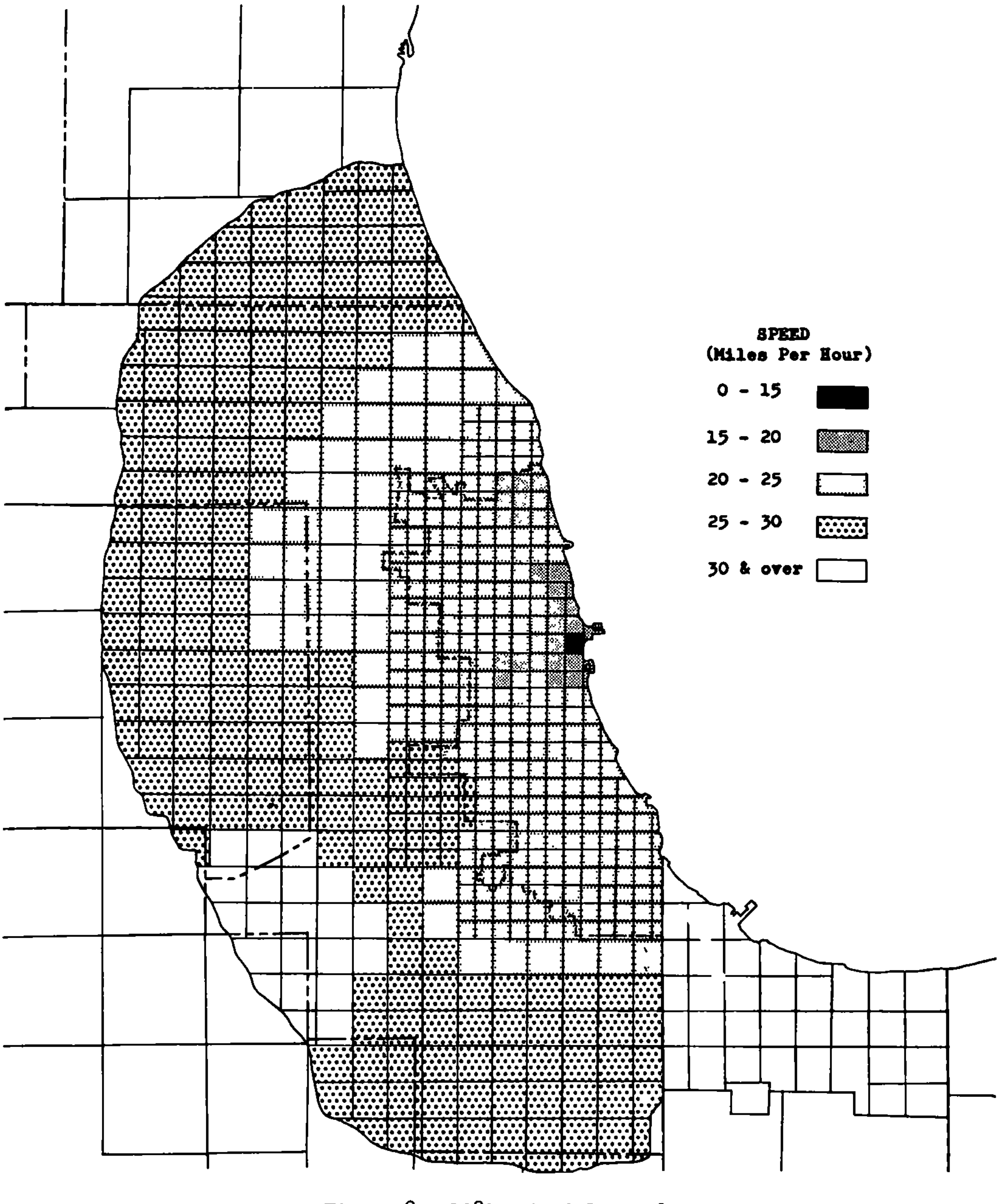

Figure 8. 1980 arterial speeds.

system, these profits would be, at least partially, eliminated by lower transport prices. One must be careful not to add the reduction in travel costs, the increase in the trucker's profits and the reduction in the price of goods together to determine the savings due to expressway travel.

The three components of travel costs are operating costs, accident costs and time costs. All three of these components were found to be related to the average speed of a vehicle. The relationship is shown in Figure 11 and Table 6. The minimum total cost per vehicle-mile is obtained at speeds of 51-54 mph.

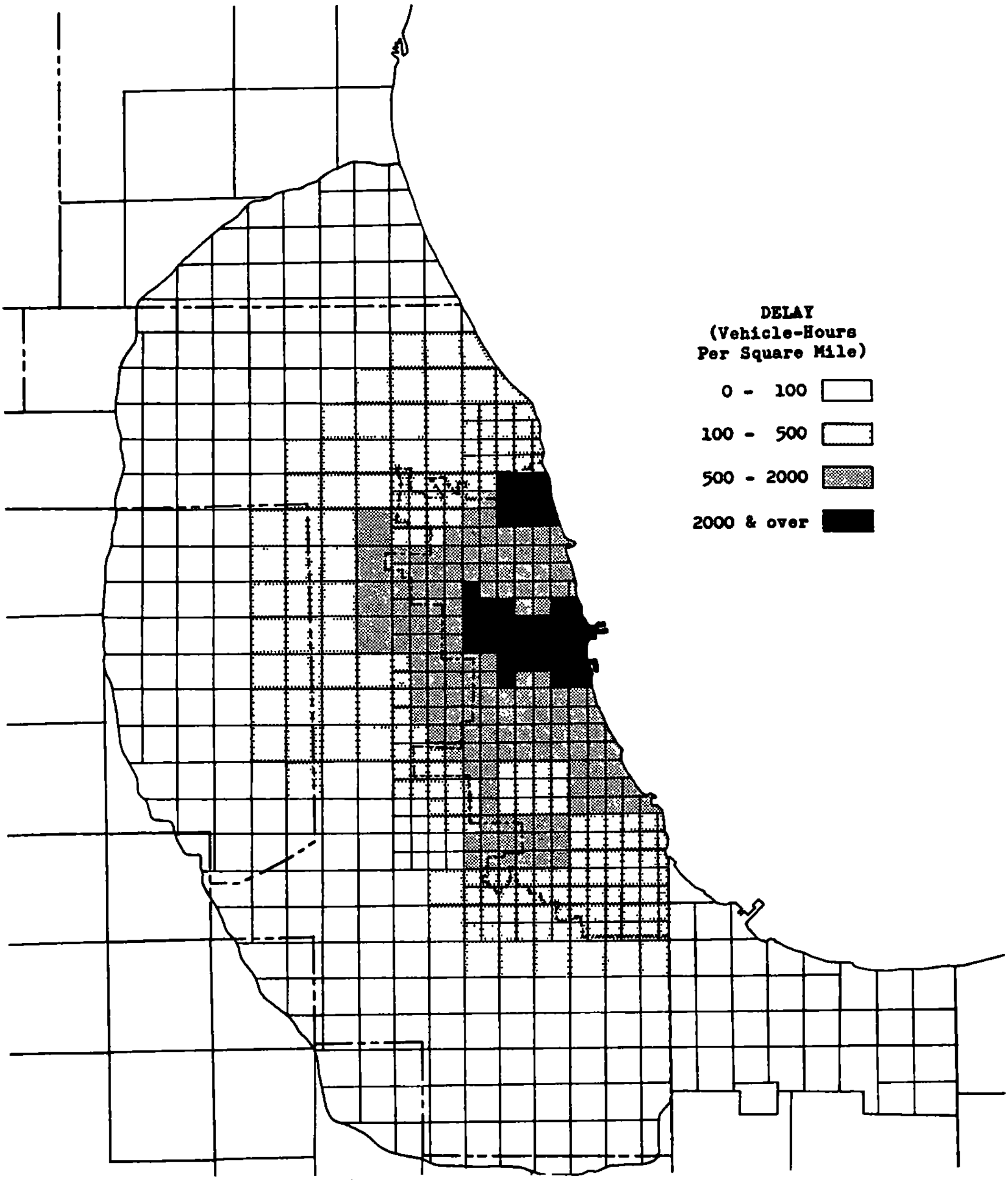

Figure 9. Vehicle-hours of delay due to congestion—1956 travel on 1956 network.

<u>Operating Costs</u>

The operating cost of a vehicle was related to its average speed on a link. Fixed costs of automobile ownership, such as license fees or obsolescence, were not included in the analysis because they are not affected by the types of facility or the quality of traffic flow. Such operating costs as fuel, oil, tire, and maintenance costs, which vary with traffic conditions were considered.

For each average speed, a running speed was calculated (6, 7). The number of stops per mile was calculated by dividing stopped time per mile by 0.35 min. This number

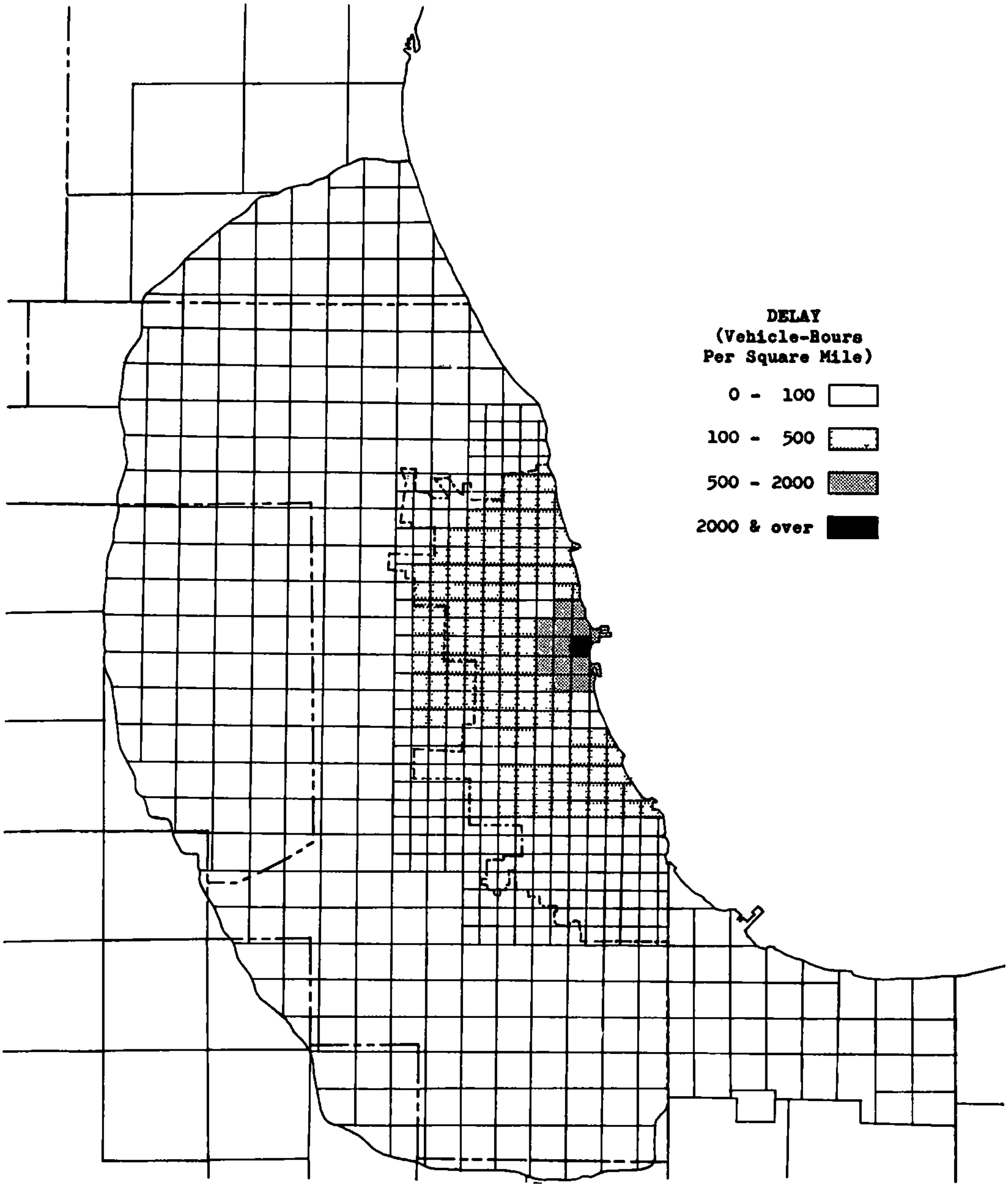

Figure 10. Vehicle-hours of delay due to congestion—1956 travel on 1980 network.

TABLE 5

ELEMENTS OF DELAY—ARTERIAL STREETS, STUDY AREA, TYPICAL WEEKDAY—1956

Element	Vehicle-Hours of Delay
Delay due to congestion	220,891
Delay due to signalization	199,444
Delay due to lack of access control	376,608
Delay due to lack of infinite speed[a]	505,725
Total delay or all time spent in travel	1,302,668

[a]Some might argue that infinite speed is unattainable. Using the speed of light, 186,000 mi per sec, the irreducible time spent for all travel in the Study Area would be 190 vehicle-seconds.

was derived empirically by speed and delay time runs on Chicago arterials during both peak and off-peak hours. The variable operating costs were obtained by summing the running and stopping costs for each average speed (8, 9). A detailed explanation of the costs and procedures which were used is in a CATS Research News article (10).

To avoid double-counting, fuel taxes were not included in operating costs. Taxes on travelers are transfer payments and do not represent goods or services consumed. Therefore, they should be included in travel costs only when they are consumed for travel. In this economic analysis, fuel taxes are included as they are spent for highway construction and are not included as travel costs.

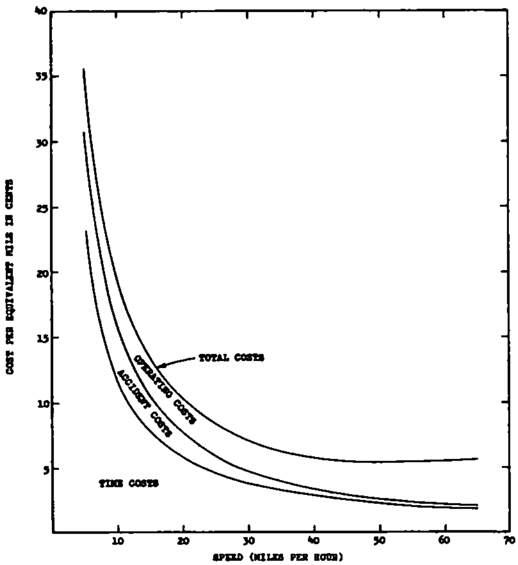

Figure 11. Cost parameters related to speed.

Accident Costs

The accident cost per vehicle-mile of travel was related inversely to the average speed on a link. This is not an accidential relationship, but was determined from a study of accident rates on arterials and expressways (11). It was found that accident rates on arterials were 14.3 per million vehicle-miles and were 2.8 on expressways. The direct reported accident costs associated with these rates were 0.62 cents per vehicle-mile on arterials and 0.13 cents on expressways. However, Chicago area insurance rates, plus studies of unreported accidents (12), indicated that three times this cost was more appropriate, yielding 1.86 cents per mile on arterials and 0.38 cents per mile on expressways. Accident rates were found to be highest in the congested parts of the city and lower with movement away from the congested area of the city. Thus, the average arterial rate was further broken down into outlying areas, central areas, and the CBD. James J. McDonough, Engineer-Manager of the Calumet Skyway, provided additonal data for the Skyway, and the Illinois State Toll Highway Commission's "Summary of Motor Vehicle Accidents" strengthened the speed-cost relationship. Table 7 summarizes the data. (This table was suggested from an unpublished memorandum by Irving Hoch, "Benefit-Costs: The Answer (I Hope)," Oct. 23, 1959, and was modified to include later data gathered by the authors. A table similar to Table 6 also appears in this memo.)

Figure 12 is a plot of the data from Table 7. The reduction in accident costs with increase in average speed is a fact that many people find difficult to accept. After all, there are many traffic slogans which caution against excess speed. But Figure 12 refers to the average speed of vehicles and not to an individual whose speed differs considerably from the average traffic flow. Such an individual would, of course, have an accident potential greater than the average. A study (13) found "that measures used to decrease congestion on the streets will, at the same time, increase speed and bring about a reduction in accidents." This is another confirmation of the evidence found in the Chicago area.

Time Costs

Although time costs represent the largest component of travel costs, they are the most difficult to justify as to their magnitude in dollars. Certainly some value should be attached to time savings. People pay more for faster plane and train service and for faster travel on toll roads.

The value of time for automobiles was set at $1.17 per hour. This was based upon a 75 cents per hour value of passenger time and an average occupancy of 1.56 persons

TABLE 6

COST PARAMETERS RELATED TO SPEED

Average Speed	Cost in Cents per Vehicle-Mile			
	Operating	Accident	Time	Total
05	4 80	6 75	23 40	34 95
06	4 52	6 25	19 50	30 27
07	4 29	5.75	16 71	26 75
08	4 08	5 25	14 63	23 96
09	3 88	4 75	13 00	21 63
10	3 69	4 25	11 70	19 64
11	3 53	3 80	10 64	17 97
12	3 39	3 40	9 75	16 54
13	3 29	3 15	9 00	15 44
14	3 19	2 90	8 36	14 45
15	3 10	2 70	7 80	13 60
16	3 01	2 50	7 31	12 82
17	2 93	2.30	6 88	12 11
18	2 88	2 10	6 50	11 48
19	2 83	1 95	6 16	10 94
20	2 78	1 80	5 85	10 43
21	2 73	1 65	5 57	9 95
22	2 69	1 50	5 32	9 51
23	2 65	1 40	5 09	9 14
24	2 61	1 27	4 88	8 76
25	2 57	1 15	4 68	8 40
26	2.53	1 08	4 50	8 11
27	2 50	1 01	4 33	7 84
28	2 47	0 94	4 18	7 59
29	2 44	0 87	4 03	7 34
30	2 41	0 80	3 90	7 11
31	2 40	0 75	3 77	6.92
32	2 39	0.70	3 66	6 75
33	2 38	0.65	3 55	6 58
34	2 37	0.60	3 44	6 41
35	2 36	0 55	3 34	6 25
36	2 35	0 51	3 25	6 11
37	2 34	0 47	3 16	5 97
38	2 33	0 44	3 08	5 85
39	2 33	0 41	3 00	5 74
40	2 32	0 38	2 93	5 63
41	2 37	0 37	2 85	5 59
42	2 42	0 36	2.79	5 57
43	2 47	0 35	2 72	5 54
44	2 52	0 34	2 66	5 52
45	2 57	0 33	2 60	5 50
46	2.62	0 32	2.54	5 48
47	2 67	0 31	2 49	5 47
48	2 72	0 30	2.44	5 46
49	2 77	0 29	2 39	5 45
50	2 82	0 28	2 34	5 44
51	2 87	0 27	2 29	5 43
52	2.92	0 26	2 25	5 43
53	2 97	0 25	2 21	5 43
54	3 02	0 24	2 17	5 43
55	3 08	0 23	2 13	5 44
56	3 13	0 22	2 09	5 44
57	3 18	0 21	2 05	5 44
58	3 23	0.20	2 02	5 45
59	3 29	0 19	1 98	5 46
60	3 35	0 18	1 95	5 48
61	3 41	0 17	1 92	5 50
62	3 47	0 16	1 89	5 52
63	3 53	0 15	1 86	5 54
64	3 59	0 14	1 83	5 56
65	3 65	0 13	1 80	5 58

per vehicle (14). The current Federal minimum wage is $1.00 per hour and no one may work in covered employment for less. Thus $1.00 per hour per employed person would be a minimum figure. But, because some passengers are unemployed, the hourly rate was dropped to 75 cents per hour.

In the future, real income per capita should rise, thereby justifying a higher hourly rate, while average occupancy per automobile may fall.

TABLE 7

ACCIDENT COSTS RELATED TO SPEED

Estimated Speed	Location	Crude[a] Accident Rate per Million Vehicle-Miles	Accident Cost-Cents per Vehicle-Mile
8	CBD	51	5.60
15	Average in Central areas	25	2.70
20	Average in arterials	17	1.86
30	Average in outlying areas	7	0.77
40	Congress St. Expressway	2.8	0.38
60	Calumet Skyway	1.2	0.17
65	Illinois Toll Roads	0.94	0.13

[a]The crude accident rate for arterials does not contain a reduction for the double-counting of arterial intersection accidents. However; the accident costs do. The arterial average of 14.3, which was stated in the text, is the refined rate which eliminates double counting.

Facility Costs—Construction Costs

The testing of several alternate schemes requires a method for estimating facility costs that is both easy to compute and accurate. Because these schemes consist of lines on paper and only give approximate locations, the conventional methods of cost estimation are not adequate. Detailed estimates, such as required on the Interstate system which consider the amount of concrete to be poured and the weight of steel to be used, cannot be made unless the specific route is determined.

A method for the determination of expressway construction costs, which requires only an approximate location of the facility, has been developed at the Study (15). Construction costs of Congress Street, Edens, Calumet, and Kingery Expressways were broken down by each Study Area ring. (Study Area rings radiate outward from the CBD.) Because there has been an increase in the price level since these expressways were built and the expressways were built at different times, price level adjustments were made. The Bureau of Public Roads highway construction cost

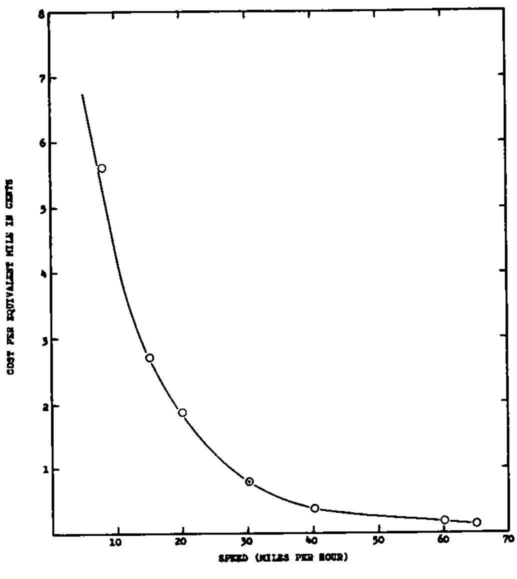

Figure 12. Accident costs per vehicle-mile related to speed.

index for a composite standard mile was used to obtain price level factors for each year. (The index numbers were obtained from the U. S. Department of Commerce, Office of Business Economics.) Each cost item was multiplied by the appropriate price level factor to bring all construction costs to the 1958 price level.

Net residential density was found to be the best single predictor of construction costs. Denser residential land means greater construction costs because of extensive utility relocations, difficulty of moving materials to construction sites, more expressway ramps to facilitate exit and entrance, more pedestrian overpasses, more extensive drainage requirements, and more bridges. A linear relationship was discovered between total construction costs per mile and net residential density. A regression line was computed with the equation:

$$Y = 0.999 + 0.0708X \tag{14}$$

in which Y is total construction cost per mile in millions of dollars and X is not residential density in thousands of persons per square mile. This was a relationship found for the Chicago Area and should not be used elsewhere without appropriate investigation.

ROW Costs

An equation to permit rapid estimation of the right-of-way costs of a proposed expressway was developed for the Chicago Area by Clyde Browning, John Hamburg, and Robert Sharkey. This was in response to the need for a method of estimating the ROW costs of an expressway in a proposed vicinity when the exact location was not specified. The basic data consisted of Northwest Expressway ROW costs (16) and detailed estimates for two other routes under study. A regression equation was fitted and yielded the results:

$$Y = -5.05 + 5.85 \log X \tag{15}$$

in which Y is the estimated ROW cost in millions of dollars and X is the net residential density in thousands of persons per square mile. At densities of less than approximately 7,300, the equation would give a negative ROW cost. However, all the district densities in the Chicago Area are greater than 7,300.

Other Facility Costs

Many highway construction projects other than expressways will be undertaken in the future. To the extent that they will be the same for all plans, they have been omitted in the analysis. To the extent that they would vary from plan to plan, they have been included.

Plans with fewer expressways would require more arterial widenings to provide adequate capacity for the future. Seventeen major street widenings are programed for the current year (1960) at an average cost of $210,000 per route mile (17). The Study used a design capacity of 14,000 equivalent vehicles per day for the widened arterials in the 1980 assignments. These arterials previously had capacities of about 7,000 vehicles per day. Thus, very approximately, widened arterials cost about $30 per additional vehicle-mile of design capacity provided.

TESTING AND SELECTING PROPOSED PLANS

Description of Alternate Plans

Previous sections have described the procedures, speeds, and cost parameters that were used to obtain daily travel costs and total facility costs. Table 8 gives the results for four alternate plans that were tested at the Study. None of the four is the final Chicago Area plan.

Figures 13 through 16 show the expressway parts of the traffic networks for Plans A through D. The arterials are not shown on the maps, but their costs are included in Table 8. Plan A contains the facilities which are committed to be built. Plans B, C, and D call for additional investment beyond the committed system.

TABLE 8

COST COMPARISON OF ALTERNATE PLANS

	Plan			
	A	B	C	D
Daily vehicle equivalent hours	2, 255, 935	2, 048, 905	2, 016, 691	1, 989, 575
Daily time cost ($)	2, 639, 442	2, 397, 223	2, 359, 529	2, 327, 801
Daily operating cost ($)	1, 846, 719	1, 906, 825	1, 820, 565	1, 746, 173
Daily accident cost ($)	606, 564	510, 301	491, 051	469, 968
Daily total travel cost ($)	5, 092, 725	4, 814, 349	4, 671, 145	4, 543, 942
Annual total travel cost ($) (daily x 339. 5)	1, 729. 0 $\overline{M}$	1, 634. 5 $\overline{M}$	1, 585. 9 $\overline{M}$	1, 542. 7 $\overline{M}$
Total additional facility costs over 1956 system[a] ($)	1, 979. 0 $\overline{M}$	2, 501. 6 $\overline{M}$	2, 847. 6 $\overline{M}$	3, 380. 3 $\overline{M}$

[a]Several hundred million dollars have been expended for highway construction since 1956, but because only differences between plans will be considered, this does not matter.

Daily time costs were obtained by multiplying vehicle hours by $1. 17 per hour. Daily operating and accident costs were obtained by summing the costs for each link in the coded network. The daily costs are for typical weekdays. Daily costs were multiplied by a factor of 339. 5 to obtain yearly costs. In 1958, there were 104 weekend days and 261 weekdays, of which 7 were holidays. Traffic counts on Ashland Avenue and the Congress Expressway in Chicago indicated that weekend days and holidays average 77 percent of weekday traffic. Therefore, the 111 holiday and weekend days were multiplied by 77 percent and added to the 254 weekdays remaining, to give a total of 339. 5 equivalent weekdays for the year 1958. This factor was assumed to remain stable over time.

