being interviewed. This picture was taken on Potomac Street where the interviewers were kept busy but still were able to handle the traffic without difficulty. Figure 16 is a picture made on Prospect Street and shows the heavy movement of traffic in both directions. During this particular period from 4:00 p.m. to 5:00 p.m., contrary to expectation, more traffic was moving toward the downtown area than in the opposite direction This was due to the fact that employees adjacent to this station were departing from work

The length of time required to conduct the field work by the types of surveys illustrated above, ranges from 10 days to six weeks. If properly organized and sufficient office personnel is available, trips can be coded even while the field work is in progress. Punching can be started as soon as the data are coded. If the charts are prepared concurrently, the whole job can be completed in from one to four months.

The biggest problem in the city is to adapt the ancient street pattern to a type of traffic that did not exist when the grid system of streets was laid out. The number of motor vehicles has tripled since 1920 while the miles per vehicle have doubled. This means that today, motor travel is some six times that of 1920. New and improved facilities must be built to accommodate this travel if the present city is to survive. The only way in which we can be sure that these new facilities will adequately accommodate the present and future traffic requirement is by a proper understanding of travel desires developed through carefully organized, statistically sound surveys.

THE PHOENIX-TUCSON ROUTE STUDY

Karl Moskowitz, *U. S. Public Roads Administration, Phoenix, Arizona*

SYNOPSIS

Choosing one of several alternate routes between two cities over 100 miles apart is discussed.

There are 14 zones of traffic origin or destination involved in the two cities and intermediate points. Determination of the number of daily trips between each zone and each other zone by means of a few strategically placed interview stations on the several existing highways is explained.

The annual cost of vehicle operation for all inter-zone trips is added to the annual cost of owning the network of roads required, including the proposed route, for each alternate. The route offering the least sum is held to be the logical choice. This criterion is compared with the benefit quotient and with the Oregon (McCullough) Composite Quotient.

The unit costs used were 2½ cents per mile plus 57 cents per hour for passenger cars, 12 cents per mile for light trucks, and 30 cents per mile for heavy trucks. The sources of these figures are given.

The study involves the movement of 21,614 daily trips using portions of 286 miles of existing roads, at a current yearly vehicle operation cost of about $15,000,000 (1947). The conclusion is that the shortest route is the best route, although one segment of it will carry less traffic than the existing equivalent segment of existing road already carries.

Phoenix and Tucson are the two principal cities in Arizona. Phoenix is the capital and center of the major agricultural area of the State, has a metropolitan population of 161,000, and is surrounded by several satellite communities. About 200,000 people live within 20 miles. Tucson has a metropolitan population of about 70,000. The relation of these two cities to the Interstate Highway System is shown in Figure 1. The airline distance between the cities is 107 miles and the shortest existing road, 122 miles. Los Angeles is 380 miles west of Phoenix; El Paso, 320 miles east of Tucson.

The highway between these cities, which is the most important of any length in the State, was designed in the late 1920's and surfaced about 1930. It served its purpose in putting motor transportation into business with the funds available, but it does not meet present standards, particularly in width; and the pavement, a low cost bituminous mix, is failing.

possible between the two cities has been considered for a long time, but the present traffic flow pattern, with the large difference in volume near the towns and the large volumes diverted on branch routes at Casa Grande and Florence Junction, makes it uncertain that as many people would use this shortest route, or that it would serve them as well, as one which deviated somewhat in order to serve more traffic generating areas.

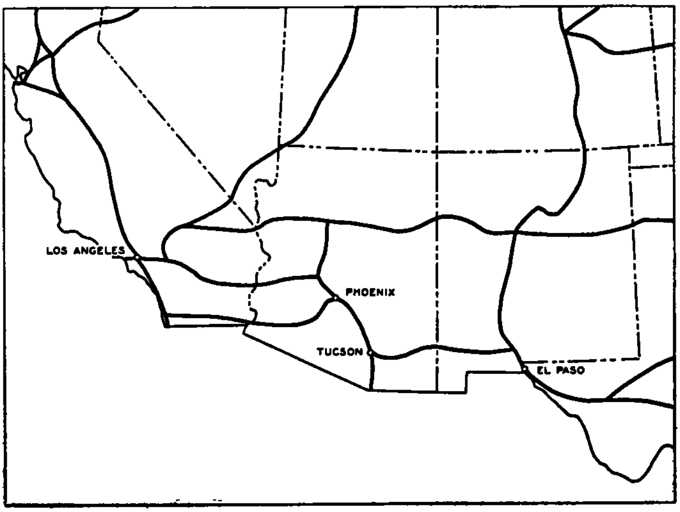

Figure 1

While this route is known as the Phoenix-Tucson Highway, there are many intermediate traffic sources as well as branch routes, and through traffic forms only a fraction of the total (see Fig. 2). The size of this fraction was unknown.

The Arizona Highway Department, Mr. W. C. Lefebvre, State Highway Engineer, and Mr. E. V. Miller, Deputy State Highway Engineer, in charge of planning and programming, decided last year that before spending any money on the rehabilitation of this highway, they would find out where it should go to do the most good; that is, to serve all desired lines of travel the most economically. Physically the problem is fairly simple, as the country is either flat, where streams have deposited flat alluvial plains between mountain ranges, or else it is very rugged and when a road is built it goes around the mountains.

The idea of building a road as straight as

OBJECTIVE OF THE STUDY

Figure 3 shows several of the physically feasible routes between Phoenix and Tucson, superimposed upon the present road net.

In order to examine and assign to possible routes the traffic flow on the existing network, which changes at each intersection, it was divided up into trips. In Figure 4, the circles marked D-1 to D-14 are zones where population is relatively dense and it is reasonable to suppose trips originate or end. There are 91 possible combinations of any two of the 14 zones; in other words the total interzone travel was classified into 91 varieties.

The function of the new route, plus an undetermined mileage of existing road which will remain in service, will be to serve all the trips which occur between all of these zones.

The total annual cost of accomplishing all these trips consists of two items: first, the cost of operating all the vehicles which make the trips during a year; second, the cost of owning the roads they traverse. The cost of owning the roads would include the construction of the new road, retired over a reasonable period of years, the renewal of existing roads which would remain in service, reduced to an annual basis, the interest on the construction cost, and the maintenance of the whole network.

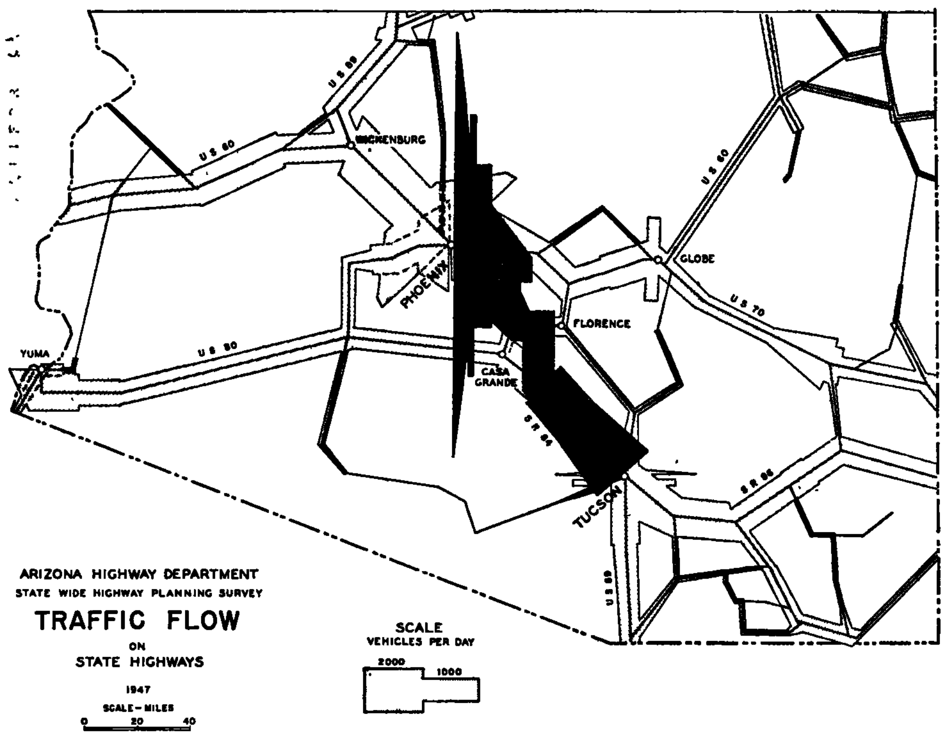

Figure 2

It was held that whichever combination of new route segments and remaining road segments shown in Figure 3 proved least in total annual cost as just defined, would serve the public to greatest advantage. This appears to be axiomatic, but it differs from the various "quotient" methods of route analysis which have been advanced. These other methods would compute a "benefit," being the savings to road users offered by each of the alternates, which is then manipulated to arrive at a quotient. The higher the quotient the greater would be the priority of the considered route.