Additional facility costs were computed by the methods shown in the previous section. In addition, Plans C and D contain intermediate facilities (junior expressways) whose costs vary from 30 percent to 67 percent of those of full expressways.

Selection of the Economically Best Plan

Plans A through D represent different levels of investment. As the amount of investment increases, the travel costs decline. Investment dollars can almost always be traded for travel cost dollars. At some point the trade is no longer economically justified. Any plan whose level of investment exceeds this point will be rejected.

A minimum attractive rate of return, r, of 10 percent was used to analyze the four alternate plans. This rate is comparable to that used by public utilities to justify project proposals. It is somewhat less than the effective interest rate usually charged to finance new car purchases. Money can be used in the private or governmental sectors of the economy; and if the rate of return on governmental projects is less than that for private projects, a transfer from government to private investment would yield a greater total social product.

A facility life of 25 yr was used in the analysis of the plans. At the end of this time, the pavement would have been reconstructed. Although bridges and ROW have longer lives, it was decided to use a shorter life to allow for presently unforeseeable techno-

Figure 13. Expressway Plan A.

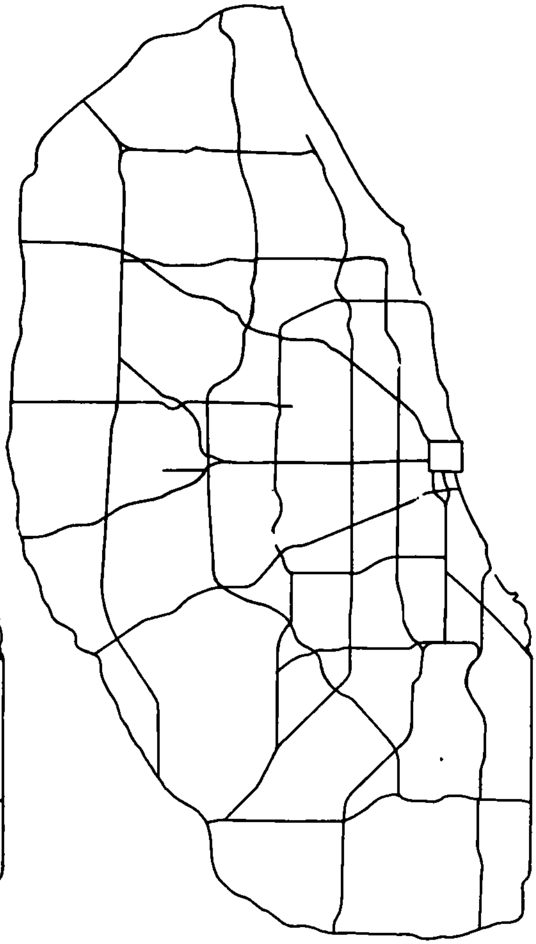

Figure 14. Expressway Plan B.

logical innovations which might cause facility obsolescence in the future. A 10 percent rate of return and a 25-yr life is approximately equivalent to an 11 percent rate of return and an infinite life.

The costs of building any of the four plans would be spread over time and the travel costs would vary from year to year. A simplification was made that the annual travel costs would be the 1980 travel costs given in Table 8. Because the four plans could probably not be completed much before 1980, this is not too unreasonable an assumption.

Three methods—rate of return on marginal investment, benefit-cost ratios, and least total travel and facility cost—will be used to determine which plan is the best economically. All three methods will yield the same answer.

The rate of return on marginal investment method is to find the interest rate which equates an increment of investment to a series of savings. Table 9 gives the marginal investment of each plan over the plan with the next lower amount of investment. For Plan A, the committed system, this is "zero" because the amount of investment for that plan is the minimum that will be spent. The marginal annual travel cost saving is the increment of travel cost saving of each plan over the plan with the next lower amount of investment. The ratio of marginal annual travel cost saving to marginal investment gives the rate of return for each plan over the plan with the next lower investment cost if the facilities were assumed to have infinite life. Because the facili-

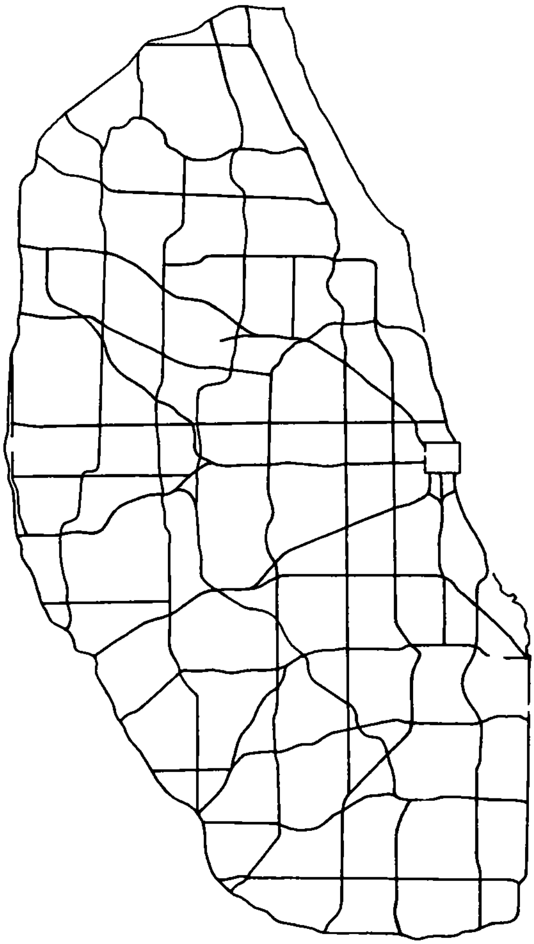

Figure 15. Expressway Plan C.

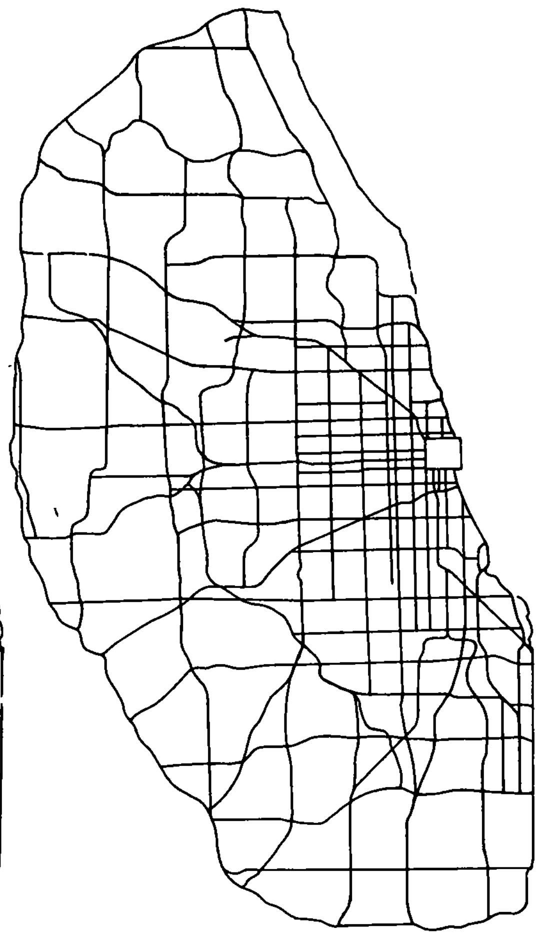

Figure 16. Expressway Plan D.

ties are assumed to have only 25-yr life, the ratio must be looked up in a book of interest tables under Capital Recovery Factor (CRF) and 25 yr to find which interest rate yields the CRF which is closest to the ratio.

The rates of return on marginal investment given in Table 9 indicate that Plan C is the best plan economically. First, Plan B is compared to Plan A and is shown to yield an 18 percent rate of return for its increment of investment. Because this is greater than the 10 percent minimum attractive rate of return, Plan B is better than Plan A. Next, Plan C is compared to Plan B and is shown to yield a 13 percent rate of return for its marginal investment over that of Plan B. Because this is also greater than the 10 percent minimum attractive rate of return, Plan C is better than Plan B. Next, Plan D is compared to Plan C and is shown to have a 6 percent rate of return. Because this is less than 10 percent, Plan D must be rejected. Therefore, Plan C is the economically best plan because it is better than Plan D and better than Plan B which is better than Plan A.

Benefit-cost ratios between the annual marginal travel cost saving and the annual marginal investment are given in Table 10. The marginal investment for each plan was multiplied by the Capital Recovery Factor for r = 10 percent and n = 25 yr to obtain the annual marginal investment. Again, Plan C is the best plan. Marginal investments should be made if the B-C ratio for the increment is greater than one. The incremental investments for B and C are justified, whereas that for D is not. Plan C is better than Plan B because its marginal saving is greater than its marginal investment cost.

TABLE 9

RATE OF RETURN ON MARGINAL INVESTMENT

	Plan			
	A	B	C	D
Marginal investment	-	$522.6M̄	$346.0M̄	$532.7M̄
Marginal annual travel cost saving	-	94.5M̄	48.6M̄	43.2M̄
Ratio of marginal annual travel cost saving to marginal investment	-	0.1808	0.1405	0.0811
Rate of return on marginal investment	-	18%	13%	6%

TABLE 10

BENEFIT-COST RATIOS

	Plan			
	A	B	C	D
Marginal annual travel cost saving	-	$ 94.5M̄	$ 48.6M̄	$ 43.2M̄
Annual marginal investment (r = 10%, n = 25 yr)	-	57.6M̄	38.1M̄	58.7M̄
B-C ratio	-	1.64	1.28	0.74

The total annual costs of each plan are compared in Table 11, and, of course, Plan C has the lowest cost. Annual facility costs were obtained by multiplying the total additional facility costs in Table 8 by the capital recovery factor for r = 10 percent and n = 25 yr. The plan with the lowest total annual cost is the best one.

TABLE 11

TOTAL ANNUAL COSTS

	Plan			
	A	B	C	D
Annual total travel cost	$1,729.0M̄	$1,634.5M̄	$1,585.9M̄	$1,542.7M̄
Annual total additional facility cost over 1956 system	218.0M̄	275.6M̄	313.7M̄	372.4M̄
Total annual cost	$1,947.0M̄	$1,910.1M̄	$1,899.6M̄	$1,915.1M̄

All three methods for selecting the economically best plan, given the costs, are equivalent and yield the same results—Plan C is best. There are other correct methods which also would yield the same result, but this discussion was not meant to be exhaustive.

REVIEW AND EVALUATION

Four alternate traffic systems were compared in the economic analysis at the Study. Although other plans will also be considered, these four serve to illustrate the economic comparison developed in this paper. The plans, when ranked in increasing order of total investment required, were in descending order of total travel cost. The choice of interest rate determined the economically best plan.

The investment costs were determined from an examination of the elements of the system and the historical record of the cost of building similar elements of the existing system. This was done in a general way with no regard to the design or construction problems to be encountered by any specific segment of the network.

The travel costs were determined through the use of a common parameter—average daily speed. Accident costs were found to be inversely related to speed. Operating costs were minimized at a certain speed level and were found to be higher at very low and very high speeds. Time costs, inversely related to speed, were determined by setting a monetary value on travel time.

The average daily speed was determined for each link in the network and was based on speed and delay considerations. This speed was a function of the physical characteristics of the route—effect of signalization, access control, intensity of development—and the traffic load imposed on the route. The distribution of traffic volume throughout the day was considered in converting hourly speed-volume relationships to daily performance measures. Travel costs for each link of the four networks compared were then computed. Because of the large number of coded segments of the Study Area network, all computations were handled first on a punched-card system and later in an electronic computer.

The economic analysis of traffic networks suggested here, provides a rational and objective method of selecting a plan. The primary criterion of the traffic plan has been designated and the method of comparison presented. The treatment of each plan as a network rather than as a separate collection of routes is fundamental to the analysis. However, two plans, differing only by a single route may be compared yielding the effect of that route. The effect on every link in the network is thus obtained.

Some caution must be urged in using the results of the economic analysis. The evaluation relies heavily on the results of traffic assignments to the networks under consideration. These assignments, even though pioneered and refined at the Chicago Area Transportation Study, yield only approximate results. Even if these assignments were perfect predictions of 1980 traffic flow, other imperfections in the economic analysis would still be present. The simplifications required in the average daily speed determination, the crudeness of the accident cost relationship, the arbitrary designation of time value, and the assumptions required in the operating cost function, all tend to reduce the confidence in results of the economic analysis.' It is in these areas that further work may also improve the accuracy of the analysis.

Although these difficulties weaken the economic analysis to a certain extent, economic evaluation has still been found useful to the planning process at the Study. The analysis can direct the planner in a general way toward the optimal plan. However, the final planning decision must still be a product of all the available measures of the plans compared, and the skill and ingenuity of the planner.

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The authors are particularly indebted to Irving Hoch for his preliminary work on benefit-cost done at the Transportation Study in 1959. Dr. Hoch, now at the University of California, Berkeley, suggested part of the analytic approach which the authors expanded and implemented.

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Cost Comparison of Four-Lane vs Stage Construction on Interstate Highways

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Throughout the planning of many highway improvements there frequently arise occasions when it might be desirable and economically profitable to construct the final full facility in a series of stages. Such opportunity is afforded on the Interstate Highway System wherein today's traffic volume hardly justifies four-lane construction and yet at some time in the future four lanes of highway would be required

This paper works out in detail the analysis of three Interstate Highway projects to determine the relative economy of initially constructing the four lanes of completed highway as compared to building two lanes now and the additional two lanes at some time in the future. The economy of designing and building the two lanes of original construction designed to four-lane Interstate standards is compared to constructing the two original lanes designed for two-lane, two directional operation on the four-lane right-of-way so as to provide for more freedom in passing than is provided for in the four-lane design.

The details of calculating the present worth of the various disbursements for construction and maintenance for the three designs of each of the three projects are given. The analysis points out that the relative economy of the stage construction depends on two primary factors: first, the additional costs of construction because the whole highway is built in two stages rather than in one, and second, the time interval between the stages of construction. Also, an important factor is the rapidity with which the traffic volume increases, which in turn affects the period of time between initial construction and the second stage of construction.

Although this analysis is presented for three specific projects, the procedure applies to any proposed highway facility to be constructed in a series of stages as compared to building the entire completed project initially.

FOR many highway construction projects, as well as for other public works and private construction, management officials must decide between initially constructing the whole of a project to ultimate capacity, in excess of that required for the intermediate and near future, and some plan of construction in two or more stages.

When stage construction possibilities exist, the engineer and administrator are required to make the decision of how much of the project should be constructed now and how much could be postponed to some future year. The final decision on stage construction is based on the relative economy of the alternate possibilities, plus weight given to attaining an acceptable quality of service, and other relevant factors. The cost factors are the time value of money invested in the highway facility, the annual disbursements for its operation, the costs of motor vehicle operation, and the annual net monetary benefits (advantages less the disadvantages) of any other factors which are reducible to reliable dollar values.

A current question in some states is whether to build initially (now) the full four lanes of a new section of a four-lane divided Interstate highway or to construct initially only two new lanes, followed later with the second two new lanes at a time when warranted by the traffic requirements. Such considerations exist on sections of Interstate routes where two lanes would carry the traffic satisfactorily now and for some years into the future.

The analysis presented assumes that by prior decision, the highway is to be programed for construction within a year or two. The difference in the amount of money required for four lanes and for two lanes as initial construction would be programed for other projects at the same time the two-lane construction was programed. That is, there is specific immediate use for all available construction money.

An analysis of the economy of constructing the ultimate four-lane divided highway in two stages, each stage of two new lanes separated by some period of years, requires a decision as to what elements of the final four-lane highway would be provided in the first stage or initial construction, and what elements of construction would be postponed to the second stage. Rights-of-way and controlled access would be logical choices for the initial stage although part of the ultimate rights-of-way might not be obtained until the second stage. The extent that grading, drainage, and structures would be provided in the initial stage would be decided largely on consideration of local conditions of terrain and traffic. The paving and shoulders for the second two lanes would, of course, be postponed to the second construction stage.

In general, the greatest economy will be achieved by postponing all construction that can be postponed, consistent with still providing convenient, safe and speedy transportation on the two lanes.

One of the penalities for delaying construction to a second stage is that the total construction costs will be greater when constructed in two stages as compared to constructing the whole four-lane highway immediately. The total costs are greater because the contractor must move in twice, and would handle smaller total quantities of construction work per move in. General overheads and engineering would be more under two contracts than under one. In addition, certain elements of the first stage of construction for the two-lane operation will be abandoned, removed, or become unnecessary when the highway is later converted to four-lane divided operation. Extra construction costs for earthwork will be noticeably higher in the stage construction when adequate passing sight distance is provided in the first two lanes used for two-directional travel beyond the lesser sight distance needed after the first two lanes are converted to operation in only one direction.

Considering only highway costs for the moment, the economy of two-lane stage construction has to be evaluated in terms of the time value of the money difference in the two basic plans. In other words, at what point in future time will interest charges on the four-lane investment accumulate to the interest charges on the first stage of two lanes plus the extra dollars of construction cost caused by stage construction with both plans adjusted to include annual highway maintenance costs.

Because the running costs of motor vehicles, accident costs, and the travel time will be different for two-lane operation than for four-lane operation, the analysis will also include motor vehicle operating costs along with the highway costs. Vehicle speeds will be greater on the four-lane divided highway than on the two-lane highway. For the highways considered, the vehicle running costs will be greater at the higher speeds on the four-lane divided highway, but the time costs will be less. Accident costs will be more on two-lane operation than on four-lane operation. Traffic volume will generally increase year by year. Because traffic speed decreases with an increase in traffic volume (up to possible capacity), straight running costs at constant speed per vehicle-mile will decrease year to year. In the analysis then, the motor vehicle costs need to be developed year by year as traffic increases in daily volume and as speeds decrease.

The goal of the analysis is to determine that point in future time when today's present worth of all costs of highway construction, highway maintenance, and motor vehicle operation becomes equal for the initially completed four-lane construction and the two-lane stage construction. This date of equality of present worths can be determined from a time series of solutions by considering that the second two lanes would be constructed in each successive year beginning with the year of initial construction.

The goal could be set to determine which alternative is the more economical for that period of time between the present date and the future date when the four lanes would be needed to meet the requirements of traffic. Either goal is acceptable, and the correct answer would be reached in either procedure because the solutions would use the same basic factors.

The term "present worth" is used in its commonly accepted meaning as applied to compound interest. Specifically, it means the amount today (the present) which at a specific rate of interest would compound itself to a given sum in a given number of years. The present worth factor is the reciprocal of the compound interest factor. Thus, the present worth of a $1,000 expediture 10 yr from today at 6 percent interest rate per annum is ($1,000) (0.5584) or $558.40. At 6 percent compound interest $558.40 will accumulate to $1,000 in 10 yr—($558.40) (1.791) = $1,000.00.

The question of whether stage construction is the preferred economy can be answered by any one of the following solutions:

1. Determine the present worth of all money costs for the applicable time period. The total present worth so calculated represents that sum of dollars, which, at compound interest on remaining balances, would be sufficient to provide money for all disbursements for construction, highway maintenance, and motor vehicle costs at the end of each future year as indicated. The construction plan having the greatest economy is that plan, which to a given future date in time, has the smaller present worth of all disbursements.
2. Determine the accumulated compound amounts of all costs to the appropriate future date. The alternate having the lowest compound amount is the preferred one.
3. Equate all costs to equivalent equal annual costs. The alternate having the lowest equivalent equal annual cost would be the preferred one.

In this analysis the present worth basis is used because of its simplicity and directness.

This present worth procedure is applied to three Interstate projects to illustrate the steps of analysis and to show the effects of specific factors.

ILLUSTRATIVE PROJECTS

The information on design, cost, and traffic of the three rural Interstate projects analyzed herein was submitted by the respective highway departments in three western states. Each project is proposed on complete new rights-of-way. The projects are described, as follows:

1. Project A: 7.100 mi; two horizontal curves, 20 deg or less totaling 0.6 mi; and an average grade of 1.74 percent.
2. Project B: 6.814 mi; eight horizontal curves, 20 deg 15 min or less, totaling 4.3 mi; and an average grade of 1.62 percent.
3. Project C: 5.095 mi; three horizontal curves; 1 deg 30 min or less; and an average grade of 2.02 percent.

The estimated construction costs of these three rural projects are given in Table 1. Note that the three states did not assume that the same elements of the highway would be built in the same stages. Each project, however, provides for full rights-of-way with the initial stage of two lanes, and for the paving of the second two lanes to be delayed to the second stage. Annual highway maintenance costs are as estimated by the State.

The analyses given in this paper consider only the cost figures submitted by the States for the elements of the highway they would build in the first stage and in the second stage. Actually, for a full analysis several alternatives should be examined. These alternatives would include such items as buying only part of the rights-of-way for the initial stage of construction and acquiring the remainder of the rights-of-way at the time the second two lanes are to be built. Also to be considered would be delaying to the second stage part of the earthwork and construction of the interchanges, with due consideration given to traffic services. Perhaps up-hill truck lanes would be desirable for a few years. In a more detailed analysis each project under consideration would have to be analyzed carefully from the requirements which were essential to handling the volume of traffic for each year under consideration.

HIGHWAY COSTS AND PRESENT WORTHS

Table 2 gives the calculations for the present worth of the disbursements for highway construction and maintenance. An interest rate of 6 percent per annum is used. These calculations are on the basis that the initial construction is in place December 31, 1960, and that the second stage of construction would be completed also by the end of 1960 and successively at each succeeding 2-yr period thereafter. Only alternate years were calculated as a means of reducing the volume of calculations.

The calculations are made on the basis that the present is December 31, 1960. The present worth of all disbursements are calculated as of this date. Although the maintenance disbursements would be made continuously day by day during each year, they are all assumed to take place at the end of each year for the present worth calculations. The first year of maintenance costs is 1961, the year following completion of the initial construction.

TABLE 1

ESTIMATED CONSTRUCTION AND MAINTENANCE COSTS IN DOLLARS

Highway Element	Project A (7 100 mi) Two-Lane Stage Construction 1960	Project A Two-Lane Stage Construction Future	Project A Four-Lane Construction 1960	Project B (6 814 mi) Two-Lane Stage Construction 1960	Project B Two-Lane Stage Construction Future	Project B Four-Lane Construction 1960	Project C (5 095 mi) Two-Lane Stage Construction 1960	Project C Two-Lane Stage Construction Future	Project C Four-Lane Construction 1960
Preliminary engineering	63,300	16,600	72,000	35,000	50,000	70,000	10,238	-	13,947
Rights-of-way	500,000	-	500,000	130,000	-	130,000	42,562	-	42,562
Clear and grub, demolition	25,300	40,000	50,300	-	-	-	100	-	100
Utility adjustments	9,400	-	9,400	49,300	-	49,300	830	-	830
Grade and drain, minor structures	1,457,200	963,900	1,695,400	352,000	604,000	714,000	229,333	283,268	480,894
Base, surfacing, shoulders	649,400	573,000	1,094,500	400,000	493,000	696,000	330,103	560,011	611,318
Railroad grade separations	126,000	-	126,000	-	-	-	-	-	-
Highway grade separations w/o ramps	373,700	230,400	589,000	-	25,000	20,600	-	48,091	48,091
Interchanges complete	511,200	-	511,200	-	280,000	251,000	-	206,546	206,546
Other bridges, tunnels	225,000	240,800	378,000	35,000	83,000	113,000	-	134,334	134,334
Guardrail, fencing, lighting, traffic control	185,400	46,000	185,300	78,000	113,000	151,000	29,069	24,365	51,495
Roadside improvement	45,300	16,400	54,000	10,600	15,000	20,000	10,718	18,583	19,368
All other items	30,900	1,000	30,900	3,000	5,000	6,000	1,315	900	1,715
Construction engineering; contingencies	363,900	211,200	492,400	92,800	161,800	202,100	60,147	129,610	155,469
Total estimated construction cost	4,566,000	2,339,300	5,788,400	1,185,700	1,829,800	2,423,000	714,413	1,405,708	1,766,369
Annual maintenance cost	23,000	33,000	33,000	7,400	17,900	17,900	10,200	23,600	23,600

Attention is directed in Table 2 to the decrease, year by year, of the present worths of construction costs plus annual maintenance costs of the two-lane stage construction plan and to the increase, year by year, for the four-lane immediate construction plan. Under the stage construction analysis, it is assumed that the second stage is, in turn, constructed in each alternate future year. Thus, the farther into the future the second stage is constructed, the less is the present worth of its cost. These present worths of construction costs decrease at a rate greater than the present worths of the maintenance cost increase. The four-lane construction present worths increase because of the annual maintenance cost. The present worths at 1960 are higher for the two-lane stage construction than for the four-lane construction by the amount of the greater total construction cost when total construction is in two stages.

The construction costs for building the first two lanes to the design standards for one-half of a four-lane highway were available and a complete analysis was made of the relative economy of this plan. Under this plan the construction costs were lower than for the two lanes designed for two-directional operation by reason that the passing sight distance for two-directional operation required greater earthwork costs than for one-half of a four-lane design. The data and analysis for this condition are not presented herein because of the uncertainty of the difference in motor vehicle running costs and accident costs on the two-lane, two-directional design, and the two-lane, one-directional design. But in the analysis as made, the combined highway costs and motor vehicle costs on the one-directional design were slightly less than for the two-lane, two-directional design. There is also the question of whether it would be good judgment to design and construct a highway for operation in only one direction and then put it into two-directional operation except in terrain where vertical curves were a minor consideration in safety of operation.

MOTOR VEHICLE COSTS AND PRESENT WORTHS

The traffic volumes in Table 3 are straight line extensions year by year between the 1960 and 1975 volumes estimated by the States. The single unit trucks and the combination vehicles were separated from the total truck percentage, estimated by the State, on the basis of similar classifications in western States.