It does not seem feasible to devise one formula which will do everything in planning highway improvements. This report deals with the selection of one of several alternates, the priority for which among all projects on the State highway system is established by other methods. Furthermore, elaborate studies of a different nature are required for the determination of the extent of any highway system which is to be supported by given classes and amounts of revenue. When the need for a project is established, its priority determined, and the solvency of the system is determined, then all that is necessary is to compare the several alternates with each other, and not with the existing road nor with improvements in other sections of the system.

DETERMINING THE VEHICLE TRIPS

Whether the preferred route were selected simply by adding up costs to find out which was cheapest, or by determining those subtractual benefits and dividing by cost, the total travel on each alternate had to be known.

Figure 4 shows all of the dustless roads connecting any of the zones. Short paved roads, not shown on this map, carry local traffic which will not affect the comparison of the through routes with each other. Also on this figure is a chart with origins as stubs and destinations as column headings, one triangular half of which has a space for each possible trip. Interview stations were spotted on the map by trial, until each space on this chart had at least one station or combination of stations which would intercept all trips between any two zones. For example, all trips from 1 to 12 have to go through either station 7 or station 8; therefore, 1 to 12 trips at station 7 plus 1 to 12 trips at station 8 equals all of the 1 to 12 trips. 1 to 12 trips which go through station 7 will also have to go through either station 4 or station 6; therefore, 1 to 12 trips at station 4 plus those at 6 should equal those at 7. 1 to 12 trips also have to go through either 1 or 2, so the results from stations 1 and 2 are added, and the sum should compare with but not be added to the sum through 7 and 8.

This procedure eliminates the problem of trying to assign fractional factors based on the number of stations a given trip passes through, and the expansion factor at one station is constant for all the different kinds of trips interviewed. Fortunately, the Phoenix Metropolitan Survey was being conducted simultaneously with this study and the cordon interviews of that survey furnished information on trips from zone 1 to every other zone. Trips between zones 2, 3, and 5 were computed by subtracting known trips from total traffic on roads between those zones.

The interview was phrased;

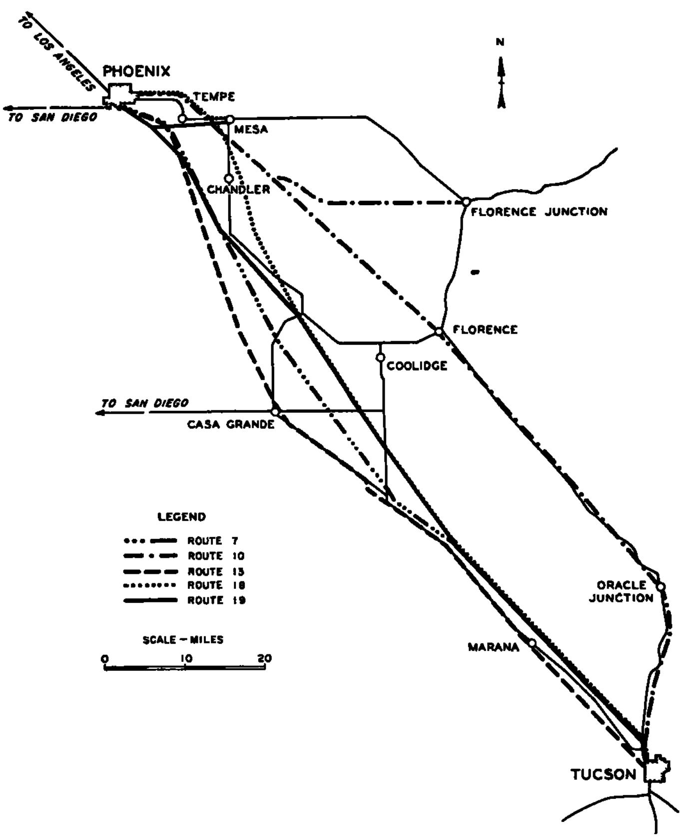

Figure 3. Routes Analysed

Where did this trip begin?
Where did you stop last, and for what purpose?
Where will you stop next, and for what purpose?
Where will the trip end?
What is the main reason for the trip?

Each interview was coded to represent but one trip. If the purpose of an intermediate stop was of a character which would control the route of travel, that stop was used as either the origin or the destination, and the ultimate terminus was ignored. The counterpart of the other portion of the trip was considered to be intercepted at one of the other stations The coded trip was punched on the IBM card, with an expansion factor to convert the volume of complete interviews to the annual average traffic volume at the station.

The method of correlating the information obtained at several stations, for the same trips, may be of interest. Table 1 is an actual work sheet, showing computations of daily trips between zones 1 and 12. One of these forms was prepared for each possible movement—for 14 zones, there are 91 possible interzone movements, and so 91 sheets were prepared.

The punch cards from any station were maintained in one block throughout the sorting and tabulating operations. The tabulation for each station as it came out of the machine showed the number of trips of each vehicle type, from each zone to each other zone, which passed through that station. One station might have as many as 20 different zone-to-zone totals. Each total was entered in the appropriate space on one of the 91 work sheets like Table 1. Whether the total at one

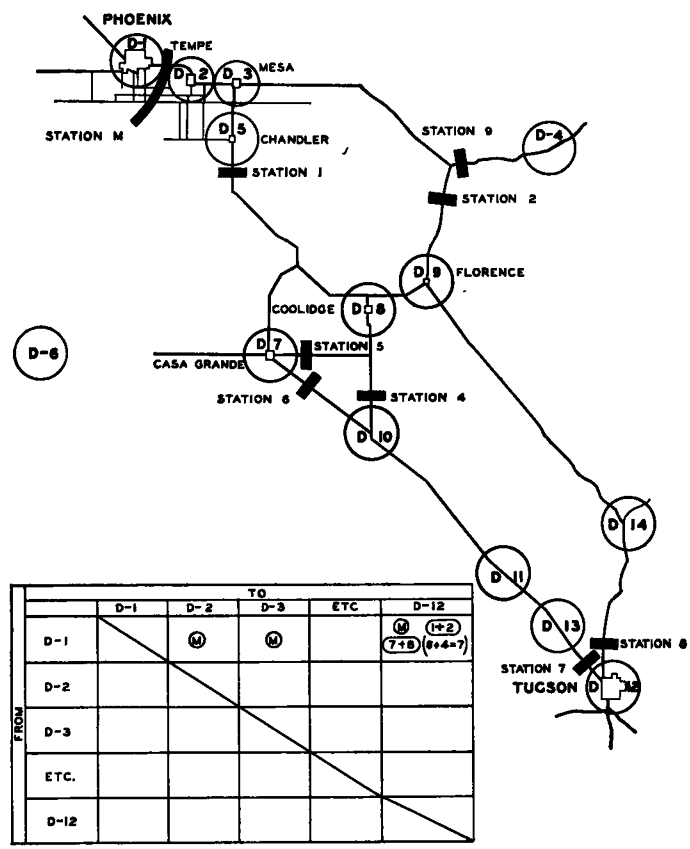

Figure 4. Zones of Origin and Destination and Interview Stations

station was added to the total at another station, or compared with the total at another station, or simply ignored because of being an indeterminate fraction of the zone-to-zone movement, was decided by consulting the map and chart previously described (Fig. 4).

For the figures used later in cost computations, one rounded average for all types in both directions was used. This rounded figure was is not an essential step in the subsequent analysis. Traffic between zones 1, 2, 3, and 5 is omitted because of scale.

Flow maps showing predicted volumes on the new route and all remaining roads were prepared for each of 14 possible route combinations and examination of the 14 maps eliminated from further consideration all but five of the alternates.