Table 4 gives the average annual speeds for the three classes of vehicles for each project, for two-lane and four-lane operation. These speeds were calculated by ref-

TABLE 2

PRESENT WORTH[a] OF ALL HIGHWAY COSTS IN DOLLARS

Construction	1960	1962	1964	1966	1968	1970	1972	1974	1976
Project A									
A Two-lane stage									
Present worth of first stage construction	4,566,000	-	-	-	-	-	-	-	-
Present worth of second stage construction[b]	2,339,300	2,081,977	1,852,959	1,649,206	1,467,677	1,306,265	1,162,632	1,034,672	920,748
Present worth of first stage annual maintenance[c]	(23,000)	42,159	79,695	113,091	142,830	169,280	192,832	213,785	232,438
Total present worth all disbursements[d]	6,905,300	6,690,136	6,498,654	6,328,297	6,176,507	6,041,545	5,921,464	5,814,457	5,719,186
B Four-lane									
Present worth of construction	5,788,400	-	-	-	-	-	-	-	-
Present worth of annual maintenance	(33,000)	60,489	114,345	162,261	204,930	242,880	276,672	306,735	333 498
Total present worth, all disbursements[d]	5,788,400	5,848,889	5,902,745	5,950,661	5,993,330	6,031,280	6,065,072	6,095,135	6,121,898
Project B									
A Two-lane stage									
Present worth of first stage construction	1,185,700	-	-	-	-	-	-	-	-
Present worth of second stage construction[b]	1,829,800	1,628,522	1,449,385	1,290,009	1,148,017	1,021,760	909,411	809,321	720,209
Present worth of first stage annual maintenance[c]	(7,400)	13,564	25,641	36,386	45,954	54,464	62,042	68,783	74,784
Total present worth, all disbursements[d]	3,015,500	2,827,786	2,660,726	2,512,095	2,379,671	2,261,924	2,157,153	2,063,804	1,980,692
B Four-lane									
Present worth of construction	2,423,000	-	-	-	-	-	-	-	-
Present worth of annual maintenance	(17,900)	32,811	62,024	88,014	111,159	131,744	150,074	166,381	180,897
Total present worth, all disbursements[d]	2,423,000	2,455,811	2,485,024	2,511,014	2,534,159	2,554,744	2,573,074	2,589,381	2,603,897
Project C									
A Two-lane stage									
Present worth of first stage construction	714,413	-	-	-	-	-	-	-	-
Present worth of second stage construction[b]	1,405,708	1,251,080	1,113,461	991,024	881,941	784,947	698,637	621,745	553,287
Present worth of first stage annual maintenance[c]	(10,200)	18,697	35,343	50 153	63,342	75,072	85,517	94 809	103 081
Total present worth, all disbursements[d]	2,120,121	1,984,190	1,863,217	1,755,590	1,659,696	1,574,432	1,498,567	1,430,967	1,370,781
B Four-lane									
Present worth of construction	1,766,369	-	-	-	-	-	-	-	-
Present worth of annual maintenance	(23,600)	43,259	81,774	116,041	146,556	173,696	197,862	219 362	238,502
Total present worth, all disbursements[d]	1,766,369	1,809,628	1,848,143	1.882,410	1,912,925	1,940,065	1,964,231	1,985,731	2,004,871

[a]Present worth is calculated as of December 31, 1960, at a discount rate of 6 percent per annum

[b]Calculated on the basis that the first stage would be constructed in 1960 The second stage in turn is assumed to be constructed first in 1960, then in 1962 and so on to 1976

[c]The first year of maintenance is assumed to be 1961, so the present worth of the costs for 1961 and 1962 is the annual cost times the present worth series factor for n = 2, or 1 833 The annual maintenance cost is assumed to continue until completion of the second stage

[d]Note that the initial (1960) construction has a present worth of its full cost for each year, assumed for the second stage construction

TABLE 3

ESTIMATED AVERAGE DAILY TRAFFIC VOLUME

Vehicle Classification	1960	1962	1964	1966	1968	1970	1972	1974	1976
Project A									
Passenger cars	2,910	3,589	4,268	4,947	5,626	6,305	6,984	7,663	8,342
Single unit truck	30	37	44	51	58	65	72	79	86
Combination vehicles	60	74	88	102	116	130	144	158	172
Total volume	3,000	3,700	4,400	5,100	5,800	6,500	7,200	7,900	8,600
Project B									
Passenger cars	1,965	2,555	3,145	3,735	4,325	4,915	5,505	6,095	6,685
Single unit trucks	210	270	330	390	450	510	570	630	690
Combination vehicles	525	675	825	975	1,125	1,275	1,425	1,575	1,725
Total volume	2,700	3,500	4,300	5,100	5,900	6,700	7,500	8,300	9,100
Project C									
Passenger cars	1,050	1,243	1,436	1,629	1,822	2,015	2,208	2,401	2,594
Single unit trucks	40	52	64	76	88	100	112	124	136
Combination vehicles	50	65	80	95	110	125	140	155	170
Total volume	1,140	1,360	1,580	1,800	2,020	2,240	2,460	2,680	2,900

TABLE 4

AVERAGE YEARLY SPEEDS (MPH), INCLUDING EFFECTS OF GRADES

Year Construction	Project A			Project B			Project C		
	Passenger Cars	Single Unit Truck	Combination Vehicles	Passenger Cars	Single Unit Truck	Combination Vehicles	Passenger Cars	Single Unit Truck	Combination Vehicles
Two-Lane Stage									
1960	55 8	47 5	40 0	56 5	48 7	40 4	56 3	47 0	38 0
1962	55 0	47 2	39 8	55 9	48 0	39 9	56 3	46 9	38 0
1964	54 4	46 9	39 6	54 9	47 3	39 5	56 3	46 8	38 0
1966	54 0	46 6	39 3	53 1	46 4	38 9	56 3	46 7	38 0
1968	53 4	46 3	39 1	50 1	45 3	38 3	56 2	46 5	38 0
1970	52 6	46 0	38 9	45 9	43 7	37 6	56 0	46 4	38 0
1972	51 3	45 5	38 6	42 9	41 8	37 0	55 7	46 3	38 0
1974	49 4	45 0	38 3	41 3	41 0	36 6	55 4	46 1	38 0
1976	47 2	44 5	38 0	40 8	40 7	36 5	55 0	45 8	38 0
Four-Lane									
1960	58 2	48 0	40 0	58 2	49 0	41 0	58 0	47 0	39 0
1962	57 9	48 0	40 0	57 6	49 0	41 0	58 0	47 0	39 0
1964	57 7	48 0	40 0	57 1	49 0	41 0	57 9	47 0	39 0
1966	57 3	48 0	40 0	56 5	49 0	41 0	57 9	47 0	39 0
1968	57 0	48 0	40 0	55 8	49 0	41 0	57 8	47 0	39 0
1970	56 6	48 0	40 0	55 0	48 8	40 8	57 7	47 0	39 0
1972	56 3	48 0	40 0	54 3	48 6	40 6	57 6	47 0	39 0
1974	55 9	48 0	40 0	53 5	48 3	40 3	57 4	47 0	39 0
1976	55 5	48 0	40 0	52 8	48 0	40 0	57 0	47 0	39 0

TABLE 5

TRAFFIC ACCIDENT RATES AND COST OF ACCIDENTS[a]

Type of Accident	Two-Lane Stage Construction			Four-Lane Construction		
	Accidents per 100 Million Veh-Mi	Cost per Accident, $	Cost per 100 Million Veh-Mi, $	Accidents per 100 Million Veh-Mi, $	Cost per Accident, $	Cost per 100 Million Veh-Mi, $
Property damage	50	400	20,000	26	600	15,600
Personal injury	150	900	135,000	125	1,000	125,000
Fatalities	(5.0)	5,000	25,000	(3.3)	5,000	16,500
Total	200	-	180,000	151	-	157,100

[a]See text for sources.

TABLE 6

PROJECT A—YEARLY TOTAL MOTOR VEHICLE DOLLAR COSTS

Year Construction	Passenger Cars				Single Unit Trucks				Combination Vehicles			
	Running	Accident	Time	Total	Running	Accident	Time	Total	Running	Accident	Time	Total
Two-Lane Stage												
1960	383,023	13,574	162,213	558,810	6,225	140	4,908	11,273	31,204	280	14,587	46,062
1962	463,743	16,742	202,946	683,431	7,636	173	6,095	13,904	38,375	345	18,071	56,791
1964	544,840	19,909	243,995	808,744	9,017	205	7,293	16,515	45,506	411	21,601	67,518
1966	626,395	23,076	284,865	934,336	10,396	238	8,511	19,145	52,493	476	25,220	78,189
1968	702,601	26,244	327,608	1,056,453	11,752	271	9,738	21,761	59,531	541	28,831	88,903
1970	776,448	29,411	372,702	1,178,561	13,086	303	10,983	24,372	66,531	606	32,477	99,614
1972	839,732	32,578	423,336	1,295,646	14,364	336	12,303	27,003	73,367	672	36,256	110,295
1974	971,090	35,746	482,368	1,489,204	15,604	368	13,647	29,619	80,172	737	40,094	121,003
1976	937,586	38,913	549,537	1,526,036	16,778	401	15,028	32,207	86,898	802	43,982	131,682
Four-Lane												
1960	403,233	11,847	155,502	570,582	6,310	122	4,856	11,288	31,587	244	14,578	46,409
1962	493,134	14,612	192,808	700,554	7,788	151	5,994	13,933	38,960	301	17,981	57,242
1964	584,658	17,376	230,058	832,092	9,258	179	7,125	16,562	46,334	358	21,384	68,076
1966	671,907	20,141	268,455	960,503	10,736	208	8,263	19,207	53,687	415	24,778	78,880
1968	759,316	22,905	306,905	1,089,126	12,206	236	9,394	21,836	61,061	472	28,181	89,714
1970	843,603	25,669	346,395	1,215,667	13,676	265	10,525	24,466	68,434	529	31,584	100,547
1972	928,841	28,434	385,690	1,342,965	15,154	293	11,663	27,110	75,808	586	34,988	111,382
1974	1,010,609	31,198	426,366	1,468,173	16,624	322	12,794	29,740	83,182	643	38,391	122,216
1976	1,091,508	33,962	467,388	1,592,858	18,102	350	13,931	32,383	90,535	700	41,784	133,019

erence to speed-volume relationships (1), percentage of trucks, and average grade for the project length. The hourly speeds were converted to average annual speeds by the factors given by AASHO (2). The speed of the vehicle is an important factor in determining the running costs per mile. The running costs for each class of vehicle for specific speeds were taken from the Highway Engineering Handbook (3, Sec. 3) for the speeds and the average gradients prevailing.

Accident frequency rates per 100 million vehicle-miles and their unit cost were based on scattered information, published and unpublished, available to the author and adjusted by judgment to the local conditions. The same rate per vehicle-mile was used for all three classes of vehicles. No adjustment in accident frequency rate was made for the increasing average daily traffic. The three projects considered are of the access controlled type, both two-lane and four-lane operations. The literature does not provide adequate accident rates nor accident costs for this type of highway operation. Table 5 gives the basic accident rates from which the accident costs were calculated (4, 5).

Travel time value was based on the following rates for each class of vehicle, including all occupants and cargo: passenger cars, $1.20 per hour; single unit trucks, $3.00 per hour; and combination vehicles, $3.75 per hour.

No adjustment in the vehicle running costs was made for slowdown or stops for the reason that operating data for these items under controlled access for two-lane operation were not available. Vehicular stops under either the two-lane or the four-lane construction would be few in number. The item of comfort and convenience or impedance to uniform driving speed is omitted. This element is largely one of driver perference rather than of economy of vehicle operation Such consideration as is due comfort and convenience should be given outside of the analysis for the relative economy of the alternate proposals.

The total motor vehicle running costs, accident costs, and travel time costs are summarized in Tables 6, 7, and 8 for the three projects for the even years 1960 to 1976. The vehicle running cost for each class of vehicle is greater on the four-lane divided than on the two-lane, two-direction-

TABLE 7

PROJECT B—YEARLY TOTAL MOTOR VEHICLE DOLLAR COSTS

Year Construction	Passenger Cars				Single Unit Trucks				Combination Vehicles			
	Running	Accident	Time	Total	Running	Accident	Time	Total	Running	Accident	Time	Total
Two-Lane Stage												
1960	252,717	8,797	103,804	365,318	42,954	940	32,174	76,068	261,375	2,350	121,195	384,920
1962	318,360	11,438	136,431	466,229	54,378	1,209	41,969	97,556	333,376	3,022	157,774	494,172
1964	390,547	14,079	170,987	575,613	65,500	1,477	52,049	119,026	404,922	3,693	194,807	603,422
1966	446,258	16,721	209,938	672,917	75,980	1,746	62,720	140,446	474,407	4,365	233,760	712,532
1968	489,000	19,362	257,623	765,985	85,775	2,015	74,125	161,915	542,168	5,036	273,952	821,156
1970	521,725	22,003	319,538	863,266	94,394	2,283	87,076	183,753	608,534	5,708	316,254	930,496
1972	562,858	24,645	382,951	970,454	102,251	2,552	101,741	206,544	674,655	6,379	359,195	1,040,229
1974	612,723	27,286	440,518	1,080,527	111,657	2,820	114,650	229,127	741,643	7,051	401,356	1,150,050
1976	668,377	29,927	488,979	1,187,283	121,689	3,089	126,494	251,272	811,062	7,722	440,775	1,259,559
Four-Lane												
1960	262,980	7,678	100,774	371,432	43,398	821	31,975	76,194	267,042	2,051	119,419	388,512
1962	337,424	9,983	132,364	479,771	55,795	1,055	41,109	97,959	343,348	2,637	153,543	499,528
1964	410,728	12,288	164,416	587,432	68,192	1,289	50,243	119,724	419,655	3,224	187,667	610,546
1966	481,279	14,593	197,305	693,177	80,597	1,524	59,383	141,504	495,941	3,810	221,781	721,532
1968	549,022	16,899	231,377	797,298	92,603	1,758	68,517	162,878	572,247	4,396	255,905	832,548
1970	613,161	19,204	266,730	899,095	104,503	1,993	77,981	184,477	646,334	4,982	291,456	942,772
1972	676,908	21,509	302,582	1,000,999	116,796	2,227	87,508	206,531	720,019	5,568	327,333	1,052,920
1974	737,480	23,815	340,014	1,101,309	128,313	2,462	97,320	228,095	791,979	6,154	364,495	1,162,628
1976	797,896	26,120	377,916	1,201,932	139,656	2,696	107,256	249,608	863,231	6,740	402,206	1,272,177

TABLE 8

PROJECT C—YEARLY TOTAL MOTOR VEHICLE DOLLAR COSTS

Year Construction	Passenger Cars				Single Unit Trucks				Combination Vehicles			
	Running	Accident	Time	Total	Running	Accident	Time	Total	Running	Accident	Time	Total
Two-Lane Stage												
1960	100,798	3,515	41,612	145,925	5,968	134	4,749	10,851	18,728	167	9,177	28,072
1962	119,325	4,161	49,260	172,746	7,738	174	6,186	14,098	24,347	218	11,930	36,495
1964	137,851	4,807	56,908	199,566	9,502	214	7,628	17,344	29,965	268	14,684	44,917
1966	156,383	5,453	64,559	226,395	11,263	254	9,077	20,594	35,584	318	17,437	53,339
1968	174,570	6,099	72,342	253,011	12,983	294	10,555	23,832	41,202	368	20,190	61,760
1970	192,274	6,745	80,305	279,324	14,733	335	12,027	27,095	46,821	419	22,943	70,183
1972	209,334	7,391	88,448	305,173	16,458	375	13,496	30,329	52,439	469	25,696	78,604
1974	226,247	8,037	96,714	330,998	18,148	415	15,007	33,570	58,058	519	28,449	87,026
1976	242,213	8,683	105,260	356,156	19,418	455	16,565	36,438	63,656	569	31,193	95,418
Four-Lane												
1960	105,016	3,068	40,401	148,485	5,996	117	4,749	10,862	19,336	146	8,942	28,424
1962	124,156	3,632	47,827	175,615	7,793	152	6,172	14,117	25,136	190	11,625	36,951
1964	143,272	4,195	55,359	202,826	9,590	187	7,596	17,373	30,937	234	14,307	45,478
1966	162,381	4,759	62,802	229,942	11,387	222	9,019	20,628	36,738	278	16,990	54,006
1968	181,381	5,323	70,343	257,047	13,185	257	10,443	23,885	42,538	321	19,672	62,531
1970	200,181	5,887	77,944	284,012	14,990	292	11,872	27,154	48,339	365	22,355	71,059
1972	218,902	6,451	85,532	310,885	16,787	327	13,296	30,410	54,140	409	25,037	79,586
1974	237,008	7,015	93,365	337,388	18,584	362	14,719	33,665	59,940	453	27,720	88,113
1976	253,791	7,579	101,545	362,915	20,381	397	16,143	36,921	65,720	497	30,393	96,610

al operation. For the comparatively low traffic volumes considered, the higher speeds and the resulting higher fuel, oil, and tire consumption on the four-lane divided highway result in higher total running costs than on two-lanes. With one exception, these higher running costs are greater than the resulting lesser time costs at the higher speeds. The results, except for the years 1972 to 1976 in Table 7 for the single unit trucks, are such as to cause the total motor vehicle costs to be greater than on the four-lane divided than on the two-lane operation. The present worths of the motor vehicle costs in Tables 6, 7, and 8 are given in Table 9.

RESULTS

The present worths of the motor vehicle costs and the corresponding present worth of the highway costs are combined in Table 10. The total present worths of all costs, highway and vehicular, are greater for the stage construction than for the four-lane construction for the first few years, as is to be expected. The higher construction cost and the resulting investment charge for the stage construction, when the second two lanes were built soon after the initial two lanes, are in excess of the similar charges for the lesser cost four-lane construction. However, as the date of construction of the second stage is pushed farther into the future, this excess is reduced until it becomes more economical to construct the highway in two stages.

TABLE 9

MOTOR VEHICLE COSTS AND THEIR PRESENT WORTH IN DOLLARS

Construction	1960	1962	1964	1966	1968	1970	1972	1974	1976
Project A									
A Two-lane stage									
Yearly total costs	616,145	754,126	892,777	1,031,670	1,167,117	1,302,547	1,432,944	1,639,826	1,689,925
Present worth of yearly totals	616,145	671,172	707,169	727,327	732,249	727,342	712,173	725,295	665,154
Accumulated present worths[a]	-	1,134,830	2,711,169	4,155,744	5,617,781	7,074,918	8,506,848	9,950,877	11,311,255
B Four-lane									
Yearly total costs	628,279	771,729	916,730	1,058,590	1,200,676	1,340,680	1,481,457	1,620,129	1,758,260
Present worth of yearly totals	628,279	686,839	726,142	746,306	753,304	748,636	736,284	716,583	692,051
Accumulated present worths[a]	-	1,344,398	2,777,030	4,259,560	5,762,669	7,262,275	8,741,019	10,184,035	11,580,403
Project B									
A Two-lane stage									
Yearly total costs	826,306	1,057,957	1,298,061	1,525,895	1,749,056	1,977,515	2,217,227	2,459,704	2,698,114
Present worth of yearly totals	826,306	941,582	1,028,194	1,075,756	1,097,358	1,104,244	1,101,962	1,089,157	1,061,978
Accumulated present worths[a]	-	1,825,526	3,838,608	5,966,339	8,150,254	10,355,299	12,560,364	14,745,080	16,882,625
B Four-lane									
Yearly total costs	836,138	1,077,258	1,317,702	1,556,213	1,792,724	2,026,344	2,260,450	2,492,032	2,723,717
Present worth of yearly totals	836,138	958,760	1,043,752	1,097,130	1,124,755	1,131,510	1,123,444	1,102,226	1,072,055
Accumulated present worths[a]	-	1,856,209	3,901,217	6,068,788	8,304,485	10,564,127	12,815,048	15,030,109	17,189,304
Project C									
A. Two-lane stage									
Yearly total costs	184,848	223,339	261,827	300,328	338,603	376,602	414,106	451,594	488,012
Present worth of yearly totals	184,848	198,772	207,393	211,731	212,440	210,295	205,811	199,740	199,082
Accumulated present worths[a]	-	390,582	801,057	1,222,350	1,646,875	2,068,537	2,482,401	2,884,916	3,272,909
B Four-lane									
Yearly total costs	187,771	226,683	265,677	304,576	343,463	382,225	420,881	459,166	496,446
Present worth of yearly totals	187,771	201,748	210,443	214,726	215,489	213,434	209,178	203,089	195,401
Accumulated present worths[a]	-	396,507	813,045	1,240,355	1,670,951	2,098,846	2,519,330	2,928,552	3,323,198

[a]Accumulated, assuming that the intervening odd year is the average of the two adjacent even years

The year when the money costs of the two plans—stage construction in two-lane stages and complete initial four-lane construction—become of equal choice is shown in Figure 1 at the time point of the crossing of the curves.

At any point in time to the left of the date of crossing of the curves of Figure 1, stage construction would be more costly than immediate four-lane construction; to the right of this date of equality, stage construction would be less costly than immediate four-lane construction. The choice—two-lane stage or four-lane immediate construction—is therefore dependent on whether the traffic volume increases to that volume necessitating four lanes before or after the date of equality of costs.

For the period of years considered, 1960 to 1976, the traffic volume does not increase to the volume necessary to cause marked increases in motor vehicle costs because of slow speed and congestion. Thus, this analysis shows that two-lane economy would continue through 1976, the latest year analyzed. But this indication is without consideration of the limiting traffic volume to retain satisfactory operation.

Useful guides to decision-making obtainable from the type of analysis given in Table 10 are the date of equality of costs and the corresponding estimated average daily traffic volume. As given in the text table on page 74.

TABLE 10

SUMMARY TABLE OF HIGHWAY AND MOTOR VEHICLE TOTAL PRESENT WORTHS IN DOLLARS

Construction	1960	1962	1964	1966	1968	1970	1972	1974	1976
Project A									
A Two-lane stage									
Present worth of highway costs	6,905,300	6,690,100	6,498,700	6,328,300	6,176,500	6,041,500	5,921,500	5,814,500	5,719,200
Present worth of motor vehicle costs	-	1,314,800	2,711,200	4,155,700	5,617,800	7,074,900	8,506,800	9,950,900	11,311,300
Total present worths	6,905,300	8,004,900	9,209,900	10,484,000	11,794,300	13,116,400	14,428,300	15,765,400	17,030,500
B Four-lane									
Present worth of highway costs	5,788,400	5,848,900	5,902,700	5,950,700	5,993,300	6,031,300	6,065,100	6,095,100	6,121,900
Present worth of motor vehicle costs	-	1,344,400	2,777,000	4,259,600	5,762,700	7,262,300	8,741,000	10,184,000	11,580,400
Total present worths	5,788,400	7,193,300	8,679,700	10,210,300	11,756,000	13,293,600	14,806,100	16,279,100	17,702,300
Differences, 4-lane minus 2-lane	(-1,116,900)	(-811,600)	(-530,200)	(-273,700)	(-38,300)	177,200	377,800	513,700	671,800
Project B									
A Two-lane stage									
Present worth of highway costs	3,015,500	2,827,800	2,660,700	2,512,100	2,379,700	2,261,900	2,157,200	2,063,800	1,980,700
Present worth of motor vehicle costs	-	1,825,500	3,838,600	5,966,300	8,150,300	10,355,300	12,560,400	14,745,100	16,882,600
Total present worth	3,015,500	4,653,300	6,499,300	8,478,400	10,530,000	12,617,200	14,717,600	16,808,900	18,863,300
B Four-lane									
Present worth of highway costs	2,423,000	2,455,800	2,485,000	2,511,000	2,534,200	2,554,700	2,573,100	2,589,400	2,603,900
Present worth of motor vehicle costs	-	1,856,200	3,901,200	6,068,800	8,304,500	10,564,100	12,815,000	15,030,100	17,189,300
Total present worths	2,423,000	4,312,000	6,386,200	8,579,800	10,838,700	13,118,800	15,388,100	17,619,500	19,793,200
Differences, 4-lane minus 2-lane	(-592,500)	(-341,300)	(-113,100)	101,400	308,700	501,600	670,500	810,600	929,900
Project C									
A Two-lane stage									
Present worth of highway costs	2,120,100	1,984,200	1,863,200	1,755,600	1,659,700	1,574,400	1,498,600	1,431,000	1,370,800
Present worth of motor vehicle costs	-	390,600	801,100	1,222,400	1,646,900	2,068,500	2,482,400	2,884,900	3,272,900
Total present worths	2,120,100	2,374,800	2,664,300	2,978,000	3,306,600	3,642,900	3,981,000	4,315,900	4,643,700
B Four-lane									
Present worth of highway costs	1,766,400	1,809,600	1,848,100	1,882,400	1,912,900	1,940,000	1,964,200	1,985,700	2,004,900
Present worth of motor vehicle costs	-	396,500	813,000	1,240,400	1,671,000	2,098,800	2,159,300	2,928,600	3,323,200
Total present worths	1,766,400	2,206,100	2,661,100	3,122,800	3,583,900	4,038,800	4,483,500	4,914,300	5,328,100
Differences, 4-lane minus 2-lane	(-353,700)	(-168,700)	(-3,200)	144,800	277,300	395,900	502,500	598,400	684,400

Project	Date of Equality of Costs	ADT
A	April 1969	6,150
B	January 1966	4,700
C	January 1965	1,580

The decision to be made is, of course, what to do now—whether to build four lanes or only two. If the present decision is to build only two lanes, the decision on the timing of the additional two lanes will be made in the future depending on the actual growth of traffic. The foregoing figures indicate clearly that Project C should be built now with only two lanes. If the limiting traffic volume to retain satisfactory operations is approximately 5,000 vehicles per day, there is a slight advantage in building Project B now with only two lanes. On the other hand, immediate construction of four lanes seems to be indicated for Project A.

However, there would be a considerable difference in the result for Project A if the $511,200 cost for interchanges was shifted to the second stage as is provided for in Projects B and C. A higher percentage of the grading, drainage and small structure cost is also included in the first stage of Project A than is included in the other two projects.

SHORT PROCEDURE

The procedure illustrated in the foregoing example on a biyearly basis, 1960 to 1976, results in a comparison of the economy of stage construction over a long continuous period. The year of equality of economy is then easily selected for comparison with the year the traffic forecast would warrant four lanes. This procedure involves the calculation of the present worths of both the highway motor vehicle costs (expenditures) for a series of individual years.

The volume of calculations can be materially reduced by making them for only two specific years. These two trial years should be 2 to 4 yr apart and in the time period when the traffic volume is estimated to be that for which consideration should be given to the need of four lanes or at about the period when it is thought that the present worths of stage construction costs would equal the present worths of the costs of immediate full construction. Two trial years are preferred to one year, because such results will define the trend of the present worths for the two alternates. With the approximate trend established, the decision—two-lane or four-lane initial construction—can be made with knowledge of the year of equality of present worths in relation to the year the traffic volume would warrant four lanes.

Table 11 gives the details of a sample calculation for Project A, using 1968 and 1970 as the test years. The present worths (as of December 31, 1960) are calculated for the yearly highway disbursements, 1960 to 1968 and 1960 to 1970, for both stage construction and immediate four-lane construction and for all motor vehicle costs incurred yearly during the same two periods.

The final answers are in reasonable agreement with the results of the biyearly continuous analysis. The results would agree exactly, except that in the short procedure the motor vehicle costs were approximated and assumed to be identical per vehicle-mile for each year 1960 to 1970.

At least for a preliminary check, this short procedure does well. But even a still shorter and quicker check can be made by considering only the highway costs. Such a method is not far in error when the conditions are such that there is but a small difference in motor vehicle costs between operation on the first stage of construction and on immediate complete construction.

The results of the long procedure are compared with the results obtained by using only the highway costs in Table 12.

When using highway costs only, should the dates of equality of present worths of the two construction plans be near to the year when the traffic volume would warrant the additional lanes, a more precise analysis could be made.

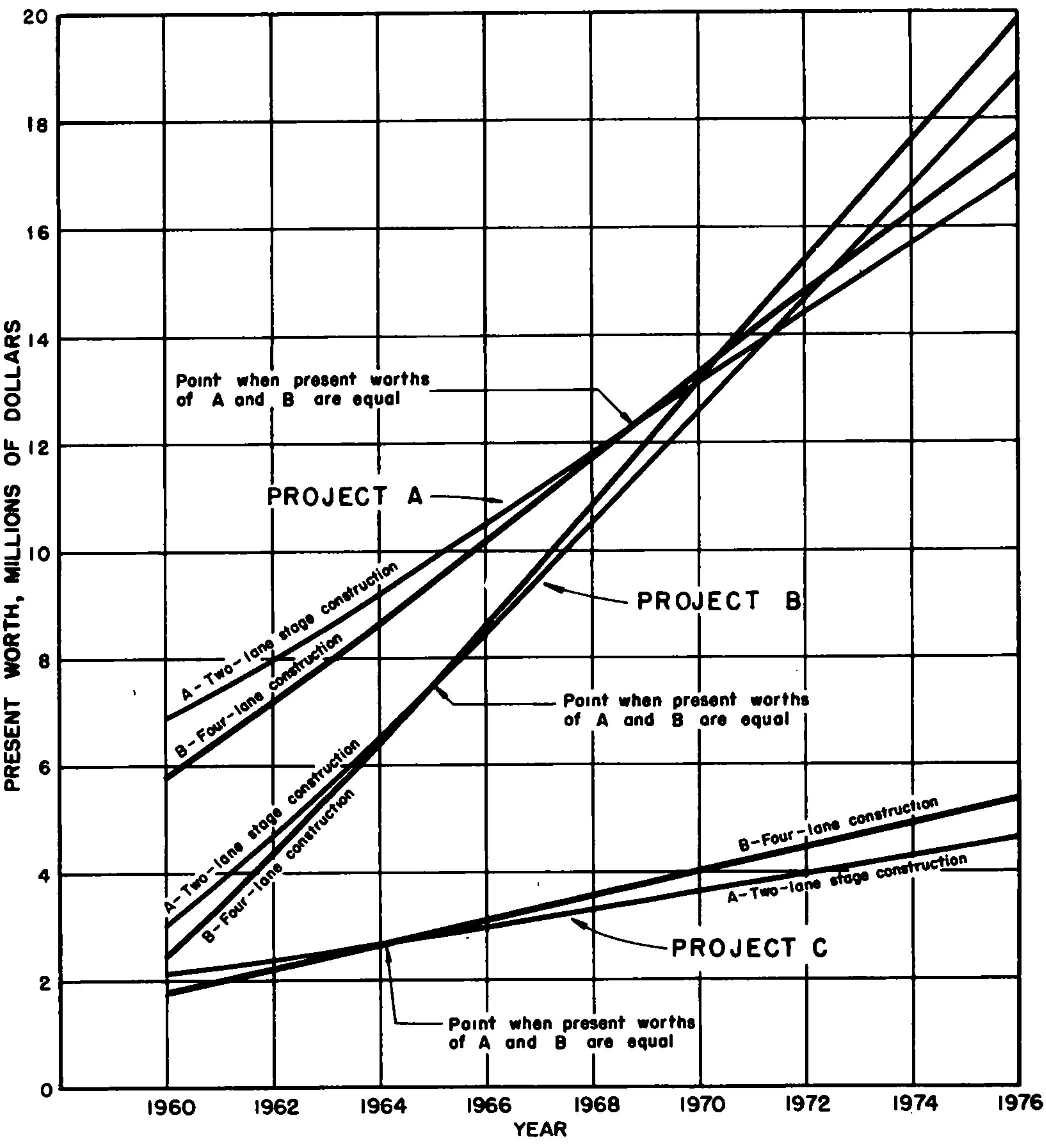

Figure 1. Curves of the present worth of the total highway and motor vehicle costs for, A, two-lane stage construction and B, four-lane immediate construction.

A GENERALIZED SOLUTION

The economy of stage construction for any proposal may be expressed in present worth terms by the following equation in terms of an equality of cost between constructing the whole project initially and constructing it in two stages:

$$C + M(spwf) + V(spwf) = S_1 + M_S(spwf) + V_S(spwf) + S_2(pwf)$$

TABLE 11

CALCULATION OF PRESENT WORTHS BY SHORT APPROXIMATE METHOD—PROJECT A

Construction	1968	1970
Two-Lane Stage		
1. Present worth of highway costs (same as given in Table 2)	$ 6,176,507	$ 6,041,545
Present worth of motor vehicle costs		
2. Motor vehicle costs, cents per mile	7.75	7.75
3. Total vehicle-miles of travel	15,030,700	16,844,700
4. Annual increase in vehicle-miles	907,000	907,000
5. Annual increase in vehicle costs	70,300	70,300
6. Factor (6%) to convert annual increase in motor vehicle costs to equivalent equal annual sum[a]	3.20	4.02
7. Equivalent equal annual motor vehicle costs	$ 224,960	$ 282,600
8. 1961 motor vehicle costs, dollars, $672,800	-	-
9. Total equivalent annual motor vehicle costs (1961 costs plus equivalent annual increase)	$ 897,760	$ 955,400
10. Present worth series factor (6%)	6.210	7.360
11. Present worth of motor vehicle annual costs	$ 5,575,100	$ 7,031,700
12. Present worth of highway costs and motor vehicle costs	$11,751,600	$13,073,200
Four-Lane		
13. Present worth of highway costs (same as Table 2)	$ 5,993,330	$ 6,031,280
Present worth of motor vehicle costs		
14. Motor vehicle costs, cents per mile	8.0	8.0
15. Annual increase in vehicle costs	$ 72,560	$ 72,560
16. Equivalent equal annual motor vehicle costs	$ 232,200	$ 291,700
17. 1961 motor vehicle costs, $694,500	-	-
18. Total equivalent equal annual motor vehicle costs	$ 926,700	$ 986,200
19. Present worth of motor vehicle costs	$ 5,754,800	$ 7,258,400
20. Total present worth of highway and motor vehicle costs	$11,748,100	$13,289,700
21. Difference, 4-lane minus 2-lane	$ 3,500	$ 216,480

[a] See Grant and Ireson, "Principles of Engineering Economy," Table E-23, page 560, Ronald Press, New York, 1960.

in which

C = total construction cost of constructing entire project now;
M = annual maintenance and operating costs of total project, C;
V = motor vehicle costs per year on complete construction, C;
spwf = series present worth factor from compound interest tables;

S_1 = construction cost of first stage;
M_S = annual maintenance and operating costs of S_1;
V_S = total motor vehicle cost per year on S_1;
S_2 = construction cost of second stage; and
pwf = single payment present worth factor from compound interest tables.

TABLE 12

COMPARISON OF RESULTS BY THE COMPLETE PROCEDURE WITH RESULTS USING HIGHWAY COSTS ONLY

	Approximate Date of Equality of Present Worth of Costs	
Project	Total Highway Plus Motor Vehicle Costs	Highway Costs Only
A	April 1969	February 1971
B	January 1966	January 1967
C	January 1965	March 1965

The solution of this equation is by trial to find the number of years that will produce an equality. As an alternate solution, the equation can be solved for the number of years required in traffic growth to make the construction of the second stage desirable. At this number of years the greater economy will be indicated by the side of the equation having the smaller value. The vehicle costs under increasing daily traffic volumes should be computed on the basis of equivalent equal annual costs for the number of years for which the equation is solved.

The equation may be rewritten, as follows:

$$(C-S_1) + (M-M_S)\ (spwf) + (V-V_S)\ (spwf) = S_S\ (pwf)$$

In this form the relationships of C, S_1, and S_2 are more readily apparent. In fact, neglecting highway maintenance costs and motor vehicle costs, the equation can be generalized to fit any combination of C, S, and S_2:

$$(pwf) = \frac{C - S_1}{S_2},$$

from which the number of years to produce an equality of present worths can be found directly from a compound interest table by reading the "N" periods which produce a present worth factor equal to the ratio of $(C - S_1)$ to S_2. This ratio will always be between 0 and 1.

As an example for project A,

$$(pwf) = \frac{5,788,400 - 4,566,000}{2,339,300} = 0.523$$

The ratio, 0.523, corresponds to an N period of slightly less than 11 yr at a 6 percent interest rate per annum. Considering only highway construction costs, the year of equality of the economy of stage construction and immediate complete construction would be 1971. For comparison, the previous complete solution gave April 1969.

DISCUSSION AND EVALUATION

This present worth solution has been based on the break-even date of stage construction compared to initial complete construction of all four lanes. This solution is not to be used as a justification of constructing the project itself, or as an analysis of all the possible alternatives.

As indicated at the beginning of this paper, the economy of delaying the construction of the second two lanes of a four-lane Interstate project depends to a large extent on how much of the final construction, other than the paving, can be delayed to the second stage and still produce, in the meantime, a two-lane highway with acceptable operating conditions. The other factor of importance is how rapidly the total traffic volume is forecasted to increase. An examination of the factors involved in this solution will provide a basis for evaluating the results.

In Tables 6, 7, and 8, it is evident that the cost of travel time of operating motor vehicles is about one-third of the total costs of vehicular travel. Further, it is evident from these tables that year to year the cost of travel time on the two-lane construction is greater than on the four-lane construction, whereas the running costs of motor vehicles, in general, is greater on the four-lane operation. Thus, the value of the decreased running time on the four-lanes would have to be greater than the increased running cost of the vehicles on the four-lane construction as compared to the two-lane construction in order that the total vehicular cost would break even. Actually, Tables 6, 7, and 8 show that the total vehicular costs are higher on the four-lane construction than on the two-lane stage construction. This greater cost prevails because the increased speeds on the four-lane construction cause increased running costs in excess of the value of the reduction in travel time for the pasenger cars.

Time for passenger cars in this analysis was computed at $1.20 an hour or 2 cents a minute. Table 13 compares the running costs of passenger cars at a range in speeds with the travel time, and shows what the value of the increment of time for 5-mph speed changes would have to be in order that the increment of time saved would have a value equal to the increased operating costs of the vehicle at the higher speed. For an increase in speed from 50 to 55 mph, the value of passenger car time would have to be 3.69 cents a minute in order that the traveler's value of time would compensate him for the increased running costs of his vehicle. When increasing the car speed from 25 to 30 mph, the value of time in order to compensate for increased running costs would be only 0.042 cents per minute.

From these figures it is evident that the value of time plays an important role in any analysis of the engineering economy of highway design so far as it affects the travel of automobiles. At the higher speeds (above 45 mph) the time saved is not only a small amount when increasing speed, but this time saved would have to be priced at a high value per minute to compensate for the increase in vehicular operation costs attributed to the change in speeds.

This whole analysis of the economy of stage construction vs initial complete construction is designed for the purpose of aiding management in making a decision as to what to do now. Future decisons are completely ignored. This factor is an important element to consider. Once the first stage of two lanes is completed, a future analysis on the relative economy of continuing to use the two lanes or building the two additional lanes would require that the cost of the initial two lanes be considered as a so-called "sunk cost." The construction of the two additional lanes would have to be justified on a basis of economy of the operation of traffic over the then existing two lanes as compared to operation over a proposed four-lane facility. In order that such construction of two additional lanes would prove economical, a real high traffic volume would have to prevail; in fact, the traffic volume would have to be so high and resulting speed so low that the combined running cost and time cost would justify the construction of two additional lanes of highway.

A word is in order about the discount rate (interest rate) of 6 percent used to bring all costs to a common date. This rate is perhaps the minimum that should be used in an analysis of this type. Grant recommends a 7 percent rate per annum for highway economy studies (6).

It is to be remembered that the discount rate to use is not that for which money could be borrowed on bonds, for the consideration is not one of the cost to finance, but one of general economy to the citizens who, in the end, furnish the money for highway construction. Although the risks are not great with respect to the future usefulness of highway construction, the future is not certain. Something in excess of a pure interest rate is certainly justifiable in an analysis of this type. The rate is important because the higher it is, the less the present worth of future disbursements. With a rate of zero percent and neglecting maintenance costs, there would never be justification of building a project in stage construction, provided the total stage construction would cost more than initial complete construction.

TABLE 13

DIFFERENCES IN RUNNING COST OF PASSENGER CARS AT A RANGE OF SPEEDS REDUCED TO EQUIVALENT VALUE OF TIME

Speed	Running Cost/Mile (cents (3))	Minutes per Mile	Minutes Saved per Mile at 5-MPH Higher Speed	Increased Running Cost (¢/Mile)	Time Value, ¢/Minute to Equal Running Cost Increase
10	4.093	6.00	-	-	-
15	3.861	4.00	2.00	-0.231	-0.115
20	3.725	3.00	1.00	-0.136	-0.136
25	3.681	2.67	0.33	-0.044	-0.133
30	3.709	2.00	0.67	0.028	0.042
35	3.793	1.71	0.29	0.084	0.29
40	3.942	1.50	0.21	0.149	0.71
45	4.165	1.33	0.17	0.223	1.31
50	4.472	1.20	0.13	0.307	2.36
55	4.878	1.09	0.11	0.406	3.69
60	5.402	1.00	0.09	0.524	5.82
65	6,084	0.92	0.08	0.682	8.52
70	6.995	0.86	0.06	0.911	15.18

In the analysis presented, certain elements which possibly should be considered in a more rigid analysis have been omitted. These items include the following:

1. Because of progress in highway design and construction, there is some benefit to delaying construction as long as it can be delayed. Thus, the second stage of two lanes might be of better design at the time it was constructed than would the four-lane design built in 1960.
2. During a course of construction of the second stage, certain traffic interferences would occur. These interferences would be a cost to the highway users and thus a charge against the second stage in favor of building all four lanes initially.
3. Perhaps it would take a longer time period to construct initially the four complete lanes than it would to construct only the two lanes. If so, there would be advantage in constructing only the first stage of two lanes because the advantages of the new highway would accrue to the traveling public at an earlier date.
4. It is probable that the annual maintenance and operating costs of the highway would increase somewhat with age of the highway. Any such increase is ignored in the analysis in favor of using a uniform annual maintenance cost for each period considered.
5. Any difference in the rate of growth of traffic volume attributed to the fact of having for the initial period only two lanes as compared to four, might be a factor. Perhaps the four lanes would attract a greater number of vehicles than would the two lanes.
6. Any difference in potential service life of the two lanes of pavement carrying the full volume of traffic as compared to carrying the same traffic volume on the four lanes could be a factor.
7. Rightfully, an interest charge during construction would be an element of cost. For convenience, however, it is omitted in the analyses given herein.
8. There is no consideration given to any changes in price levels that may occur in the future. Should rights-of-way not be purchased for the full development of four lanes at the time of construction of the initial two lanes under stage construction, it would be proper to take into consideration any reliable estimates of the future costs of

rights-of-way. Inflation—the decreasing purchasing power of the dollar—as such, however, is not an item to include, because the incomes (benefits) would be affected by the same forces of inflation. Price level changes to consider should include only those attributed to the forces of competition, changes in technology and management, using a constant value of the dollar.

CONCLUDING STATEMENTS

A rigid analysis of the economy of a proposed stage construction of a highway project requires more precise and reliable motor vehicle running and accident costs than are now available for the particular highway conditions. In view of the increased costs with speed of vehicle operation, many highway improvements bring higher motor vehicle unit running costs but at a saving of time. Therefore, motor vehicle economy comes from the value placed on time as well as on reduction in motor vehicle running costs. The unit value of travel time is an important factor. As yet, the literature does not contain estimates of the value of highway travel time that are based on anything more than some individual's assumed value (7, 8).

No general statements are warranted as to the traffic volume, present and estimated future, required to make two-lane stage construction preferred economy. Each project must be analyzed according to the prevailing factors and possible alternates. The type of analysis presented herein is a reliable procedure and will give results correct within the degree of applicability of the highway costs and motor vehicle costs used in the analysis.

This paper devotes but little attention to the traffic and highway design features of stage construction, and to just what elements would be built in each stage. Nevertheless, such consideration should be given great weight in reaching the decision on whether to adopt stage construction. The analysis should be made for several alternatives of designs for each stage construction.

The general procedure presented herein is applicable to any proposal for stage construction. Although applied to proposals for Interstage highway projects on new rights-of-way, the method applies equally well for reconstruction of highways or other facilities.

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Economic Concepts of Highway Planning

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The paper discusses (a) the micro-economic treatment of highway projects, defined as the smallest units of decision-making; (b) program analyses where system effects, compatibilities and incompatibilities of various projects in time or space have to be resolved; and (c) the micro-economic reconciliation of highway claims for resources with possible other demands for them. The analysis aims at rational resource allocation and attempts to provide economic criteria for the solution of broad transportation problems; for example, in a regional or metropolitan context.

●IT IS THE purpose of this paper to inquire into the usefulness and limitations of economic concepts in the highway field. Economic abstractions under fairly rigorous assumptions are presented. Any practical examples used in the text are meant as illustrative and should therefore be regarded as incidental to the main theoretical theme. At the same time, the concepts put forward are designed for practical application to the many important highway decisions which now must be made.

There is an urgent need to employ the best possible economic tools in highway decision-making all the time. In 1959, for example, public highway expenditures alone amounted to an estimated $10.5 billion (1). The magnitude of all private and public spending on highway transportation currently may be approximately $75 billion per year. The size of this segment of the economy and the causal relationship between governmental and private action impose special responsibilities on the public decision-makers in the highway sphere.

Specifically, this paper carries the discussion into the urban transportation sphere. The 184 metropolitan areas in the United States contain 66 percent of the population and 70 percent of all industrial workers, and it is said that these regions "are being strangled by congestion." (2, p. 52) About 25 percent of all highway-user tax proceeds were spent in urban areas in 1958, whereas in 1946-47 this proportion was only about 10 percent. It is generally predicted (3) that the big conurbations will attract increasing shares of the population in the years to come; there may be 30 Standard Metropolitan Areas in 1980, as compared with 14 in 1950, with populations of more than 1 million; by 1980 the New York-Northeastern Standard Metropolitan Area alone may comprise some 20 million inhabitants.

Massive and complex metropolitan transportation problems will have to be solved in future years, especially in the passenger transportation segment. The interactions between highway transportation and many social, political, esthetic and other wider aspects of urban life are particularly powerful. Thus, there is every reason to make sure that the economic tools are equal to these tasks.

OBJECTIVES AND ASSUMPTIONS

Economic Objectives

Economic objectives in transportation are stated succinctly and authoritatively in the recent U.S. Department of Commerce report on transportation to the President:

> The Nation requires policies which will encourage maximum efficiency in the performance of the transportation function. A part of the cost of nearly all goods and services purchased by the public represents payment for transportation of one kind or another. Hence a reduction in the cost of transport enhances the national product and enlarges the opportunities of all the consumption of direct goods and services...At a given level and structure of capital investment, efficiency requires that traffic be distrubuted among (different carriers) in such a way that each type receives the traffic which it can carry with the least consumption of resources by the carrier for the service standards required by the user. It requires also that several forms of transport be used in coordination where such a combination can produce a better service-cost result than any single form working alone. (4)

Efficiency requires, the report postulates, that transport services of a given standard be performed with the least consumption of resources. Therefore, two aspects must be considered by the analyst: resource consumption, or cost; and service standards, or the right service quantity-quality admixture. If transportation of the same or higher service standards can be performed at lower cost, resources can be put to better use in fields other than transportation. The prices such resources command in the market place provide a good index for their usefulness in alternative employments. Therefore, the opportunity costs of resource use for highway or other transportation purposes must be considered.

How is it possible that "a reduction in the cost of transport enhances the national product?" Is transport not part of the national product, so that when one increases in dollar magnitude, the other does too? The staff study which accompanies the report states: "The transportation service is not, for the most part, an item of direct consumption. It is a facilitating service required in connection with virtually all production throughout the economy." (2) The transportation function is seen as a means to an end, but not as an end in itself. If it can be performed satisfactorily at lower costs, that much more resources are available for the consumption of direct goods and services. The study mentions that beneficial multiplier effects may result from transport cost reductions. The national product will be enhanced if resources can be spared from transportation (a facilitating service) without impairing its performance, and can be put into the production of direct consumption goods.

Simultaneously with costs, quantity and quality of service have to be taken into account. The constraint is "service standards required by the user." This raises questions: Who determines these requirements? Is "desired" the same as "required"? Granted that identical service performance at lower cost is an unequivocal efficiency improvement, how can one judge the merits of a higher service standard at higher cost, or of lower service standards at lower costs? The analyst's task is greatly eased when a definite requirement for a certain quantity and quality of necessary transportation services can be assumed. This may be applicable to the typical metropolitan passenger transport situation. The objective then simply becomes performance of the given task at minimum cost.

Assumptions

The following general assumptions are made:

1. Resources are scare relative to the possible uses for them. This is a basic assumption in economics and gives meaning to the efforts to economize.
2. Expenditures on highway transportation—as compared with expenditures on other things—are not presumed to have any special employment-creating or other beneficial macro-economic effects. There would have to be evidence for the superior Keynesian multiplier repercussions of investment in highways, as compared with investment in other transportation facilities, hospitals, schools, housing, private enterprises, etc.,

before these could legitimately be considered in the analyses. If there were unemployment of specific highway transportation resources, coupled with a signal lack of mobility of such resources for switching to other fields, these special conditions would normally be reflected in lower factor prices. They would thus be taken care of automatically in the analyses.

3. There is one public agency in charge of transportation matters within the metropolitan region or other area under study. This agency is sovereign within its jurisdictional boundaries. Efficiency of the appropriate administrative organs is guaranteed. In short, it is assumed that the necessary institutional and administrative arrangements can be made to carry out policies which were found desirable on analytical grounds. (These assumptions conveniently remove many intricate aspects of inter-governmental responsibilites, grant-in-aid procedures, integrity, competence and organizational efficiency of various levels of public authority, etc., from the scope of this paper. It is felt that these complex and important questions can best be dealt with by means of specific case studies.)

4. The chosen metropolitan or other transportation agency has as its objective the promotion of the public interest. Such public interest is whole and indivisible within the authority's geographic area of jurisdiction. Whenever there is conflict of interests, different functional and sectional groups (users and non-users, suppliers and consumers, private and public organizations, business and non-commercial factions) are given impartial consideration.

5. The chosen public agency will consider all important effects of possible actions No repercussions will be ignored or rejected by the engineering and economic analysts just because other disciplines are involved. This assumption is in accordance with the tenet of scientific method that all pertinent evidence must be brought to bear upon the problem on hand.

6. Reliable field data will be obtained.

7. The metropolitan decision-makers have no vested interests or prejudices in favor of public or private ownership of factors of production, nor in favor of one particular technology. There is no preconceived notion, for example, that driving in automobiles by itself is good for the economy and constitutes the proper metropolitan way of life. Proposals are considered strictly on the basis of their merits as revealed by unbiased analyses.

CONCEPTS AND DEFINITIONS

It will be convenient to divide the wide spectrum of decision-making authority of an assumed metropolitan transportation authority into definite, somewhat arbitrary, segments (Table 1). In accordance with assumption 5, all important effects of possible actions by the transportation agency will have to be considered. Therefore the broadest possible definitions of "costs" and "gains" apply. The various values that will enter into the analyses are categoried in Table 2. The terms "costs" and "gains" are self-explanatory: the former denotes all the undesirable effects one wishes to minimize; the latter, all the desirable effects one wishes to maximize.

Internal and External Values

Within the dichotomy of costs and gains, the distinction between internal and external values is made by defining the viewpoint, or planning horizon, or area of interest and responsibility, of the particular decision-maker. In accordance with assumption 4, the hypothetical metropolitan transportation agency under discussion is charged with the promotion of the entire, indivisible metropolitan public interest. Therefore, all cost and gain effects set up by its actions will be internal to the agency's viewpoint and will be taken into account for decision-making.

Why, then, make a distinction between "internal" and "external" effects at all? This distinction arises entirely from the location and delegation of authority. It is difficult for the human mind to comprehend all at once a great number of interrelationships. To do one's daily work with reference to so vague a concept as the national public interest, or even the geographically more limited metropolitan public interest seems quite impractical. Therefore, engineers, analysts, technicians working at the project level of decision-making are normally not required to worry about program, activity or general economic effects. Repercussions resulting from the construction of a particular highway and imposed upon the rest of the highway program, upon transportation as a whole and the community or region, will be regarded by the project engineer as being of no concern to him, as external to his viewpoint. But just because these effects are regarded as external from the very limited project viewpoint, does not mean that they can be ignored. They simply have to be analyzed at a higher decision-making level. Similarly, in private enterprise, the foreman or engineer in the shop will rarely be concerned with higher-level problems, such as personnel policy, investment strategy, budgeting, research, and public relations; but these vital aspects will certainly be studied and resolved at the company level.

In short, what may be external from the point of view of the project, will still be internal in some fashion to technology, or activity, or economy. As a mental image, it is perhaps useful to think of the various cost and gain effects set up by an action as being contained in various ways by boxes; these are little boxes (projects), within bigger boxes (programs or technologies), within still bigger boxes (activities), within one ultimate box (the economy). The choice of box to be examined analytically will determine the designation of effects to the external or internal categories.

By assumption, decision-making authority is put at the highest level, that of the metropolitan economy. This is a highly centralized, over-all planning approach within a limited geographical area. It is certainly possible to quarrel with this assumption. It might be argued that it is better, in the interest of efficiency, enterprise and staff incentive, to set the viewpoint at a lower level, for example at the program or technology level. Then planning carried out by a highway department, for instance, would simply ignore repercussions of actions upon other transportation media and upon the economy as a whole, as being external to the viewpoint and therefore of no concern to the decision-makers.* Some public agencies, in real life, appear to take this more restricted approach. If this is the case, it should be clearly stated that this is planning in the interest of the highway or other technology, and not necessarily in the general transportation or public interest. The author happens not to agree that this limited approach is appropriate for governmental agencies, simply because he believes that the public interest should not be broken down into narrow sections and technologies in this way. But there is room for honest differences of opinions, which would here simply affect the assumptions, but not the analyses themselves; if the planning and decision-making horizon is limited to program or technology, transportation and general economy costs and gains will simply be regarded as external to the viewpoint and therefore omitted from all subsequent considerations. In fact, in the present study,

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*There is frequently some confusion of public enterprise with the image of competitive private enterprise. In terms of Table 1, the individual firm can be seen to take a technology or program viewpoint, by carefully planning projects (internal processes, products, subsidiary operations, etc.), ignoring effects upon competitors (activity or industry repercussions) and the rest of the economy. Hence, why should, say a public highway department not act in the same way? This rather naive view of things ignores a number of crucial points: (a) private enterprise, precisely because of its competitive behavior--elaborately defined--is supposed to further the public interest; (b) violations of the "rules of the game" by private enterprise (e.g., infliction of external costs on the community, or anti-trust law infractions through "planning" by firms at the activity or industry level) are penalized by public action; the rendering of incidental beneficial effects (external gains) is frequently rewarded through public subsidies; (c) highway departments and other public enterprises simply do not operate within a competitive environment, as defined; indeed, the absence of the conditions necessary before private enterprise can flourish in the "public interest" led to assignment of these functions to public enterprise in the first place; the lack of penalties (immunity from anti-trust laws) and profusion of subsidies, tax exemption, and other favors calls for a doubly cautious approach. The author believes that the correct economic "model" for, say, a highway department is that of a powerful public monopoly.

TABLE 1

LEVELS OF DECISON-MAKING

Project: Smallest technical unit which can fulfill desired service objectives. For example, a complete highway connection, a complete overpass, a complete subway installation; but not partial project construction, such as grading, bridge abutment building, tunnel excavations, by itself.

Program or Technology: A number of projects which are interrelated by technical, functional and economic factors. For example, a highway network, or a subway system, or a series of interrelated construction projects planned over a period of time in a given area.

Activity: Projects and programs seen within the context of transportation as a whole.

Economy: Consideration of all activities within the jurisdictional boundary lines; in this case, the metropolitan economy.

TABLE 2

VALUE CATEGORIES AND DEFINITIONS

COSTS: Total costs, efforts, sacrifices, inputs, means, losses, outgoes.
- Internal: Internal to viewpoint, objectives, responsibilities of decision-maker or analyst; incurred by project (program or technology, activity) itself.
  - Market: Costs satisfactorily expressed by market prices; acceptable money costs.
  - Non-Market: Other costs.
- External: External to viewpoint, objectives, responsibilities of decision-maker or analyst; incurred outside project (program or technology, activity).
  - Market: Costs satisfactorily expressed by market prices; acceptable money costs.
  - Non-Market: Other costs.

GAINS: Total revenues, benefits, rewards, outputs, ends, proceeds, incomes.
- Internal: Internal to viewpoint, objectives, responsibilities of decision-maker or analyst; accruing to project (program or technology, activitity) itself.
  - Market: Gains satisfactorily expressed by market prices; acceptable money revenues.
  - Non-Market: Other gains.
- External: External to viewpoint, objectives, responsibilities of decision-maker or analyst; accruing outside project (program or technology, activity).
  - Market: Gains satisfactorily expressed by market prices; acceptable money revenues.
  - Non-Market: Other gains.

first a project viewpoint is adopted, which initially ignores repercussions external to that particular horizon. Only later, for convenience of exposition, are the wider interactions studied. It is thus up to analysts how far they wish to go in their studies.

Market and Non-Market Costs and Gains

The market and non-market value categories may next be scrutinized. The distinction arises from the measurability or non-measurability of effects for purposes of economic analysis. Difficult concepts are involved and some words of explanation necessarily brief are in order. Following Schumpeter's exposition (6, pp. 1060n and 1062n), a quantity or magnitude is defined as anything that is capable of being greater or smaller than some other thing; this implies only transitivity, asymmetry, and aliorelativity. Measurability, on the other hand, requires the fulfillment of two more conditions: (1) that it be possible to define a unit; and (2) that it be possible to define addition operationally, so that it can actually be carried out.

Non-measurability is acceptable if one is interested in a maximum problem. As Schumpeter points out, there are ways of telling whether one is on top of a hill without actually measuring the precise elevation of the spot. Likewise with a minimization problem. This is of some practical significance, as will be seen. Turning to measurability, it should be observed that generations of economists have given much time and thought to this aspect, especially in relation to the Theory of Utility. At first it was held that utility sensations, or the pleasantness and unpleasantness of sensations, could be measured directly, as a sort of psychic reality, in the same way perhaps as length can be measured. Later, Marshall adopted the much weaker assumption that, though "we cannot measure utility or 'motive' or pleasantness of sensations directly, we can measure them indirectly by their observable effects, a pleasure for instance by the sum of money a man is prepared to give up in order to obtain it rather than go without it." (6, p. 1060) An analogy might perhaps be the measuring of heat with a thermometer. These two approaches, direct and indirect measurability, are generally known under the name of "cardinal utility theory." Further developments resulted in various versions of the theory of ordinal utility, which embraces the indifference curve apparatus and the system of marginal rates of substitution. When employing these newer economic tools, the analyst enjoys independence from measurability of utility, inasmuch as there are just scales of preferences: (a) the consumer considers certain combinations of, say, two commodities as equally eligible; these are shown on the same indifference curve; (b) he prefers combinations on a higher indifference curve.

What is the relevance of these theoretical concepts to transportation problems in general and to the values shown in Table 2 in particular? It is submitted that the so-called "benefit"* analyses in the highway field are really cardinal utility efforts, some of them of Marshallian parentage, some of them of pre-Marshallian ancestry. Highway benefit-cost calculations now constitute one of the major intellectual links between the engineer and the economist in this field. Although the enthusiasm of the technical group for economic concepts is laudable, some of the serious shortcomings and limitations of these tools must be pointed out.

Few, if any, economists would maintain nowadays that one can directly measure (cardinal) utility and disutility. Let us consider the indirect measurement of utility, which is achieved by observing the amount of money persons are prepared to surrender in various situations. Here, it should be noted, rather stringent conditions must be fulfilled before money outlay is acceptable as an indirect measuring rod for sensations which cannot be measured directly. In particular, the notion of the market transaction has been evolved by economists. Money outlays or prices are said to be true expressions of value when the exchange of goods and services between sellers and buyers takes place under competitive market conditions; that is, when (a) there are many buyers and sellers bargaining freely, (b) each one of them has equal knowledge of what is going on, (c) the goods or services exchanged are identically similar, and (d) no single buyer or seller can influence the market price. But even if some sorts of price signals come through, there may be, as Ciriacy-Wantrup (7) points out, serious distortions at work (for example, if an equalitarian society is held to be desirable, on ethical or political grounds, price signals received from rich people would be considered to be too strong and those from poor people too weak), monopolistic, duopolistic, etc., market organizations, heavy advertising, and other imperfections, would also be the cause of warped price signals.

Consequently, market values are spoken of when reliable price signals are being received and can serve for indirect measurement. Non-market values, on the other hand, indicate that either there is no market at all, or the price signals are seriously distorted.

To be sure, the analyst will undoubtedly encounter mixtures of both market and non-market values when the merits of particular highway proposals are being studied by him. Following a cardinal utility approach, which in itself has its drawbacks the dollar magnitudes of market value items may serve as indirect measurements for the desirable and undesirable effects of contemplated action. But what about non-market value items? Quite clearly, lacking the dollar yardstick, decisions will have to be based on what is generally known as "value judgment." This term conveniently embraces various shades of meaning. It may mean that an ethical judgment is involved—some action is held to be good or bad and any further discussion has to proceed on

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*The expression "gains" is preferred here for teminological and definitional convenience. Benefits normally denote desirable effects other than money revenues, whereas gains in this study embrace all beneficial repercussions. Besides, because of loose use in the literature, benefits have acquired a somewhat doutbful reputation of late.

grounds of moral principles. It may also mean that the judgment is a subjective one, or at least questionable or debatable, as perhaps in the case of an aesthetic judgment.

How to deal with the sometimes very elusive non-market items and how to render the best possible value judgments, are matters of very grave concern in the urban transportation field. Following are some suggested practical approaches:

1. Market and non-market values are stated separately in the analysis, the former in dollars, the latter in words. For example, a freeway might set up these effects: market costs (money construction and operating costs) $1.2 million, market gains (cash user revenues) $1.4 million, quality of service gains "good," accident effects "considerable." With reference to the earlier discussion on cardinal utility, it should be noted that only the market values are employed for indirect measurability. The quality and accident effects are appropriately stated as non-measurable quantities. It is not possible to define addition operationally, therefore cash costs and gains, accidents, quality of service cannot be aggregated. A value judgment will eventually have to be rendered for decision-making purposes.

2. As an analytically fortunate variation, consider that two projects A and B are to be compared. Project A has the characteristics of the freeway previously described, project B these: market costs $1 million, market gains $1.5 million, quality of service gains "excellent," accident effects "slight." Clearly, project B is to be preferred on all counts. (Note that the search for alternative solutions is all-important here.)

3. A further variation of this is equality of some values, and superiority in one respect. For example, if B is identical to A in all respects, except that it would result in "slight" rather than "considerable" accident effects, it should be the logical choice.

Of course, as soon as there are more complex situations—one project better in some respects, worse in others—value judgments will be required for final decision-making.

4. Non-market values are translated into precise physical, but not into money terms. This is essentially the same as items 1, 2 and 3, because the separate quantities (which now have units for counting) can only be aggregated (or weighted) for decision-making by further value judgment. The advantage is that performance units are clearly stated, so attainment or performance can, ex post, be checked from time to time. This may cause the field analysts to work more conscientiously.

5. Going a step further and converting non-market values, whether stated in words or in precise physical terms, into dollar figures. Such outright translation might be condoned on occasion when non-market effects form a very small proportion of total costs and gains.

It might be argued that complete conversion into dollar values would greatly simplify the remaining analytical task. The viewpoint might further be put forward that this procedure should be employed in a money-oriented society if at all possible, because money will be the language most easily understood.

It must clearly be borne in mind, however, that any such conversion lacks support by generally acceptable economic standards (market price) and therefore definitely requires value judgment. Conversion into money figures may obscure important moral issues (highway accident deaths) and may lead to poor decisions for this reason.

6. If the above methods have been exhausted, there is no getting away from the fact that some value judgments have to be made somewhere. The practical working principle for the analyst is that complete, detailed evidence—in whatever form it is submitted—will contribute greatly to intelligent decisions. The analyst's professional information should be purged of his personal value judgments. This does not mean that in addition he, as a citizen of integrity, intelligence and knowledge, may not submit his considered ethical, social, aesthetic, or other views. Indeed, complete detachment—"this is for the politicians to decide"—in itself constitutes an extreme value judgment.

7. The value judgment and decision-making powers will finally have to be entrusted to a person or a group of persons. These powers may be given to elected or appointed officials, or to a committee. Alternatively, and outside expert may be retained and some of the value judgments will be made by him. As a further possibility, the value

judgments can be shifted to the general populace, through a referendum, a bond issue vote, or some other form of public opinion survey. There are combinations of these methods (for example, committee reports or consultants' recommendations are put before the voters). The choice of decision-maker, outside expert, committee members or officials, voting or public opinion survey method, implies value judgments.

8. Outside standards may be applied or experience over time may guide decision. This is really a variation of delegation of decision-making power, in space or over time.* The numerous standards, manuals, recommended procedures issued by national authorities and associations (Bureau of Public Roads, AASHO, Highway Research Board) belong in this class. Although any national standards of this type are riddled with value judgments, they do spare local officials the agonies of having to formulate their own. They also have solid advantages of uniformity and administrative convenience. They are frequently based on enlightened deliberations and research.

Caution must be exercised when standards are used blindly as substitutes for value judgments. If last year's or other jurisdictions' experiences are adopted as desirable norms, rather than merely as indices of past or central tendencies, this will inevitably lead to static objectives and achievements. Acting entirely on the lowest common denominators emerging from public opinion polls and the like may have similar effects. As Musgrave (9) points out, the "premise of individual preference in a democratic society" does not rule out the so-called "merit wants" which are justified by the role of leadership in a democracy; for example, "...the advantages of education are more evident to the informed than the uninformed, thus justifying compulsion in the allocation of resources to education."

These are some of the thoughts that come to mind when considering non-market values in relation to the decision-making process. In all, eight value categories are proposed here: there is first the fundamental distinction between costs and gains; within these two broad groups there is the two-fold breakdown between external and internal, and between market and non-market values. As was pointed out before, with the analytical and decison-making viewpoint set at the highest (metropolitan) level, all effects are within the planning horizon and therefore the external-internal distinction need not be made; only four value categories remain. The definitions and classifications set forth in Tables 1 and 2 may not be ultimate perfection, but they are believed to be improvements over present practice. In the current highway and general public enterprise literature the following confusing, ill-defined value categories can be encountered: pecuniary and non-pecuniary, internal and external, private and social, non-transfer, and transfer, on-site and off-site, direct and indirect, market and extra-market, economic and non-economic, measurable and non-measurable, tangible and intangible, direct and spill-over, individual and collective, primary and secondary, monetary and non-monetary. There may be still other terms. Agreement on terminology would be a definite step forward.

A Freeway Demonstration Case

To bring this discussion to immediate, practical application, Table 3 provides a list of cost and gain effects which can be expected to be set off by major highway action in urban areas; for example, by construction of a freeway through a metropolis. Some important items may be missing from the list and some unimportant ones may have

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*The elegance of mathematical techniques employed notwithstanding, this—no more and no less—is also the gist of Vaswani's (8) proposals for highway planning. A highway official designates as satisfactory an existing highway, which is similar to the planned new facility. Given the administrator's decision, plus technical, cost, traffic, etc., data for the reference highway, it is then possible to work back to the "irreducible" factors, in this case the value of time savings to highway users. Choice of administrator, reference highway, technical standards, etc., of course, all imply value judgments. This does not detract from the advantages of flexibility and adaptability to local conditions which Vaswani's technique offers.

included, but Table 3 will do for demonstration purposes. Other students of the subject may be able to devise improved versions. As can be seen, whenever reliable market values are believed to exist, a dollar sign is shown; asterisks indicate non-market items and question marks doubtful ones. The designations are based on the author's judgment and there may be personal bias.

TABLE 3

POSSIBLE COST AND GAIN EFFECTS OF A FREEWAY PROJECT[a]

Costs		Gains	
Freeway Project Costs		Freeway Project Gains	
Right-of-way, construction, interchanges, approaches, feeders, landscaping, beautification. Public costs.	$	User charge revenues, fuel tax, license fees, parking revenues. Public gains. (No true market for highway use.)	$ *
Freeway, etc., operating. maintenance, overhead costs. Public costs.	$	Concession, advertising, etc., revenues. Public gains.	$
Vehicle fixed and operating costs net of user charges. Private costs.	$	Savings in door-to-door travel time. Private residual gain. (Time savings compared with what? No market for human time, except for employee drivers.)	$ * ?
"Wages" to drivers. Private costs.	?	Quality of service factors, convenience of ride, etc. Private residual gain. (Quality compared with what? No market for quality of service factors.)	* ?
Vehicle storage, curb space, garages. Public and private costs.	$	Hypothetical motor vehicle use charge — dummy item to balance vehicle fixed and operating costs. Private gains.	$
Project users' accident exposure, property damage. Private costs. (Market for property, but no market for human life and limbs.)	$ *		
All other project costs.		All other project gains.	
Project Costs, Sub-Total	____	Project Gains, Sub-Total	____
Program or Technology Costs		Program or Technology Gains	
Competitive effects on other highways, roads and streets.	$ *	Complementary effects on other highways, roads and streets.	$ *
Competitive effects on other highway users, congestion.	$ *	Complementary effects on other highway users, relief of congestion, more O's-and-D's offered.	$ *
All other program costs.		All other program gains.	
Program Costs, Sub-Total	____	Program Gains, Sub-Total	____
Transportation Activity Costs		Transportation Activity Gains	
Competitive effects on other transportation media.	$ *	Complementary effects on other media (park-and-ride, etc.)	$ *
All other activity costs.	$ *	All other activity gains.	$ *
Activity Costs, Sub-Total	____	Activity Gains, Sub-Total	____

TABLE 3 (continued)

POSSIBLE COST AND GAIN EFFECTS OF A FREEWAY PROJECT[a]

Costs		Gains	
Metropolitan Economy Costs		Metropolitan Economy Gains	
Accident exposure of non-users; noise, dirt, other detrimental health, social, aesthetic effects of freeway projects. (No market for most of these effects.)	*	Beneficial city planning, aesthetic, etc., effects; decentralization of metropolitan economy, skillful use of freeway for promoting desirable land use. (No market for most of these effects.)	*
"Imports" of metropolitan economy, possible loss of "foreign" aid.	$ *	"Exports" of metropolitan economy, possible gains in "foreign" aid.	$ *
Decreases in land values and metropolitan tax revenues, all other detrimental effects on Gross Metropolitan Product and metropolitan way of life. Many cross effects.	$ *	Increases in land values and metropolitan tax revenues, all other beneficial effects on Gross Metropolitan Product and metropolitan way of life. Many cross effects.	$ *
Metropolitan Costs, Sub-Total	____	Metropolitan Gains, Sub-Total	____
GRAND TOTAL: COSTS	____	GRAND TOTAL: GAINS	____

[a]$ = Market Values, * = Non-Market Values, $* = Mixed Values, ? = Doubtful Items.

A few general aspects should be singled out for discussion. First, an exposition such as the one shown in Table 3 does not in itself solve any problems; it will just help the analyst to marshal the various effects he has to study; he can thus make sure, in accordance with assumption 5 stated earlier, that nothing of significance is forgotten. This is an important first step to infuse into the highway planning process social, aesthetic, political considerations, in addition to engineering and economic ones. As Lang and Wohl (11) put it: "Highway planning has long since passed the stage where it can proceed in a vacuum, social, economic, or otherwise."

Second, the cost and gain array does not tell whether the incidences of the various effects (in other words, the income distribution repercussions) set up by the proposed highway action are desirable or undesirable.

Third, and this is a related point, extreme care must be taken not to double-count items. For example, the temptation is great to show very high user charge money revenues (produced, for example, by a charge-what-the-traffic-will-bear pricing regime) and yet also enter high quality of service gains, land value increases, etc. As Zettel (12) has pointed out, almost all general economic gains are basically user gains which have been transferred to other sectors of the economy. There are, therefore, residual in nature and none would theoretically remain to be transferred under a perfect charge-what-the-traffic-will-bear regime.

Finally, public and private gains and costs are shown combined in the accounts. This simply takes care of the fact that both roadway and vehicle are needed to produce highway transportation—one is quite useless without the other. The bookkeeping philosophy of Table 3 thus accommodates what might be called the "combined economics" of these two factors of production*, an important phenomenon to which Owen (13) drew attention. As was pointed out before, a metropolitan transportation authority, highway departments, or other governmental agencies, will normally be classified as powerful public monopolies. It would be quite misleading to visualize these organizations as competitively selling passenger-miles, or freight ton-miles, in the same way as a baker might be selling bread in competition with not only hundreds of other bakers in the city, but also with potatoes, cornflakes, crackers, biscuits and other substitute foods. The strong monopoly position of most public transportation agencies, plus the complementary nature of road and vehicle, make it absolutely necessary that the public and private sub-accounts be pooled and be analyzed jointly. This is, of course, in line with the best highway planning practice. Table 3 merely states this approach more formally.

Discussion of Individual Project Cost and Gain Items

Because of the somewhat unorthodox nature of the presentation in Table 3, at least a few items should be explained in greater detail.

It is a moot question whether some sort of pseudo-wages for drivers should be entered under project costs. One of the greatest economic merits of highway passenger transportation has been the apparent willingness of private drivers to perform their duties free of charge. Very likely they just enjoy driving. Of course, there might be some people who find driving to work every day a strain, in which case a cost item should appear here. This could be of some practical importance when, for example, the freeway project is compared with a subway or bus service solution. More research is needed here. Truck and taxi drivers' wages can simply be entered as money costs, of course.

Vehicle storage costs have suffered from acute neglect in most contemporary studies. A freeway solution for urban commuting traffic may simply dump thousands of vehicles in the city's inner core and the possibly very high costs of storage on valuable land are plainly an integral part of the project.

The treatment of accident costs is of crucial importance. According to a detailed Federal study (14, p. 21), 37,000 motor-vehicle accident deaths occurred in the United States in 1958, plus either 1.3 million nonfatal injuries (1 person in 134 of total U.S. population), or 4.7 million (1 in 37), depending on definitions of accident severity (14, p. 23). The cost of all highway accidents was an estimated \$5.4 billion (14, p. 17). With losses of this magnitude, it is obvious that the handling of the accident cost item can make or break project proposals. The author is personally perturbed by the persistent attempts to put dollar values on highway fatalities and injuries. For example, the following fatility cost figures, for ages 15 to 55 years, have been mentioned: male \$29,000; female \$17,000 (15). It does not really suffice to characterize this sort of approach as undesirable "boneyard economics." It has nothing whatsoever to do with economics; there is no market for human life, health and grief, and there will never be one, it is hoped. For professionals in the transportation field themselves to translate human life into dollars and cents is not only highly misleading, it may even be regarded as amoral by some. This does not distract from the great value of reliable information on accidents per se.

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*To check understanding of this point, consider the following typical problem that has caused some confusion in the field: Compact cars reduce vehicle operating costs, but also gas tax revenues accruing to the highway department. Granted that this is a good thing for the private compact car owners, is it also in the public interest? Answer: Given the same quality, speed and convenience of travel, total gains remain the same, although user charge revenues have shrunk. Total costs have shrunk. Therefore, from the general public point of view, this is an unequivocal good. In income distribution, compact car owners have gained, the highway department has lost, but could impose higher road user charges if desired. This same reasoning is also relevant to the introduction of diesel engines and possible future fuel cell and atomic energy propulsion devices. Highway improvements resulting in fuel (and gas tax) savings, must be analyzed in similar fashion.

But in a practical way, what can be done about accidents when decisions must be made here and now? All the earlier suggestions relating to the treatment of non-market values fully apply. There has been in the United States tremendous experience with highway accidents; the statistical trends appear fairly consistent and stable. Consequently, it should be possible to develop reasonably accurate accident forecasts. The analyst should present to the decision-makers the estimated accident consequences of, say, a proposed freeway in this way: x number of fatalities over the project's lifetime, y injury cases, z property damage accidents. It is legitimate, of course, to translate the latter into dollars and cents, because acceptable market values for property exist.

It is crucial that alternative solutions be tested and information on them also be submitted. Otherwise, the planning process—with its emphasis on choice—becomes a mockery. Thus subway proposals, which are almost certain to result in considerably fewer accidents, alternative freeway designs, bus service on freeway, or perhaps novel electronic vehicle guidance arrangements, must be developed at least as paper proposals. Because it is improper for the analyst to impose his own value judgments and attempt to convert human life and health into monetary terms, the final list of choices might look something like this:

Proposal	Net Gain ($)	Accidents (No.)
Standard freeway	a	p
Subway	b	q
Alternative freeway	c	r
Etc.		

With some luck, as previously mentioned, one proposal may be superior to all others in every respect; it should then be adopted. If a more complex choice must be made, something resembling an ordinal utility or indifference curve situation must be resolved by the decision-makers (and not by the analyst). Higher money costs, or lower money net gains, may have to be weighed against predicted lower accident exposure. Obviously, ethical or other value judgment must then be rendered by the decison-makers, be they individuals, consultants, committees, or the populace at large.

But even if, by experience, similarities of individual indifference between, say, money outlay and accident exposure were discovered, aggregation of such personal indifference functions into a collective one is open to most serious objections. Experience over time, or as between jurisdictions*, also does not get to the problem's core. It is much more honest and conducive to good decisions if the agonizing choice between money or other material resources and human life is presented anew every time the occasion arises. This is simply part of the burden of office which those in command must assume. It is not a new burden in human history.

On the project gain side of the planning accounts in Table 3, user charges revenues are designated as mixed market and non-market items. Here the author differs from those in the profession who maintain that paying the gas tax always constitutes a market transaction. To be sure, the more choice there exists in each case as between highway transportation and other modes, the more the user charge receipts take on market value characteristics. In intercity freight transportation situations, for example, when there is fierce competition between air freight, railways, pipelines, private and common carrier road transport, the trucker's gasoline or diesel tax pay-

*An intrepid researcher might want to compare the values put on human life—explicitly or implicity—in benefit-cost analyses developed by public agencies in, for example, the fields of airways, air traffic control and airports; water resources (flood control) and highways. If quantitative results could be developed, the researcher might well be in for some surprises; human life might be worth $17,000 in one case and $1 million in another. But whether consistent or not, such behavioristic experiences, it is submitted, are fairly meaningless for future decision-making.

ments do represent a fairly correct "economic vote". But in much of short-range passenger transportation, especially in the cities, all the paying of the gasoline tax and license fees frequently represents, is an "economic vote" in favor of being able to get around at all, to work, to play, to shop, rather than to stay home altogether. There are thus "markets" of different degrees of perfection in this field. Economic analysts, before inputing dollar values for this item, must ponder the monopolistic nature of passenger transportation by automobile in so many American cities, the self-promoting tendencies of highway planning and suburban developments, the distorting influences of advertising, of car ownership for prestige reasons, and so on. On the other hand, the impressive reality of high road user revenues, proven over and over again in the postwar period, should carry its proper weight in the analyses.

Although concession, advertising, etc., revenues may be regarded as market value items, the detrimental esthetic and social effects which balance them at the level of the metropolitan economy are of a non-market character. Therefore, there again exists a value judgment situation; more advertising money gains versus esthetic, city planning, etc., costs. The vast differences in advertising policies, beautification, and landscaping standards that can be observed in the various parts of the United States and Canada show how diversely increased driver irritation, esthetic losses, etc., are valued by the regional decision-makers. Research on social and highway user opinions on advertising, as contrasted with sectional interests, is overdue.

Except for money wages paid to employee drivers (chauffeurs, taxi and truck drivers), it is difficult to claim that there is a market for human time. The same applies for quality of service factors. Again, whenever true economic choice is possible (as between flying, going by train, riding on a superior toll road or riding on an ordinary public road) the pleasantness or unpleasantness of sensations can be measured indirectly by the amount of money consumers are prepared to pay in each case. If there is little choice—and unfortunately this seems to be the typical situation in urban passenger transportation—it is difficult to impute dollar values here. There are also great risks of double-counting among the user charge, concession, time saving and quality gain factors. Under a rigorous market research approach, potential freeway users would be asked: given a certain quantity and quality of service, what would be the maximum amount of money you would be prepared to pay and still patronize the new freeway? Alternatively, user charge schedules based in some fashion on costs could initially be worked out. The market researchers might then take it upon themselves to tabulate time savings and other qualitative factors and translate them, taking frequent recourse to value judgment, into money terms. Once this step in the analysis is completed, user charges (which are supposed to be equal to costs of providing the service) are deducted and the residue is entered as quality and time savings items. This particular approach seems roughly to be the one used for the so-called highway cost-benefit analyses. As can be imagined, it has many drawbacks because of its largely speculative nature.*

Once again, it is essential that alternative choices be considered. The analyst has to ask: time savings and quality improvements compared with what? Usually, the present situation becomes the zero point of measurement But if an existing in-

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*Suspect may be contemporary estimates accruing from highway improvements in the form of time savings and greater comfort and convenience of travel. Winfrey (16), with the aid of representative examples, shows the critical influence of these two non-market value factors on the total magnitude of estimated benefits. Applying fairly conservative rates for time savings ($1.35, $2.10, and $2.64 for cars, trucks, and combinations, respectively), he demonstrates that time benefits account for 84.4% and comfort benefits for 11.5% of total highway benefits. Savings in motor vehicle costs, the only factor that can be worked out with a reasonable degree of refinement and accuracy, amount to only 4.1% of total benefits. Hence, subjective, non-market factors may make up 95.9% of a highway benefit estimate. If time or comfort dollar values are increased a little, the leverage of the non-market values will be greater still.

efficient highway situation becomes the basis of comparison for simply another highway solution, and it in turn for yet another, inbreeding of projects sets in. The correct approach is to work through as many alternative proposals as possible, regardless to which technology they belong.

The hypothetical motor vehicle use charge, under project gains, is simply a dummy item to balance vehicle costs on the other side of the accounts. This bookkeeping peculiarity arises because total freeway project gains accruing to users are strangely split between (a) the money motorists are prepared to hand over to the authorities for letting them use the freeway, and (b) the money users pay to themselves, as it were (in their function as vehicle owners and operators) for traveling on the new facility. It seems paradoxical to assert that expenditures for motor vehicle operations should be rated as gains. However, it is not the payment of these expenses, but the willingness to make outlays in order to obtain travel, which is a possible measure of the gains from freeway transportation.

It is obvious that opportunities for double-counting and other accounting mistakes abound in freeway project analyses. The foregoing discussion has brought out how exceedingly difficult it is to measure total project gains, especially because of the ubiquitous qualitative and non-market value sub-items. All of the approaches suggested here seem roundabout and highly contrived. Yet they are employed in practice all the time.

Under favorable circumstances however, some more, expedient shortcuts may be employed. Consider that a definite requirement for metropolitan passenger transportation exists; in economic terms, a perfectly inelastic demand for a certain volume of these services is assumed. Now let a number of projects—various freeway configurations, a subway solution, a mixed freeway-subway solution, a bus service proposal, a combination park-and-ride project, and so on—be planned on paper. Attempt initially, if possible, to hold service quality of the various schemes equal; bring the subway or bus solutions up to private car standards (e.g., through more frequent schedules, high speeds, seats for everybody, air conditioning). Make sure, perhaps through a users poll, that the paper designs are really identical in the service quality they yield. This eliminates gains, and especially quality factors from the the comparison. Now juxtapose costs: the lowest-cost proposal should logically be carried out.

Alternatively, various freeway, subway and bus schemes could be planned, on paper, in such a way that they will all entail exactly the same project costs. Now compare gains produced by the different proposals; the project yielding the superior admixture of revenues, quality and convenience of service should be chosen.

Another intriguing method of project selection, described recently by Marschak (17), is apparently used by the nationalized Electricite de France. To avoid directly comparing total future receipts or gains of two or more alternative hydro plant proposals which would entail various analytical pitfalls the EDF analysts first set up, on paper, an "equivalent" thermal plant which could do the job in question. Then, hypotehtically, the thermal plant is replaced first by one hydro plant configuration, then by the other or others. The hydro plant proposal which makes possible the greater (net discounted) gains due to the replacement, per franc of net discounted expenditure, will be selected.

This project planning method used in France appears to be based on the "requirements" approach; in the economist's jargon, a perfectly inelastic demand for the electric power services is once more assumed. To avoid the inaccuracies inherent in absolute gain measurements, merely the relative merits of alternative schemes are compared in the fashion described. It is not quite clear why the French approach could not be reduced to a simple cost minimization problem for a given output requirement; perhaps this is not possible because "requirement" for power has complex demand parameters over time, including (a) peak instantaneous output required in the course of a year, (b) total annual output required, and (c) average daytime hourly output required in the winter months (17, pp. 137-8). One is strikingly reminded of highway peak traffic problems, the 30th highest hour concept, the difficulties of absolute gain measurements in the highway field, etc. Here seem to be exceptionally fruitful areas of research and exchange of ideas between related fields, such as electric power and transportation.

None of these short-cut methods can tell, however, whether one or all of the proposed schemes is economically justified in the first place; that is, whether project gains, V, will exceed project costs, C. To do this absolute measurements of cost and gains are needed, therefore value judgments frequently must be resorted to.

Referring once more to Table 3, technology or program effects, as well as repercussions upon the transportation activity and the metroplitan economy, are discussed in the context of transportation planning and the time dimension.

PROJECT ANALYSIS

Probably more than one-half the analytical battle is won once the right data have been collected and arranged correctly, as suggested in Table 3. It now remains to show what use can be made of such information. The narrative takes the reader quickly through descriptions of the analytical techniques available for solving economic problems at the project, program or technology, activity and metropolitan economy levels of decision-making. Some of the techniques are well known, others represent novel aspects.

It must be assumed from now on, of course, that reconciliation of market and non-market values has been accomplished in some form or another and that all the effects one wishes to study can be expressed quantitatively and can be aggregated. This is a big assumption; but it is hard to see how one could go much further in the discussion on non-market values than was done in the preceding section. The natural limitations from which the intellectual tools of the engineer, economist, or analyst suffer in the public decision-making field, should be recognized.

Project Identification

A brief defintion of "project" was given in Table 1. It was stated that the smallest unit of production which can fulfill the desired production objectives would be designated as a project. This definitional device conveniently removes compatibilities, incompatibilities and other cross-system or network effects which several projects may exercise upon each other, from the scope of project evaluation proper. The consequences of interdependence of projects can be handled with greater ease by means of program or activity analyses, to be explained later.

It is apparent that the absolute dollar size of a project to be evaluated is of no significance for project identification. At the one extreme, a complete multi-million dollar highway would be regarded as a single project, if no traffic at all would move if something less than the entire highway were built. At the other extreme, the addition of one traffic lane to an existing highway would be regarded as a project in its own right, if it adds capacity over the whole of the connection between only two traffic origin and destination points. Even maintenance and other operational activities can be defined as projects (19) and subjected to analysis, if desired. One can imagine that practically every highway process, however trivial, could be subjected to project evaluation if defintions are made sufficiently fine. Similarly in private enterprise. As Angell (18) puts it, from the micro-economic point of view, all business expenditure can be described as "investment" regardless whether it is expansion of plant, purchase of raw materials, or labor services. Conversely, very coarse definitions of "projects" can be employed. Because planning costs something, and because good highway analysts are scarce, initially the rather more important highway projects probably should be scrutinized first.

Project Life

As a simple rule, it is proposed that either physical life or economic life of the project, whichever is considered to be the shorter, should be chosen as the correct project planning period.

Typically, highway projects may have very long physical lives; a bridge may last 50 years, some structural components 100 years, the real estate tied up in highway right-of-way may have unlimited life. The temptation is great to impute very long service lives for highway and freeway projects, although there is no evidence that economic and functional obsolescence will not set in long before the facility physically expires. Of course, the more costs can be stretched out over time, the more favorable the project will appear in the economic analysis. But artificial stretching out of project life is quite inadmissible from the economic and analytical point of view.* Only the period for which project usefulness can honestly be foreseen should be employed for analytical purposes.

It should be noted that Winfrey (16) has suggested the adoption of shorter lifespans for highways than many analysts are currently using. It might further be argued that urban freeways should be allowed somewhat shorter lives than intercity ones. Freeways in cities represent technically very specialized solutions, are under heavy criticism from people outside the highway field, and may conceivably be supplemented, if not superseded, by superior urban transportation technologies in future years. Intercity highways, on the other hand, are of long standing and will probably be useful for many more years to come. Adoption of shorter urban freeway lifespans for analytical purposes would simply make for a more cautious planning approach, but would still allow the better proposals to qualify. It is believed by some that a case exists for introducing greater prudency into the metropolitan freeway planning processes.

Project Costs

All costs attributable to the project over its lifetime, as they are expected to occur over the years, should be recorded. Amortization thus does not have to be considered separately. Interest demands special attention and therefore is discussed later; it is not included with the other costs. No distinctions between direct and variable costs, or between capital and operating costs, need be made at this stage. These cost concepts only assume a specific meaning when relatively limited time horizons pertain, usually the calendar year or the fiscal year of the accountant. In ex ante project planning, the time horizon is that of the lifespan of the project. Ex ante, all costs whether capital or not, are still avoidable. They can be treated in the same way, subject to time analysis to be covered later. The unnecessary breakdown of costs into subcategories complicates analysis greatly, when for example benefit-cost criteria are used. McKean (5, p. 76) correctly states: "...investment occurs whenever more is being put into a project than is being received from it." Therefore, operating costs not at first covered by receipts are just as much "investment cost" as are construction outlays.

It is important that allowances be made for liquidation of the project at the end of its useful life. There may be positive scrap values (sales of salvagable materials), which should be credited as final gains to the project, or there may be negative ones (for example, removal of structures) and these must be treated as costs. Once more in support of prudency in urban freeway planning, it can be argued that concrete structures, interchanges, etc., are difficult and costly to demolish; therefore, there should be analytical evidence that freeway projects show sufficient economic returns over

*Examples for such malpractices can be found frequently in the highway field: traffic (i.e., functional, economic usefulness) may be predicted over 20 years to 1980, but the annual costs of, say, a freeway are computed on the basis of 40-yr amortization. The resulting benefit-cost ratios are quite distroted in economic terms, it can be argued, of course, that "freeways will surely be useful after 1980;" if so, the analyst should go out on a limb and predict traffic to the year 2000 as well. A better method would be to calculate differential scrap values for the components of a freeway as of 1980: high scrap value for real estate, low for pavement, etc.

It appears that the AASHO approach (20) favors the use of physcial project life for amortization purposes, although traffic (and therefore benefit) forecasts apply to shorter periods. The AASHO procedures have had, and still have, tremendous practical influence upon highway planning in the United States, Canada, and elsewhere. Perhaps the time has come to draw up improved planning guidelines, more in line with the theoretical and practical advances that have been made since 1952.

and above project costs to cover final site clearance costs. Although it is true that many highway projects will retain or even enhance their usefulness in future years, no one should be so presumptuous as to believe that all of the current creations will meet the approval of future generations.

Accepting the propostion that the analysis must cover all costs of initiating a project, running it during its lifetime, and liquidating it, one is now interested in total project costs which are incurred at different levels of output. This output-cost relationship may be represented as in Figure 1. Marginal cost curve MC is a truly long-range one, indicating the costs incurred when producing one more unit (or bundle) of output. Why long-range? This implies that true total costs are incorporated and that no planners are, ex ante, able to make any changes in design and construction which are economically desirable and technologically possible. Average costs are not shown in order not to clutter up the diagram, but can easily be derived from the given information. The area under the MC curve (i.e., OBDA for output OA) represents total costs over the long run.

The smoothness of the MC curve, as drawn, suggests that factors of production can be varied continuously. But it is well known that indivisibilities of factors exist and that costs are likely to show sudden jumps; for example, from four lanes to six lanes of highway. How can one resolve the problem created when, in effect, a calculus of continuous variation is to be applied to a lumpy material? If one is satisfied that he

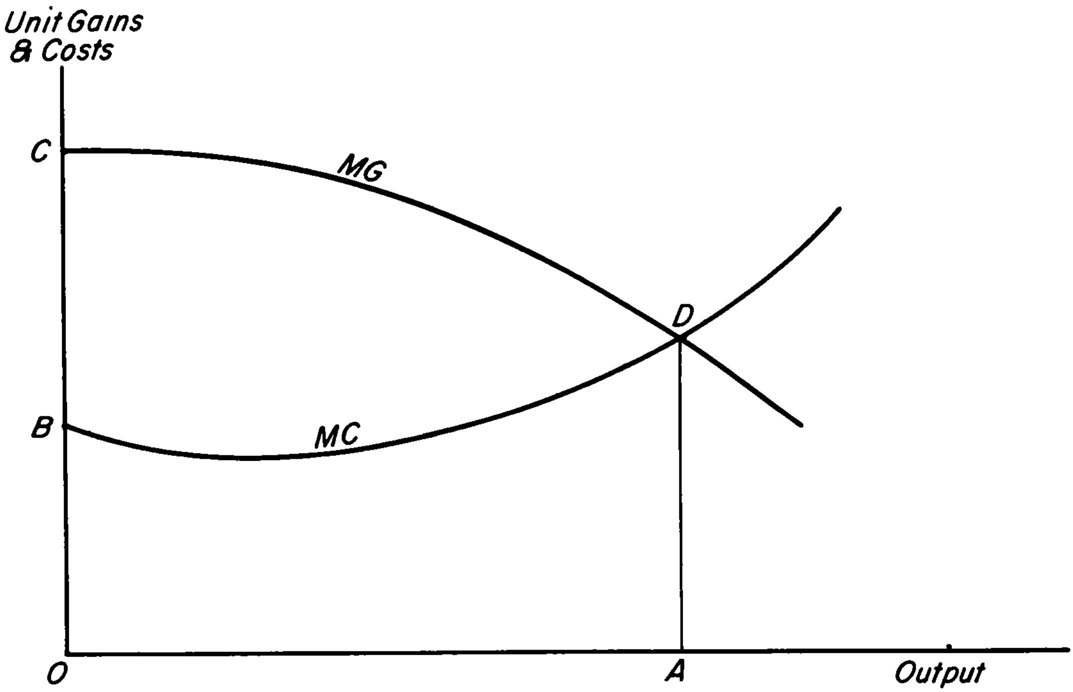

Figure 1.

is really dealing with the smallest possible quanta of decision-making, then two distinct incompatible projects exist—a four-lane highway and a six-lane highway. With intermediate output solutions ruled out, the two possibilities must separately be subjected to gain-cost analyses and then be compared to findthe better compromise. If there are side effects, with the choice of four or six lanes setting up further reactions through the highway network, the two project proposals must be subjected to program analysis, as described later herein under "Program or Technology Analysis."

Gains

It will be recalled that gains are taken to mean all ascertainable desirable effects caused by carrying out the project. It is evident that the "with and without" principle (21, pp. 51-5) applies to both costs and gains. With its aid a distinction can be made between the relevant true project effects and irrelevant ones brought about by the passage of time and other extraneous circumstances. Once more it must be assumed that market and non-market values have somehow been aggregated into total gains.

Magnitudes of gains realized from disposing of various output quantities are recorded on the marginal gain curve MG in Figure 1. The properties of this second curve also deserve scrutiny. Curve MG is the locus of points denoting the gains accruing to the project when disposing of one more unit of output. The area under the MG curve (i.e., OCDA for output OA) represent maximum total gains that would accrue to the project.

Once more the familiar objections to such a smoothly drawn curve can be raised; but if a step-like MG curve is the one found to represent reality, this information should simply be employed for analytical purposes. In case of output conflicts, compromise solutions, as mentioned before, may then have to be worked out.

Output Determination

Briefly, the desired output for a highway project will be determined by the intersection of the marginal gain and cost curves. In Figure 1, curves MG and MC meet at point D, designating OA as the optimal output. At this point net gains accruing to the project (OCDA-OBDA=CBD) are maximized.* No other output position can better the net gain yield. Provided all other goods and services elsewhere in the economy are also produced in such quantities that marginal gains (or more conventionally, marginal revenues in the absence of non-market items), equal marginal costs, at this level of project output both most efficient use of productive factors will be made and consumers' welfare will be maximized. (For a more detailed discussion, with special reference to water resource economics, see Eckstein (21, pp. 19-46) or Krutilla and Eckstein (23, Chap. II). For brevity, one may refer to this method of output determination, which thus results in maximization of net gains for the project, optimum allocation of resources and maximization of consumers' satisfactions, as the marginal rule.

Critical Comments

Some special difficulties arising in highway project analyses should be examined critically. Only highlights of these problems can be presented as follows:

1. Shape of Marginal Gain Curve. It was stated that the size of the surplus of

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*It should be noted that this is not the same as maximizing the benefit-cost ratio. If such a ratio were to be maximized, it might be better to produce just the first few, highly profitable, output units. In private business terms, if maximization of revenue-cost ratios were the right criterion, bakers would sell only a few, highly profitable loaves of bread, investment brokers would perhaps invest only a few dollars of their clients' millions in exceptional opportunities, etc. Other sales or ventures, which are still profitable but would depress the average revenue-cost ratio, would be ignored. This is, of course, absurd. This is one of a number of reasons why benefit-cost ratios, unless hedged around with many assumptions and conditions, offer poor guidance for highway planning and investment decisions. (See also Grant and Ogelsby (22), and McKean (5) for criticisms of the benefit-cost ratio method of planning.)

gains over costs (area BCD) will determine project acceptance or rejection. If two alternative project proposals are compared, the one promising to yield the larger surplus should be chosen.

It is clear that the configuration of the MG curve is crucial here. If it is a rather steep curve—this will be the case if the service offered is essential and no good alternative choices exist—the surplus area BCD will be large. The project then has an excellent chance of being chosen. Conversely, in a rather competitive situation, the MG curve will be flat and the surplus area will be small. The project will have a hard time to get accepted. Hence, the way in which the individual points on the MG curve are arrived at is most critical. How should the market studies and demand analyses for projects be carried out in practice?

Consider the example of a river crossing. Potential travelers may be desperate to get from one side to the other. Possible solutions include a ferry, a subway, a low-quality bridge, or a high-quality bridge. Under present highway planning rules-of-the-game, other technologies (ferries, subways, etc.) do not even come within the effective decision-making horizon. Using a crude benefit-cost approach, the time, fuel, etc., savings for the low-quality and the high-quality bridge approach only would be assessed, would be given some more or less arbitrary money weights, and then compared with each other through the benefit-cost ratio mechanism.

More sophisticated approaches would follow Marshall's prescription and ascertain what amounts of money users would be prepared to pay, at the most, for being able to cross the river by bridge. But if the market researchers were to ask prospective customers "how much toll would you pay for a bridge?", or ".....for the bridge we have in mind?", very inelastic (steep) MG curves would result. No good comparisons between alternative project proposals are possible; everybody knows, in this age of rapid traffic growth, that a bridge is better than none. But this still misses the whole essence of economic planning, which is comparison of alternatives.

Under the circumstances depicted, the correct approach of the market researchers to prospective users should be something like this: "We will definitely accomodate river crossings; the following solutions are possible: (a) ferry, (b) subway, (c) a low-quality bridge, (d) a high-quality bridge, etc., etc. Given this choice, and given certain qualities of service, speed, etc., for each, how much would you be prepared to pay for solution (a), for (b), (c), or (d)?"

Under this market research approach, there would be separate collective demand curves for each alternative; in fact, there would be four or more separate diagrams here. The demand curves for each, since alternatives exist in the users' minds, would be far more elastic (horizontal), the formerly large surplus areas would shrink and much more sensitive comparisons between the project proposals could be made.

It is clear that we are still far removed from such theoretical market research perfection in actual highway planning. There is little, if any, choice now between alternative proposals. (Laudable exceptions are the recent Chicago (<u>24</u>) Detroit (<u>25</u>), and Washington, D. C. (<u>26</u>), transportation plans. These studies represent important milestones in the evolution of urban transportation planning in the United States. Therefore, there is also little, if any, choice now between the non-market designation of the category "project user revenues" in Table 3. The essential interactions between different projects, programs or technologies are also brought out once again by the preceding cussion.

2. <u>Incidence of Costs and Gains</u>. Project investment analysis as such does not tell anything about the distributive effects of the proposal: Who will reap the gains? Will everybody pay a fair share of costs? Will not one class of users subsidize another? Should services be sold exactly at cost? Or at a loss? Or should the transportation agency be allowed to make a profit?

If an isolated project, such as the one depicted in Figure 1, is considered, freedom of pricing policies may be assumed. If so, there is an almost infinite variety of distributive effects that can be brought about by the right charging schemes. These might range from a completely discriminatory pricing regine, through various monopolistic devices, the uniform charge case, to the long-range marginal cost pricing solution.

Some of the possible solutions, which still satisfy the marginal rule, have been described elsewhere (27). This particular area has been written about excessively in recent years, and may perhaps have been researched almost to death in the highway field. The interest in distributive effects, which was presumably sparked by rail-truck competitive struggles, has greatly declined lately, perhaps because of piggyback, the consolidation of the positions of the media, the shift in emphasis to urban problems, etc.

Because of the prevalence of joint costs (as between heavy and light vehicles, peak users and off-peak users, and even highway users and non-users), little more than convenient, or equitable, or fair—whatever these terms may mean—pricing schemes can emerge from economic analysis.

3. Influence of Uniform Charges. It is fundamental in the highway field that there are, within broad user groups such as passenger cars, fairly uniform charges. Uniform charges are convenient, easy and cheap to collect, have great administrative advantages and appear fair to the public.

Figure 2 shows what uniform charging does to highway project operation. Suppose a tax is struck according to the principle that the highway function as a whole must break even—also called the "no deficit" constraint. Let it be assumed that $0.01 per vehicle-mile is just right. The highway department runs separate roads, A, B, and C, which differ in their cost curve configurations as shown.

As can be seen, the uniform charge plays havoc with the "right" outputs according to the marginal rule:

Highway A: Actual output is OF, which is correct according to the marginal rule; there is a large surplus which is diverted to Highway C; if Highway A were autonomous, it could be run at output OG and still break even. This is the typical urban-to-rural highway money transfer case.

Highway B: Actual output is OI; according to the marginal rule, correct output should be OH, using different charges; as things are, some users, who generate a surplus, subsidize other users who are being accommodated at a loss at the given highway price. The highway by itself just breaks even nicely. This is the typical case, where it is usually alleged that trucks do not pay their fair share of costs and are cross-subsidized by automobiles, or vice versa.

Highway C: Actual output is OK; according to the marginal rule, with a different pricing regime, it should be OJ: the highway by itself is a dead loss and, under the no deficit rule, should never have been built at all. As things are, the facility is being subsidized heavily by Highway A. This is the typical case of the low-travel, high-cost rural road, or possibly of an exceptionally expensive urban freeway.*

Comment. Under the circumstances depicted, something has to give; it is not possible to satisfy simultaneously (a) the marginal rule, (b) individual and aggregate break-even, and (c) uniform charges. The situation shown in Figure 2 probably truthfully represents many a highway department's current experience.

It should be noted that Highways A, B and C are assumed to be independent of each other. Feeder, network, etc., effects are discussed in the next section of this paper.

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*The controversial Embarcadero Freeway in San Francisco, at current traffic volumes, costs the highway authorities about $0.25 to $0.30 per vehicle-mile to own, operate and maintain; at maximum projected traffic volumes, to be reached 20 years from now, its total costs would still be as high as $0.10 to $0.12 per vehicle-mile. By contrast, highway user charges in California are about $0.0075 per vehicle-mile for automobiles, and about $0.01 per vehicle-mile on the average for all vehicles combined. There are other complex features of the Embarcadero project which should be taken into account, in particular the beneficial system effects (as described in the next section of this paper) which the facility may confer upon the Bay Bridge and possibly upon parts of San Francisco's network of streets. With rising urban land costs and the gradual exhaustion of the obviously more worthwhile freeway projects, it is evident that much improved planning analyses are urgently needed to show whether facilities of the Embarcadero type should be undertaken at all.

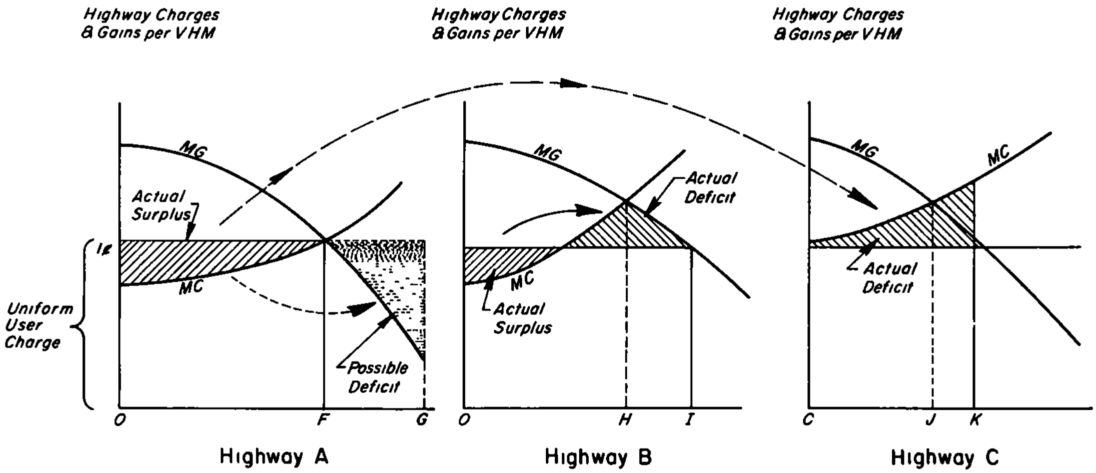

Figure 2. A highway department situation including uniform user charges, pooling of revenues, and break-even for the highway department as a whole.

4. Superior Analytical Treatment. As the foregoing discussion suggests, given uniform user charges it is not possible to always satisfy the marginal rule output requirements. But a superior analytical treatment suggests itself, which may lead to better solutions. As was pointed out, highway and vehicle are singly merely factors of production, which are needed jointly to produce the desired output—highway transportation. A joint gain-cost approach was therefore incorporated in Table 3.

To follow it up, one must show unit gains and costs for the combined product, highway transportation, as demonstrated in Figure 3. The gain curve, as was explained, denotes the total amount of money people would be prepared to surrender, at most, for facility use. The cost curve then shows correspondingly what total expenditures are necessary to satisfy these user desires. The artificial distinctions between private and public, highway and vehicle outlays, disappear. A correct marginal rule output solution (output OL) will follow. As vehicle costs and highway costs are, within limits, substitutes for each other, one can be raised to lower the other; similarly, with highway user charges and time savings, etc., on the gain side. Therefore, with some internal adjustments, highway costs can be made to equal highway user charges by biting into residual time, etc., gains. Gains from motor vehicle use and motor vehicle costs are identical, by definition (Table 3).

The great advantage of this analytical treatment is that adaptation to the correct output does not rely exclusively on raising and lowering highway user charges; this is difficult to implement administratively and the leverage effect of these imposts is very weak, in any event. Here, the adaptation to correct output relies on variations in total gains and costs. In other words, the highway department, with reference to a correctly planned highway, now says: If it is underutilized, it will offer very low total highway transportation costs and will therefore attract users up to the correct output; if it is overutilized, congestion will set in, this will increase total highway transportation costs and therefore cut down on usage.

Rationing by congestion, as it were, provided there are alternative transportation choices, appears to be the only possible economic approach, when differential road user charges (toll gates) are ruled out. Many beneficial consequences arise for highway planning, too, which should be explored.

The joint highway-vehicle planning concept becomes a little easier to understand, if it is imagined that Figure 3 represents, say, a subway case. Total marginal gains constitute simply the maximum fares which might be exacted from users. There is no need to specify how much users "gain" from the rolling stock and how much from the tracks, tunnels, stations, etc. Similarly on the cost side; the breakdown between

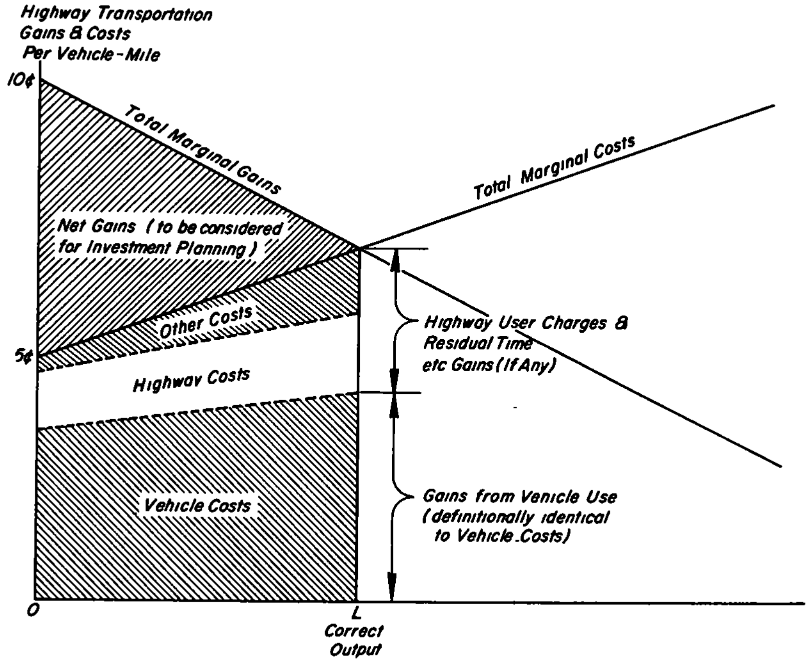

Figure 3. Superior analytical treatment; analysis of complete highway transportation operation.

vehicle and track, plant, etc., costs are quite irrelevant for subway investment planning as such; it is a subsidiary problem, in the same way as "more capital costs, less maintenance costs, or vice versa" is one.

PROGRAM OR TECHNOLOGY ANALYSIS

The preceding investigations will result in a list of possible projects, such as freeways, feeders, interchanges, for a metropolitan area, complete with information on gains and costs for each. Decision-making responsibility is now raised to the program or technology level, and the planning horizon expands correspondingly. Consequently, many relationships which are external to individual projects, but internal to the metroplitan freeway program or highway technology, can be recognized. These relationships are brought about by technical, functional and economic factors; they may be referred to as systems, or network effects. The following forms of project interrelationships may be encountered:

Perfect Incompatibility. A number of mutually exclusive uses for a single site are proposed (for example, a freeway location, or a parking lot, or residential streets). Or different design configurations for the same purpose are considered, such as low-level bridge, or a high-level one, or a tunnel, for the crossing of a river. Or, various levels of peak and off-peak demand have to be satisfied by a single facility which can only be constructed to one definite capacity. Or solutions with peculiar rival economic characteristics (toll road versus public road) must be compared.

Perfect Dependence. At the other extreme, projects may be completely dependent upon each other. Of course, if all of several projects cannot exist without each other, then according to the earlier definitions they must be treated as one single project. But there will be cases where a subsidiary activity is completely dependent upon the main activity for survival, but the latter can, if necessary, stand on its own feet. Examples are primary highways with their feeders, or toll roads with their toll road restaurants and similar ancillary activities.

Neutrality, Partial Dependence, or Incompatibility. Between these two extremes, there may be cases of projects helping or hindering each other to greater or lesser degrees, or having no effects upon each other at all. In other words, there may be partial dependence and complementarity, or partial incompatibility and competition, or neutrality, between the several projects.

It is the objective of program or technology analysis to identify these system effects created by the interaction of several projects upon each other and then, from the stated conditions, find optimal solutions. How this might be done will be demonstrated with the aid of a greatly simplified metropolitan road planning example.

A Metropolitan Road Planning Case

Assume that there are four distinct road projects, designated as A, B, C and D, which are being considered simultaneously by the metropolitan transportation authority. Costs and gains predicted for each project treated individually have been worked out by means of preceding project analyses. Assume that there are no budget limitations imposed upon any possible project grouping and that therefore the objective is maximization of net gains for the four projects considered as a whole.

Consider, for purposes of demonstration of the analytical techniques, that perhaps the following conditions pertain (see Figure 4 and Table 4):

Project A might be a planned freeway, which takes a more circuitous route than toll road B, its incompatible rival. Either A or B, but not both projects, can be built. Route C is a pure feeder to A and is thus completely dependent for its own survival upon the main freeway project, A. The latter, in turn, gains somewhat from the services provided by C, but these are not essential to A's survival. Project B, the toll road solution, stands by itself, and no special feeders are considered. Routes C and B are perfectly neutral in their effects upon each other. Route D, finally, is a complementary feeder to C to some extent, is neutral to A, and mildly competitive to B.

Other program or technology interrelationships can, of course, be readily devised. The present example is designed to demonstrate all possibilities, from complete incompatibility, through rivalry, neutrality, to complementarity and complete dependence. Instead of feeders, interchanges, downtown parking garage projects, etc., can also readily be visualized. Relationships get exceedingly complex and hard to trace when more elaborate models, with more projects, are constructed.

Putting values on the various effects, the interrelationships can for convenience be represented by a quadratic matrix, as shown in Table 4. The values conform to the descriptions given in the preceding paragraphs. Some examples will explain this representation. Project A by itself (by A on A) yields 500 gross gains or, at 300 project costs, 200 net gains. Toll road solution B, by itself (by B on B), with 350 costs being the bigger undertaking, yields 600 gross gains. If there was a straightforward comparison, ignoring all systems or network effects, between the two rival projects, B should be selected because it results in the larger net gains; namely, 250. As can be seen from Table 4, A and B are incompatible and both their gains are cancelled out when they are undertaken simultaneously (A on B, and B on A). This was a basic condition of the model.

Looking now at feeder road C, by itself; with gross gains of only 20 and project costs of 140, it results in a net loss of 120. But C, regarded in conjunction with A, becomes profitable. Freeway A confers 120 systems gains upon C and C confers 90 gains upon A. Both taken together therefore yield 730 gross gains at 440 costs and hence 290 net gains. This, incidentally, is the substance of the famous "branch line" problem in railroad economics, the "loss leader" phenome-

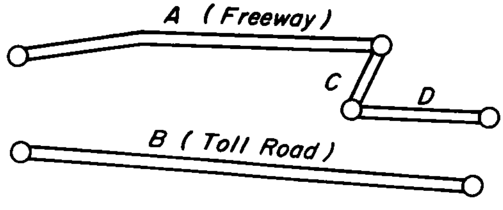

Figure 4. Metropolitan road project proposals (circles are access and egress points).

non in retailing, and numerous other system or cross subsidization situations found in the real world.

All other interrelationships can readily be observed in this way in Table 4.

TABLE 4

PROJECT OR TECHNOLOGY EFFECTS*

By \ On	A	B	C	D	Individual Project Costs	
A	500	-600	120	0	A	-300
B	-500	600	0	-30	B	-350
C	90	0	20	50	C	-140
D	0	- 30	40	100	D	-100

*Positive values are gains, negative values are costs.

To find the optimal solution under the assumption that there are no budget constraints (i.e., the one which maximizes net gains), all possible combinations of the four projects must be tried out. This has been done in Table 5. It will be seen that combination ACD is the optimal one, leading to net gains of 380, which cannot be exceeded in any other way. It should be noted in the last column of the table that toll road project B, by itself, would result in a higher rate of return than the ACD project combination (net gains divided by costs for B = 71.4 percent, and for ACD = 70.4 percent). Similarly, the benefit-cost ratio of B (600/350 = 1.714) would be higher than that of the ACD combination (920/540 = 1.704). This once again shows the possibly misleading effects of such planning tools.

It is easy to see from Table 5 that the profitability performances of individual projects take on quite different complexions when segments are placed into the program or network context. Take, for example, project D. By itself it would yield 100 gross gains at 100 cost and therefore zero net gains. Individually, it would be the classic example of the marginal project which might or might not be undertaken. But when D is withdrawn from the optimal combination ACD, net gains decline from 380 to 290 as a result. Hence, in the context of the given network ACD, project D makes a net gain contribution of 90. Even more extreme is the case of feeder road C. By itself it results in a net loss of 120. If, however, C is withdrawn from the optimal combination ACD it can be seen that C makes in fact a net gain contribution of 180 in this context.

It follows that profitability of a project by itself is not a decisive criterion if system effects are present. As a rule, even proposals showing negative returns during the project analysis must still be processed through the program analysis if there is any reason to believe that they might result in positive system effects. This has great practical significance in the highway field, where network effects are prominent. The correct procedure is to test whether withdrawal of a network segment results in a decline of net gains for the system as a whole. If yes, the network addition is worthwhile and should be retained. If, however, withdrawal leads to increase in net gains (i.e., cost savings) abandonment is indicated. (As McKean (5, pp. 54-55) puts it, one has to test "...whether or not uneconomic features or uneconomic additions in size are riding on the coattails of the truly profitable parts of a proposal.") This procedure is obviously already incorporated in the trial-and-error selection method depicted in Table 5. Hence, optimal solutions obtained in this way are also correct with respect to deletions or additions of network segments.

Another interesting observation can be made by referring to Figure 4. As it is drawn, road C is a feeder to main freeway A, and D is really a feeder to C (or C to D). It follows that through the positive intervention of C, if C is also built, D becomes a feeder to A and A, in turn, will likely stimulate D. But these cross effects between A and D depend entirely on the existence of the link C between them. Consequently, although A and D, if analyzed by themselves, may be neutral in their reaction upon each other, they will show positive effect upon each other if A is confronted with the combination CD, or D with the combination AC. A quick check reveals that such possible tertiary system effects are not incorporated in Table 4; that is, A's effects on D, and vice versa, are shown to be zero whether C is there or not. Indeed, these further effects cannot be handled by one representation, such as Table 4, alone. To trace and exhaust all possible network combinations, further tables need be drawn up which would confront, for example, the AC combination with network additions B and D. Further tertiary, etc., effects and combination can be visualized, but the nature of the actual problem in hand and the availability of data will determine whether it is worthwhile to carry the analyses to such high degrees of refinement.

Program analyses will also be the appropriate vehicle for testing different design configurations when indivisibilities of factors exist and system effects are present. Highways provide a good illustration. Assume that either a two-lane or a four-lane design may be built. By itself the two-lane highway may maximize net gains, but it may have an inhibiting effect on associated parts of the network. The four-lane highway, although somewhat extravagant by itself, may bring about large net gains in other segments. If confirmed by program analysis, the four-lane might be preferred.

Some Practical Observations

To really get the best results from program analysis, all possible combinations of projects should be played through. As can be seen from Table 5, where only four projects are considered, fifteen combinations must be tested. As further projects are introduced for more elaborate models, the computational work rises to horrendous proportions. (The number of combinations is: $\sum_{K=1}^{n} \binom{n}{k} = 2^n - 1$. If, for example, 20 projects are considered, there will be 1,048,575 possible combinations.) This would be the case with everyday highway problems; for example, in freeway planning where different locations, number of lanes, spacing and design of interchanges, feeders roads, etc., must be considered.

What can be done to keep the computational work within reasonable bounds? First, the empirical data can be checked to see whether simpler relationships prevail. Projects may have identical cross effects upon each other (for example) when traffic is balanced in both directions and as much is passed on to the other project as is received from it. Similarly with traffic abstraction. In Table 4, projects B and D hinder each other equally by inflicting 30 costs both ways. It can be said that a symmetrical relationship exists under these circumstances. If such symmetry prevails throughout the network, the relationships and calculations are rendered much simpler. Triangular traffic patterns and external values will, however, deny such simplification. Turning once more to Table 4, it can be observed that C confers 90 gains upon A, but A confers 120 gains upon C. The explanation might be that there is a mutual, symmetrical traffic stimulus of 90 gains between the two roads, but that in addition property values along C rise (or other external gains specific to C are realized) to an amount equivalent to 30 gains, whereas no corresponding effects are bestowed upon properties along A by virtue of the new connection with C. Second, problems of this type lend themselves to linear programming techniques, which would constitute a great improvement over crude trial-and-error approaches. For the purpose, to give an illustration, the values in Table 4 can readily be expressed net of costs. All that is necessary is to subtract individual project costs from individual project gains. The diagonal values then are: AA = 200, BB = 250, CC = -120, DD = 0. From then on the objective is straightforward gain maximization. Modifications of the assignment technique or other linear programming methods might possibly be used and might cut down the computational load considerably. Third, failing less expensive shortcuts, resort can, of course, be had to electronic data processing, the panacea when large numbers of computations must be carried out.

On a very practical level, it is likely that the availability and quality of the basic data themselves will impose more stringent limitations on the volume of calculations than the matehmatical techniques that can be devised. Nothing is gained by building a towering analytical pagoda upon the clay feet of poor empirical data. Further, in many cases the more remote system effects will be difficult to measure, let alone forecast, and lack of such information by itself will make for simplifications. Also, frequently one particular project will be certain to yield large net gains compared to the net gains of the other possible network components and additions. This could be the case of a main highway connection, the economic justification of which has been established beyond doubt; only minor modifications need be tested. Under those circumstances the dominant project can be taken as given and all the minor projects can be tested in relation to it. This will also make for less complex analyses.

TABLE 5

POSSIBLE PROJECT COMBINATIONS
(Derived from Table 3)

Project Combination	(1) Gross Gains (units)	(2) Costs (units)	(3) Net Gains, (1)-(2) (units)	(4) Rate of Return, (%) $\frac{(3)}{(2)} \times 100$
A	500	300	200	66.7
B	600	350	250	71.4
C	20	140	-120	-
D	100	100	0	-
AB	0	650	-650	-
AC	730	440	290	65.9
AD	600	400	200	50.0
BC	620	490	130	26.5
BD	640	450	190	42.2
CD	210	240	- 30	-
ABC	230	790	-560	-
ABD	40	750	-710	-
ACD	920	540	380	70.4
BCD	750	590	160	27.1
ABCD	360	890	-530	-

Transportation Activity Analysis

Decision-making responsibility is once more raised, this time to the transportation activity level. The planning horizon expands correspondingly and embraces anything concerning transportation within the metropolitan area. Further relationships, formerly external to projects, or to the highway technology, now are internal to the metropolitan transporation deliberations and must be analyzed.

The economic and analytical techniques are precisely the same as the ones described earlier for program planning. On reflection, it stands to reason that the rivalry between, say, a freeway and a parallel toll road, is equivalent to rivalry between a freeway and a subway. Similarly, the complementarity of the main freeway and its feeder is analogous to the dependence between bus and subway, or parking lot and subway, or freeway and express bus, or airport and the supporting ground transportation facilities.

From the purely computational point of view, transportation analysis is therefore carried out in exactly the same fashion as program analysis. No special difficulties should arise on this score. Lacking a metropolitan region authority, it may take some persuasion to convince highway authorities, transit agencies and other technological decision-makers in the area that they should voluntarily adopt broad transportation viewpoints. What organizational steps might be taken in such a situation, is a fascinating research topic in its own right. It will not be pursued here, however, because it was assumed at the beginning that the appropriate political and administrative arrangements can be made to implement the policies found desirable on analytical grounds.

A Mathematical Statement of the Program or Activity Problem

Let p_i ($i = 1, \ldots, n$) be a proposed list of projects having known costs of construction $c_i \geq 0$. Then the total cost of a program, P, may be written as

$$C = \sum_{i=1}^{n} c_i \, \delta_i \qquad (1)$$

in which

$$\delta = \begin{cases} 1 \text{ if } i^{th} \text{ project is included in P} \\ 0 \text{ otherwise} \end{cases}$$

Let the first order effects of p_i on p_j ($j = 1, \ldots, n$) be given by the matrix (G_{ij}) where the diagonal elements $G_{kk} \geq 0$ for $1 \leq k \leq n$ represent the worth of p_k taken individually. The gross worth of P may be calculated by

$$G = \sum_{i=1}^{n} \left(\sum_{j=1}^{n} G_{ij} \, \delta_j \right) \delta_i \qquad (2)$$

and the net worth of P calculated by

$$W = \sum_{i=1}^{n} \left(\sum_{j=1}^{n} A_{ij} \, \delta_j \right) \delta_i \qquad (3)$$

in which

$$(A_{ij}) = (G_{ij}) - (C_{kk}) \qquad (4)$$

and

$$(C_{kk}) = \text{a diagonal matrix.}$$

It is desired to maximize W over the set of column vectors $\delta = (\delta_1, \ldots, \delta_n)$, or, in vector notation,

$$\max_{\delta} W = \max_{\delta} \delta' A \delta \qquad (5)$$

It should be noted that the G_{ij}, and hence the A_{ij}, may take negative values, otherwise the problem would be trivial. The discrete finite nature of the problem guarantees the existence of an optimum selection of the p_i.

THE TIME DIMENSION

So far the discussion has referred to a timeless decision-making universe. Now it is convenient to introduce the time dimension into the analysis. Answers must be found to questions such as these: Should projects be carried out all at once, or should one proceed in stages? Should one prefer a facility with a long physical life, or one which is less durable and necessitates frequent repairs and renewals? Should projects be constructed now, or would it be better to postpone them?

Discounting for Present Value

Such problems call for comparisons of projects with different life spans, and different paths (or profiles) of gain and cost streams over time. Solutions can be found by giving an economic meaning to time. Discounting is an exceedingly convenient procedure for comparing projects with different lifespans and value streams, by reducing the complex time-space structures of the projects into flat images, as it were.

(It also produces unambiguous results. McKean (5, pp. 92-93) demonstrates how alternative "fuzzy" annual gain and cost concepts can give rise to different interpretations and may produce a variety of profit rates.) Steiner (28, p. 897) calls discounting "a metric for comparing unlike time profiles".

Standard procedures can be used to obtain solutions. The present value V of a series of gains from a project is

$$V = \frac{G_1}{(1 + r)} + \frac{G_2}{(1 + r)^2} + \ldots + \frac{G_T}{(1 + r)^T} + \frac{S}{(1 + r)^T} \quad (6)$$

in which G is the gain accruing at the end of any unit period t, usually year (t = 1, 2 ... T); r is the rate of interest or discount (here assumed to be constant); and S is the scrap value at the end of the project's lifespan (T).

McKean makes the subtle point (p. 75) that estimating salvage or scrap value means really that costs and gains beyond the project lifespan can be foreseen; this "may be tantamount to peering into the indefinite future". However, there may be a contract or obligation to raze a structure at the end of its life, in which case a definite scrap cost can be put in for the terminal period. As was indicated earlier in the present study, highway investment analyses should allow for site clearing costs, in order not to burden the future with unwanted costs of the past.

What is the appropriate general project selection criterion when time is taken into account? Let it be assumed that there are no budget limitations and that the interest rate is given. Following from the preceding exposition, the objective will then be to maximize the difference between the present value of future gain streams and the present value of future cost streams. In other words, the objective is maximization of the present values of net gain streams over time. This intertemporal objective of net gain maximization is analogous to the timeless net gain maximization procedures applied to projects and groups of projects as depicted by Figure 1 and Tables 4 and 5.

Some Examples of Different Time Profiles

This brief first statement of general principles makes it possible now to look at some typical project planning examples. There are no budget limitations and the interest or discount rate is alternatively given at 5 percent and 30 percent. The cases are greatly simplified for purposes of exposition. To render the computations not too cumbersome, fairly limited planning horizons (i.e., short project lifespans) are stipulated.

In Figure 5 and Table 6 different versions of the same project, which may be visualized as a toll highway or a freeway, are contrasted with each other. These are mutually exclusive project possibilities and the planning agency must select one of them. The information on the design and construction variations will have come from engineering studies and the gain data from traffic, economic and market research.

In Case A the highway is immediately, during the first year, constructed to full capacity, say to four-lane standards, at a cost of 100. Operating costs of only 10 units per annum must be carried for the remaining four years. This represents high capital intensity.* This is a model of gain and cost streams as they actually occur in time; therefore, the question of the placement of depreciation or amortization charges in time does not arise. Gains build up over the years, from 20 during the first year to 100 during the last. In the real world, gains would probably decline toward the terminal period, but this point is not essential to the present exposition. As depicted, in all four cases gains drop to zero in year 6 and project continuation would therefore mean a loss.

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*Capital intensity can conveniently be measured by the ratio of initial costs to the present value of the future stream of costs. The higher the ratio the more capital intensive is the project.

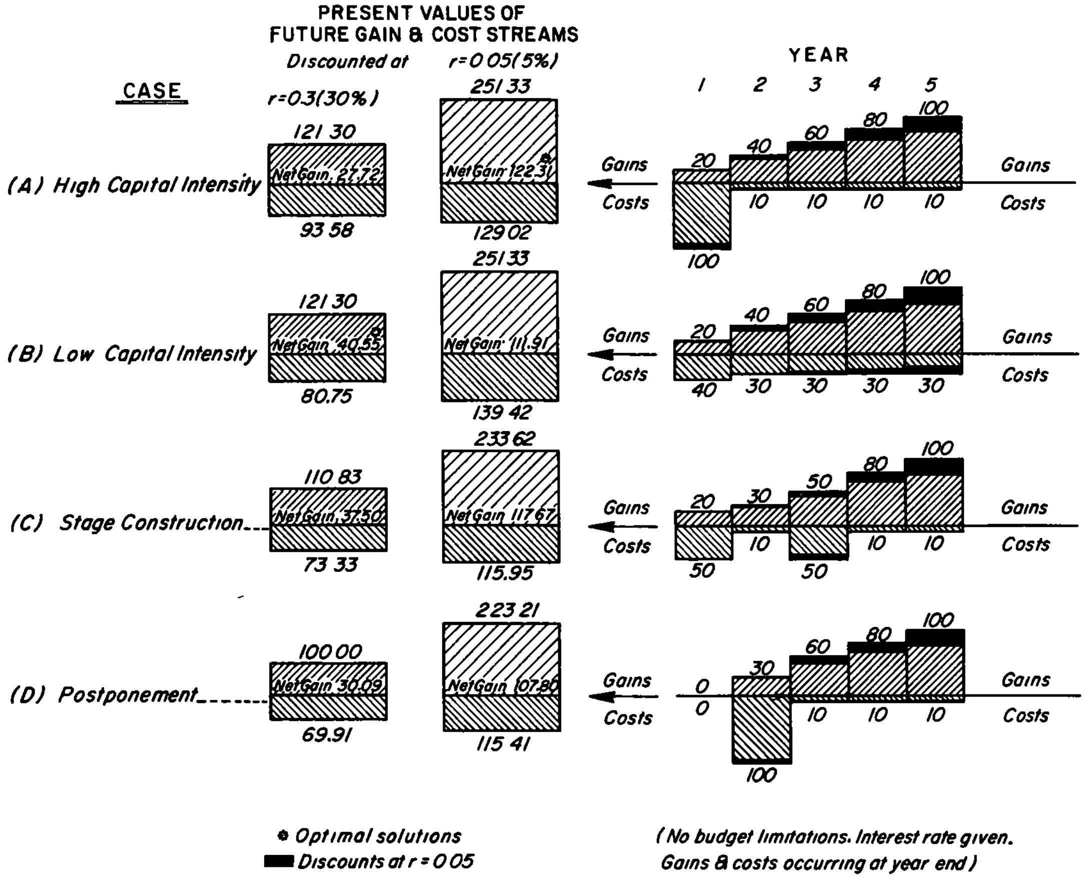

Figure 5. Project comparisons.

Case B represents a less capital intensive solution than Case A. The highway is from the outset constructed to lighter standards at an initial cost of 40, but thereafter much heavier reconstruction and maintenance expenses of 30 units per annum are incurred through to the end. Assuming that there is no deterioration of service standards despite lighter original construction and the necessity for frequent repair work on the road—a somewhat doubtful proposition—gains over the years will be the same as in Case A. If desired, reduced gain values can easily be put in as a concession to reality, but again this does not invalidate the general method.

Case C involves stage construction and is, as it were, a variation of B. During year 1 only two lanes are constructed at a cost of 50 and the highway is expanded to four-lane standards during year 3. Moderate operating expenses of 10 units per annum are incurred during the other years. As a consequence of stage construction, traffic growth is a little slower compared with the first two cases and only 30 and 50 gains, rather than 40 and 60, accrue during the second and third years, respectively. Case C can, if desired, be changed around at will (for example, by letting construction of the additional lanes occur during year 2 or year 4). Operating costs during year 2, since only two lanes have to be looked after, could also more realistically be assumed to be 5 rather than 10 units.

Case D, finally, considers postponement of four-lane construction by one year, to let demand build up more. It is an extreme variation of Case C. Penalties are incurred that way, with first-year gains lost irretrievably, of course, and second-year gains running at 30 units only, rather than 40 as in Case A. On the other hand, there are savings in operating costs during the first year.

TABLE 6

PROJECT COMPARISONS OVER TIME
(No Budget Limitations, Interest Rate Given, Gains and Costs at Year End)

	Present Values of Future Gains and Costs		Yearly Discounted (Not Discounted) Values, r = 5%				
Items	r = 30%	r = 5%	1st	2nd	3rd	4th	5th
		Case A, High Capital Intensity					
Gains	121.30	251.33	19.05 (20)	36.28 (40)	51.83 (60)	65.82 (80)	78.35 (100)
Costs	93.58	129.02	95.24 (100)	9.07 (10)	8.64 (10)	8.23 (10)	7.84 (10)
Net Gains	27.72	122.31[a]	-	-	-	-	-
		Case B, Low Capital Intensity					
Gains	121.30	251.33	19.05 (20)	36.28 (40)	51.83 (60)	65.82 (80)	78.35 (100)
Costs	80.75	139.42	38.10 (40)	27.21 (30)	25.92 (30)	24.68 (30)	23.51 (30)
Net Gains	40.55[a]	111.91	-	-	-	-	-
		Case C, Stage Construction					
Gains	110.83	233.62	19.05 (20)	27.21 (30)	43.19 (50)	65.82 (80)	78.35 (100)
Costs	73.33	115.95	47.62 (50)	9.07 (10)	43.19 (50)	8.23 (10)	7.84 (10)
Net Gains	37.50	117.67	-	-	-	-	-
		Case D, Project Postponement					
Gains	100.00	223.21	-	27.21 (30)	51.83 (60)	65.82 (80)	78.35 (100)
Costs	69.91	115.41	-	90.70 (100)	8.64 (10)	8.23 (10)	7.84 (10)
Net Gains	30.09	107.80	-	-	-	-	-

[a]Optimal solutions.

From mere inspection of the gain and cost streams over the five years and without knowledge of the economic value of time, it is impossible to say which case represents the optimal solution. However, by discounting the streams to arrive at present values, a rational choice can be made. The final results of discounting are shown in the first two columns of Table 6 and Figure 5, while the detailed discounted values year by year are given in the last five columns of the table (undiscounted actual values shown in parentheses). Gains and costs are assumed to accrue at year end.

Which project proposal is the best? If an interest rate of 30 percent is assumed (first column), Case B represents the optimal solution. Net gains are maximized at 40.55 and cannot be bettered any other way. On the other hand, if an interest rate of 50 percent prevails, the capital intensive Case A maximizes the present value of net gains at 122.31 units. Stage construction is the second best solution under both interest rates and project postponement comes third at 30 percent interest and last at 5 percent.

By the right choice of interest rates and gain and cost streams over time, any one of these four broad project cases might be made to come out best. It is difficult to phrase rules which will cover all complex situations. Generally, very high interest rates will penalize projects of high capital intensity, or high initial investment. Or, there is an inverse correlation between durability and the rate of interest. Very low interest rates will normally work in favor of future generations, as it were. Why? It is always assumed that there will be some positive payoff, some net gain from projects, otherwise they would not be carried out at all. At very low interest rates this net gain can accrue at some distant date and still count quite substantially in present terms. At the extreme, with no interest assumed at all, consideration would even be given to investing 100 cost units into a project now, although gains of 110 units would not accrue until 100 years from now and there is no payoff at all in the interim period. It can also be observed that the influence of variations in the interest rate will be very powerful when long project periods are involved. When 50-year projects are considered, as is sometimes the case in highway or transportation planning, the leverage effect upon gains and costs of moving the interest rate up or down slightly, will be quite tremendous. (Grant and Oglesby (22) chide highway planners and analysts in the United States for frequently using unjustifiably low interest rates—3½% or less—or even zero ones.) An original investment of $1 million will be $5.6 million at 3½% compound interest, but will be more than double that, with $11.5 million at 5 percent at the end of 50 years.

Intertemporal Program or Transportation Activity Analyses

Complications arise when interdependent projects must be dealt with. Consider network or systems effects, such as those depicted in Figure 4 and Tables 4 and 5. Given one particular discount rates, such as $r = 0.05$, the project bundle ACD might maximize net gains, as shown in Table 5. But when, for example, $r = 0.30$ applies, some quite different project combination might be the optimal solution. That this may happen can easily be shown with the aid of numerical examples. Indeed, given sufficiently varied gain and cost stream profiles over time, any project bundle can be made optimal at the "right" discount rate.

It can be seen, therefore, that the composition of the set of projects which maximizes net gains will change with fluctuations in the discount rate. One can imagine 16 columns representing the profiles of all values over time to rise vertically from the flat matrix used to describe the system (see Table 4). Discounting, then, can be visualized as a device to project the values represented by the vertical columns downwards onto the flat plane. But the projected values, or flat images, will be affected by the focussing of the projection apparatus itself; that is, by changes in the discount rate.

If the rules of the transportation planning game demand that several discount rates must be considered, the corresponding number of flat projections of gain and cost values must be prepared. In other words, separate lists of optimal project bundles must be drawn up for the various discount rates. It is clear that numerous "side calculations", as they are termed in the literature, then become necessary.

The complexity of the iterative processes necessary to find optimal solutions under these circumstances may alarm some. But it is well to remember that such complexity is caused by the system effects and fluctuating interest rates (i.e., by the circumstances which the analyst may encounter in the field) rather than by the analysis itself. It should also be emphasized that the phenomena discussed here are not restricted to highways or transportation, or to the public sector, but may also, of course, be found in private enterprise investment planning.

HIGHWAYS IN THE ECONOMY

There are two facets of major transportation investments in urban areas which must be studied: First, the cost and gain effects in the metropolitan region which are directly traceable to the introduction of the freeway or other project. Second, the general economic consequences of resource allocation for highway transportation, rather than for other purposes. These two aspects will be considered in turn.

Effects on the Metropolitan Economy

Decision-making responsibility is now raised to the level of the metropolitan economy and the analytical and planning horizon expands correspondingly. All remaining cost and gain effects become internal to the deliberations. It is submitted that public agencies, by virture of the statues governing them and the mandate given to them by legislatures, are obliged to adopt this broadest possible viewpoint.

Turning once more to Table 3, the first group of metropolitan economy cost items requires little explanation. Accident exposure of non-users on a controlled access freeway itself will be very slight, but will be considerable on the feeder routes, etc., leading to and from the ramps; these segments are part and parcel of the project, because the freeway itself represents neither origin nor final destination for travelers. Accident costs, as well as noise, dirt, air pollution*, etc., costs, are predominantly non-market items and the familiar problems discussed earlier apply. Similarly with most of the possible beneficial city planning, aesthetic, etc., effects of a freeway project.

The designations "imports", "exports", and "foreign aid" are somewhat unorthodox, but become reasonable on closer scrutiny. If the viewpoint of the metropolitan economy is adopted, there will be cost and gain effects which are external to it, but internal to senior levels of government, to the national economy, or, more fancifully, to the world as a whole. Exports, or gains, set up by a freeway project might be increased profitable tourist spending within the metropolis. Imports, or costs, might be accommodation of traffic from outside the metropolitan region which does not contribute to the costs it causes. The "corridor state" problem is an example for this in the intercity field. Peak-hour commuters into the central city core, who reside in dormitory suburbs outside the city boundaries where they cannot be taxed for freeway support, are another manifestation of such pseudo-imports. Metropolitan government is designed, among other things, to overcome these unwanted import aspects.

From the metropolitan viewpoint, grants-in-aid rendered by federal, state or provincial governments constitute foreign aid, as it were. Relevant to the transport analyst are highway aid, city renewal and urban transit support. The history of these intergovernmental transfers is long and the allocation formulas are most involved. The rationale for highway fund transfers seems to be based on the following considerations:

1. The senior government is the more efficient revenue or tax collector; hence, after deduction of expenses, the collection agency simply hands moneys back to the source jurisdictions.

2. The senior government has bona fide jurisdictional and functional interests in highway facilities in metropolitan areas (e.g., the urban portions of the interstate or statewide highway system), presumably as required by genuine interstate or statewide traffic. However, for reasons of administrative efficiency, close local supervision, etc., the work is actually carried out or contracted out by junior governments, hence fund transfers become necessary.

3. The senior government performs an income redistribution role; for example it takes more from automobile-rich regions (cities, densely settled states) and gives more to automobile-poor areas (rural districts, sparsely settled states).

4. The senior government takes over certain functions, because the junior governments are not fit, willing or able to carry them out efficiently.

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*Care must be taken to avoid double-counting and other social bookkeeping errors: accidents can be minimized by higher freeway project expenditures; noise, dirt, etc., can be held down by more landscaping and maintenance; air pollution health hazards can be converted, as intended by a recent California law, into motorists' private costs by making exhaust fume cleaning devices compulsory.

5. The senior government acts as a consultant, or renders technical aid, without interfering with the actual decision-making of the junior jurisdictions.

It appears that all of these five major elements are present in varying degrees in current inter-governmental highway money transfers.

What is the effect of this upon planning of, say, a metropolitan transportation facility? The distortions introduced, wittingly or unwittingly, into decision-making can be considerable: "foreign aid", if it requires little local matching effort, is almost costless—one might as well obtain it, before it is lost to another city or region. There is little doubt, that at the present time "foreign aid" works in favor of highway solutions in big cities and to the detriment of other technological proposals. If there is confidence in the quality of metropolitan decision-making it is desirable that "foreign aid" be neutral in its effects upon urban transportation planning. Although no attempt can be made here to do this topic justice, it is clear that precise definitions and distinctions of the senior governments' roles —as collection agents, bona fide decision-makers in urban areas, income redistributors, trustees, or technical consultants—would be an important first step toward removal of "foreign aid" distortions in urban transportation planning.

Land value changes and other broad effects on Gross Metropolitan Product and the general urban way of life, finally, represent one of the greatest challenges to the analyst. Opportunities for double-counting or for neglect of important effects, usually detrimental ones, abound. This perhaps explains why the results of many highway benefit and economic impact studies carried out in recent years have not always lived up to advance expectations. True, a highway or freeway project may set up faster land value increases in an adjacent zone, as compared with real estate price trends in a remoter control area. But, as a result, simultaneously a relative decline of property values elsewhere in the metropolitan area may have taken place, which may go unrecorded. Hence, from a metropolitan viewpoint, the relative gain at one locality may be offset by a relative loss at another. The true picture is further distorted by the secular land price increases (due to growth of population, incomes, etc.), by many cross effects, and by property acquisition for freeway purposes itself. It must not be forgotten that highway departments these days are important real estate customers themselves. It is further not clear whether maximization of land values (or of property assessment and tax revenues) should be the overriding human objective in urban areas. The assumptions which must be made before real estate trends can be accepted as the sole success indicators for the metropolis, certainly deserve close scrutiny.

Finally, those who regard big cities as something more than just convenient locations for producing the maximum number of vehicle-miles, would wish to draw further aesthetic, social, political, cultural cost and gain effects to the attention of the metropolitan decision-makers. The quantification of the relevant personal or collective value judgments and their aggregation with all the other effects listed in Table 3, will obviously pose tough practical problems.

Highway Investment Planning in the Macroeconomic Setting

So far it has been assumed that resources for the initiation and operation of freeways and other highway projects will somehow be forthcoming. How does resource allocation at the higest level take place? To say that funds are assigned in accordance with given budgets really begs the question, because then one must inquire how the budgets were arrived at in the first place. The budget assumption, furthermore, can be dangerous in its consequences: in economic terms, funds once budgeted are regarded as costless by the spending agency, because no alternative uses for the moneys are contemplated. If the budget is too small, profitable investment opportunities will go begging; if it is too big, uneconomical projects will be undertaken.

In the highway field, a more refined budget approach is being used. Financial self-sufficiency, or the no-deficit rule, coupled with so-called "user tax dedication", are the chief constraints, so that revenues expected to be collected from motorists will determine the spending budget. This economic regime implies, in order to function properly, that the following conditions prevail:

1. The level of user charges must be set rationally, i.e., in response to proven

highway investment opportunities and not vice versa. With inelastic demand for the usually highly monopolistic road transportation function, it is evident that mere willingness of users to pay, say $0.02, or $0.05, or $0.10, or $0.20 per gallon gasoline tax, does not constitute proper guidance for spending the moneys.

2. The highway function must be a going concern, which is neither in a sharp expansionary phase, nor in the process of contraction. If expansion was expected, credit financing should be resorted to (why should the present generation of motorists pay excessively high charges to finance facilities which will mainly be used by future generations of motorists?) If contraction of highway demand was anticipated, charges should be reduced or the money be redirected to other purposes.

3. Highway revenues, once collected as such, do not have more profitable application anywhere else in the economy. To emphasize this crucial condition, visualize the highway department as one technological division of a large concern (namely, public interprise, or "the public interest") in the same way that, say, Chevrolet is one of many divisions of General Motors. The financial autonomy rule for highways (user tax dedication, earmarking of funds), in terms of General Motors, then implies that Chevrolet profits always must go back to the Chevrolet plant, although no expansion may be needed there and although dozens of far more worthwhile G.M. projects (fuel cell development, diesel locomotives, refrigerators, VTOL vehicle, rocket ship, etc.) may go begging for lack of funds. It will be recognized at once that one of the great advantages of a big concern like General Motors is the ability to switch funds freely within its economic empire to the most profitable applications. Should this freedom of investment fund dispostion, a priori, be denied to the custodians of the general public interest?

The preceding, necessarily brief, discussion of one of the key issues of contemporary highway finance brings out the point that both the ordinary and the user-revenue determined budget alike must be regarded as subordinate means to a superior aim. This aim is clearly the disposition of funds, throughout the economy, in such a way that aggregate net gains are maximized. It is, therefore, the anticipated investment opportunities which should determine the allocation of money for investment.

One can imagine that within the economy an aggregate public-private demand schedule for investments exists. Suppose a mixed list of private and public projects, including highway ones, are hierarchically arranged by rates of return. At the top of the list there will be a few very profitable ventures. As projects with lesser profitability are included, cumulatively the total demand for investment funds will grow. When such a mixed public-private investment demand list is confronted with a given interest rate, the following results will be obtained: At the margin, there will be a public project, or a private one, or both, which just barely qualify for investment. This means that the marginal projects, when their future cost and gain streams are discounted at the given interest rate, will just promise to break even; in other words, at the given discount rate, their V's exactly equal their C's. In this position, total net gains for the economy will be maximized and no further shifting of resources, into and out of projects, or from public to private and vice versa, could enhance net gains expected from all ventures as a whole.

Clearly, all supermarginal projects (i.e., all those which show $V \geq C$ at the given discount rate) should be carried out. Adding up the investment costs of qualifying projects for each sector, such as highways or transportation, will reveal the correct individual investment budges; the grand total of all will represent the correct total investment budget for the national economy for the given period. Any other budgets will yield lesser aggregate net gains.

Consequences for Highway Investment Analysis

It is evident that the interest of discount rate thus plays a key part in investment analysis. But all the chains of causation determining the crucial interest rate factor—incomes, savings, taxation, central bank policy, attitudes to risk, dividend policies, profit expectations, technical knowledge and discoveries, etc.,—cannot possibly be described in a few simple sentences. Nor is it necessary for the present purpose to do so. The preceding discussion was designed to demonstrate that any searching inquiry into highway and other public investment planning inevitably merges into general equilibrium analysis.

Where does this leave the highway analyst who has a very immediate and practical job to do? It seems that he has to carry out calculations within a framework of assumptions and data which he and many other public and private decision-makers and analysts themselves determine in some unpredictable fashion. Would he not be forced to say: "Since everything depends on everything else, nothing can be determined"?

In this situation it is best to assume the interest rate as given. This approach has a number of attractive features. It might be visualized as a predicted general market interest rate, worked out by federal financial experts or central bank specialists. With a given interest rate, allowing somehow for risk, length of investment period, etc., projects financed on a pay-as-you-go basis, by budget allocation, or through bond issue, could be mutually compared. Furthermore, if the right interest rate range is selected, performance comparisons between various public (highways, subways, water resources, city redevelopment, etc.) and private projects become possible and optimal performance of the investment process over the whole economy can be brought about.

How should the right interest rate be chosen, if it cannot be assumed as given? Different interest rate concepts have been proposed for adoption by public agencies. Krutilla and Eckstein (24), for example, have empirically calculated the social cost of federal capital at between 5 and 6 percent. Grant and Oglesby (22), correctly proposing an opportunity cost concept for investment opportunities foregone elsewhere, mention rates of 5 to 7 percent for highway planning purposes.

Little of general value can be said here about the choice of the interest rate, or what may be called more broadly the social rate of time preference. If it is not given or forecast by some central authority, the analyst in each case must select a rate and defend his choice as well as he can. In any event, there is no excuse for using no interest at all; i.e., adopting a zero rate of discounting. Sometimes, as McKean, (5) suggests, it will be convenient to prepare analyses based on several "likely" interest rates. As Marschak (17) points out, the "études de rentabilité" of the French nationalized coal, gas, electric power and railway undertakings likewise show predicted cost and gain streams discounted at one or more "interesting" rates.

If designation or choice of the interest rate as the rationing device is completely ruled out, what is the alternative? The only other course of action seems to be to set the budget more or less arbitrarily. If so, the analytical and planning objective is still maximization of net gains over time (i.e., maximization of the present value of V - C). It can be shown mathematically that arrangement of projects in order of their benefit/cost ratios (V/C), or by internal or other rates of returns, going down the lists until the given budget is exhausted, does not necessarily lead to net gain maximization and may, indeed, result in sub-optimal decisions. Because even with a given budget maximiztion of V-C is still the correct criterion, one must find the discount rate which just exhausts the amount available. It will be convenient perhaps, as McKean (5) explains, to work out project lists based on reasonable ranges of discount rates and then determine the correct budget cut-off point by interpolation.

Project and program interrelationships (systems or network effects), make for "jumpy" project bundle choices when the interest rate is varied, as has been seen: at 5 percent the project selection ACD may be optimal, at 7 percent perhaps CDEF, at 10 percent possibly B, and so on. Or, to put it differently, there is no unique list of "ranked" projects which is correct at all discount rates. This once more shows that project selection by means of benefit-cost ratios may not lead to optimal results. Therefore, full project search procedures must be carried out for each likely discount rate. Electronic computers or improved mathematical techniques for the iterative processes may reduce the work load. This is a most promising field for research.

Even with given budget limitations as the chief constraint, all is not lost for the analyst: if he can point out to the decision-makers that an extreme discount rate of, say, 30 percent (or of 1 percent) just exhausts the budget, such information in itself may greatly influence future action. In view of such exceptionally good (or bad) investment opportunities prevailing in the sector in question, more (or less) funds might be allocated next time.

CONCLUSIONS

Summary

This paper has attempted to sketch the economic principles which might guide highway planning. Beginning at the lowest level of decision-making, it was shown how projects might be identified and how the prospective cost and gain effects over their lifetime might be analyzed. It was pointed out that maximization of net gains would determine the optimal output solution, which incidentally would also represent the best position for consumers, for contributing productive factors and for the economy at large.

Next, the interrelationships between projects and programs or technologies were traced. It was seen that such so-called systems or network effects might react back upon the selection of the optimal project bundle. Changes in the discount rate—a convenient device to reduce complex gain and cost streams over time into flat, comparable images, as it were—may further change the composition of the desired optimal project investment combination. There is no unique ranking of projects at different interest rates. Iterative techniques become necessary to obtain the optimal investment planning results.

Finally, highway investment planning was discussed in the broadest economic context. It was pointed out that adoption of the "right" interest rate (which might be a market rate or range of rates) for project selection and discounting purposes, would guarantee not only maximization of prospective net gains from all public and private investments, but also allocation of the right magnitude of funds for the various purposes (private and public; highways, rapid transit, city redevelopment, etc.). If at all possible, it would be convenient if the planning interest rate, as the crucial analytical tool, were given or forecast by some higher authority (federal financial experts, central bank specialists). But if necessary the analyst himself may have to select an appropriate rate and then defend his choice. Neglect of interest in highway or other transportation planning (i.e., adoption of a zero rate of interest) is inappropriate. Due to institutional circumstances, either arbitrary or revenue-determined (earmarking of highway user taxes) budgets may be the chief analytical constraint. If so, proposed project selections must be subjected to discounting at several "likely" rates, until the budget is just exhausted. It should then be pointed out to the decision-makers, that a certain rate, which may be rather high (or low), applies to the program selection; this in itself would strikingly indicate the need for increased (decreased) budget allocations in future.

Throughout, it was pointed out that many market and non-market cost and gain effects will be caused by highway actions. These different value species pose treacherous problems of identification, quantification and aggregation. Although they may have to be presented separately, in dollars, in words, in physical or other terms, it is not permissible to ignore any effects for which evidence exists and which are relevant to the problem at hand. Some cost and gain effects will appear to be internal, others external, to the analyst's area of responsibility. It was argued that any public agency, by virtue of its legislative mandate, must adopt the broadest possible viewpoint—that of the national, state, regional, or metropolitan economy. This means that any project effects occurring within this broadest of horizons—repercussions inflicted upon other projects, technologies, transportation or the economy as a whole—are internal to the decision-making viewpoint, and therefore of analytical interest and concern.

Some Practical Consequences

This paper has been largely presented in condensed, highly abstract form. It was felt that this was the best way in which to discuss the enormously complex problems of highway and other public investment planning.

It may well be asked that indications be given as to what all this means in immediate, practical terms. In conclusion, an attempt is therefore made to highlight some of the more important aspects of direct concern to highway planners and decision-makers. The convenient question and answer form of presentation is used. Personal judgment will have to be employed for some of the answers, with the attendant risk of bias.

1. Are the analytical techniques outlined here correct beyond doubt? Can they be relied upon by the practitioner?

It would be misleading to say that no controversy about their validity in all circumstances remains among economists themselves. Capital and investment planning theory has been built up rapidly in recent years, and there are bound to be further developments ahead. Application of some of the newer concepts to the public sector—which lacks the usual private enterprise competitive price, normal profit, survival-of-the-fittest, profit maximization motivation, etc., constraints—is regarded by most students of the subject sphere as pioneer work. Even recent books on one public sector—water resources—reveal differences of opinion on which economic yardsticks are the correct ones. However, under certain circumstances some of the more popular economic criteria (internal rate of return, maximization of benefit-cost ratios, maximization of investor's present worth) yield the same answers. At present, the maximization of investor's present worth, also called maximization of the present value of net gains technique, which was incorporated in this study, appears to be by far the most satisfactory one. It is, incidentally, also the economic criterion recommended by McKean (5) for the water resource field and other public activities. With some modifications and some additional features grafted on to it, the present worth apparatus can handle a great range of practical planning problems very well.

It is interesting to note what the Staff Study Appendix to the Commerce Department Report on Transportation (2) has to say on public investment planning concepts:

> Unfortunately, adequate tools and methods of analysis are not presently available. The use of economic analysis in public investment decision-making in recent years has received increasing attention, but the only tool that has had significant application is the benefit-cost ratio...There is need for analytical procedures for both justification and ranking. Only justified projects and programs should be undertaken at all and the best projects should be undertaken first.
>
> Although critics have pointed out several weaknesses in the benefit-cost ratio as a decision-making device, it seems to be the best tool of analysis that has been widely used. It should receive wider use in the highway field and should be applied in airways and airport investment decisions. But it needs to be studied and improved. (p. 42)

The foregoing statements and others contained in the two Commerce Reports, which may well have stirred other transportation economists and analysts into thought and action, certainly reflect the motives behind the present study.

2. Are analyses of the type described here worth bothering about? Supposing the theories shown are found to be correct, is it likely that they will be adopted in practice?

Of course, planning of this or any other type is not costless. But no planning at all would probably lead to incomparably greater costs for the community. The tangible and intangible returns from better investment planning in the highway and general transportation sphere are likely to be very large indeed. Present highway budgets and other transportation expenditures are so enormous at present, and expected future problems in this area are so great, that even slight analytical advances will yield great community returns.

The highway profession has a particualrly good tradition in planning. It is most likely that the newer economic or other analytical tools, provided they can be shown to be sound and practicable, will be received enthusistically by the decision-makers and planners in the highway field.

There is keen official interest in improved economic planning in the transportation sphere. The Commerce Department Report (4) repeatedly calls for the adoption of investment analyses as a guide to policy; examples are:

> The national transportation role will be carried out most effectively if decisions on necessary public investments are based on analytical procedures using objective criteria comparable to those which govern the economy at large. (p.21)

> The Government should evolve and keep current a comprehensive plan for its investment in all types of transport facilities. Within each type of facility, it should continue to develop adequate standards of analysis to compare costs with benefits for each project. It should also devise standards by which to compare each primary area of investment (highways, rivers, and harbors, airways and airports) with the others and with private transportation investment, so that investment decisions can be made upon similar tests of need and public advantage. (p.6)

> The Government should establish a transport investment planning staff to use objective analytical methods in making unified, long-range Federal investment plans to be published and included in the annual budget document... (p.22)

> (The Federal Government) should encourage urban long-range community planning, including total transportation planning to make full use of highway, transit, rail communication, and all other capacity to minimize total transportation cost and congestion... (p.25)

3. What is the best way to gain acceptance for improved analytical procedures?

Probably in the usual way: through research papers, workshop conferences, through the spearhead of consultants' work, through pilot projects which can be publicized to explain the methodology. The Chicago, Detroit and Washington, D.C. studies, among others, in some respects already represent significant practical advances.

Once some acceptance and experience has been gained, it seems important to review the influential AASHO, BPR, etc., manuals. Simultaneously, planners and researchers will take a growing interest anyway. That this has already happened, is attested by the growing number of relevant papers on highway planning, economics and finance presented at recent Highway Research Board meetings.

4. Applying subjective judgment, which problem areas in transportation might at present be regarded as the most critical ones?

First, in the highway field, accidents probably constitute the most serious and intractable of all problems. As was pointed out, purely economic considerations cannot and should not be the sole guides to decision-making in this respect. It may well be that the present accident toll, on purely functional grounds, cannot be drastically improved upon. After all, there seem to be limits to improvements in the average operating performance of large segments of the population put behind the steering wheel. To maintain or officially inspect the mechanical reliability of huge fleets of old and new vehicles, individually owned, also seems to be inherently difficult. Furthermore, a fair amount of risk seems to be inherent in the two-dimensionally independent movement, at high speeds, of many vehicles traveling along narrow routes at much the same time. Perhaps the inevitability, within statistically defined limits, of highway accidents should be recognized realistically. Possibly the correct high-level decision would then be to reduce the amount of highway travel (for example, by offering attractive, safe rapid transit services in cities) as the most direct and effective way to obtain improvements in transportation accident trends.

Second, highway planners, especially when their actions affect urban areas, have on occasion been accused of being insensitive to broader transportation issues and general community values. Although there may be some truth to this, for the following reason this is rather superficial criticism:

(a) As was pointed out, the determination of the decision-making level, or planning horizon, is crucial. It cannot be expected that highway planners, hired and paid to perform a highway job, will suddenly and without instructions, adopt a general transportation or community planning viewpoint.
(b) It is really the responsibility of the ultimate decision-makers (legislatures and their executive arms), either to reconcile conflicts between projects, technologies and broad economic and social activities at the highest level of authority, or to issue appropriate instructions to the lower echelons of officials.
(c) Until recently, it seems, rural highway development predominated and there traffic, technical, economic and community objectives usually coincided. The most acute conflicts of interest have only been experienced with the pushing of large-scale highway projects in purely urban areas. From the point of view of the highway profession, clashes between their objectives and city planning, esthetic, social, etc., considerations are new, rather unexpected phenomena.
(d) In all fairness it might be pointed out that highway planners have definite, everyday jobs to do. So far, it seems, the necessary precise guidance for their work has sometimes not really been forthcoming in usable form from local governments and city planners.

One can be most hopeful that with more precise definitions of objectives and governmental responsibilities in urban areas, coupled with advances in anlaytical techniques, satisfactory transportation and community planning results will be achieved in future.

Third, as practical observation in any large city during the "crush" hour will bear out, the transportation industry as a whole surely cannot be particularly proud of its contemporary urban peak passenger service performance. Here further economic research might be of very great help. The peak problem might be somewhat susceptible to pricing policies—people traveling during certain hours of the day could be economically penalized. Some flattening of the peak traffic volume curve segments might be achieved in this way. But there is serious doubt whether it is indeed desirable to suppress peak traffic: Do not certain activities have to coincide in time? Do not the foreman, the worker, the secretary and the executive depend upon each other's presence during the same hours at the same location? Would not such enforced savings in peak transportation costs result in much reduced efficiencies for the rest of the economic system? Perhaps urban peak transportation requirements should be accepted as a given fact of economic and social urban life. If so, further refinements of the investment analyses outlined here might tell how the given task might be performed most efficiently. In any event, research on urban peak problems promises to be one of the most fruitful spheres in transportation research.

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