TABLE 1
INTERZONE TRIP COMPUTATION SHEET

Zone 1 to Zone 12								Zone 12 to Zone 1							
Interview Station	Pass. Cars	Trucks					Total	Interview Station	Pass. Cars	Trucks					Total
		Pick-up Panel	2 axle	3 axle	4 axle	5 axle				Pick-up Panel	2 axle	3 axle	4 axle	5 axle	
No.								*No.*							
1	282	15	11	17	7	31	363	1	398	13	16	24	18	13	482
2	114	6	3	1			124	2	108		2				110
							487								592
4	209	15	13	11	6	6	260	4	321	6	9	17	6	4	363
6	99	2	5	2			108	6	99	4	7				110
							368[a]								473[b]
7	286	12	26	22	19	24	389	7	391	14	15	36	22	7	485
8	98	3	1				102	8	112	1	1	1			115
							491								600
Total by vehicle types	2517	91	109	131	78	85	3011								
Percent each type	83.6	3.0	3.6	4 4	2.6	2.8	100								
Percent combined types	84	6			10										
Number by combined types	912	65			108		1085								

[a] should compare with 389 from station 7
[b] should compare with 485 from station 7
Average of Trips in Both Directions $\frac{(487 + 592) + (491 + 600)}{2} = 1085$

divided into vehicle types according to the overall percentage, since the number of each type for one observation was unstable because of the small sample represented. The results of the 91 sheets were condensed and entered on the form shown in Table 2 for convenient handling.

A desire line chart (Figs. 5 and 6), showing all trips as straight bands, the width of band to numerical scale, was made for the purpose of a preliminary report to interested officials, and showed that the through trips were probably going to be important enough, compared with any other band, to warrant construction of the shortest possible route. This chart was constructed for demonstration purposes and

VEHICLE OPERATING COSTS

The next step was to tabulate all of the trips occurring on the 91 desire lines, and to extend these trips into vehicle-miles and vehicle-minutes, from which annual operating costs were determined.

One such table was prepared for each of the five alternates selected for complete study. Each of the five accounts for the same total number of interzone trips, whether the trip goes on the proposed road or on a remaining road, or part way on each. The sums of the columns of the tables are the vehicle-miles, by types, and vehicle-minutes required daily to accomplish all desired interzone trips on the route and remaining roads being considered. Intrazone trips were not included, although in three of the zones they will attain considerable volume. It is assumed that although intrazone trips will use portions of the proposed road, the location is to be governed by interzone trips. The effect on the comparison of routes will be small because the number of short trips ignored is about equal for each alternate.

TABLE 2
NUMBER OF DAILY TRIPS BETWEEN ZONES, BY VEHICLE TYPE

Zone	Between Zone 1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. Passenger cars		5290	3279	844	1487	13	280	185	86	60	5	912		10
Light Trucks		591	750	145	432	4	78	71	17	20	3	65	1	3
Heavy Trucks		213	280	42	176		16	16	1	7	1	108		
Total		6094	4309	1031	2095	17	324	272	104	87	9	1085	1	13
2. Passenger cars			235	11	120	1	17	3	1	6		12		
Light Trucks			54	4	35							6		
Heavy Trucks			20		14							1		
Total			309	15	169	1	17	3	1	6		19		
3. Passenger cars				89	325	3	25	18	13	8	1	37		
Light Trucks				19	95	4	18	9	3	4		9		
Heavy Trucks				7	37				1	6		3		
Total				115	457	7	43	27	17	18	1	49		
4. Passenger cars					11	28	8	15	69	4	1	61		5
Light Trucks					6		1	11	24	2		7		
Heavy trucks					2		1	2	8			1		
Total					19	28	10	28	101	6	1	69		5
5. Passenger cars						4	65	63	9	4	2	32		1
Light Trucks						6	20	24	3	3		3		
Heavy Trucks							8	4	1	3		3		1
Total						10	93	91	13	10	2	38		2
6. Passenger cars								5	2	16	1	519		1
Light Trucks								1		6		24		
Heavy Trucks								2				42		
Total								8	2	22	1	585		1
7. Passenger Cars								282	38	487	8	95	1	1
Light Trucks								134	13	214	9	12	1	
Heavy Trucks								31	2	14		8		
Total								447	53	715	17	115	2	1
8. Passenger cars									526	170	7	58		
Light Trucks									105	66	2	14		
Heavy Trucks									40	14	1	11		
Total									671	250	10	83		
9. Passenger cars										21	5	74		
Light Trucks										6		16		
Heavy Trucks										2		7		
Total										29	5	97		
10. Passenger cars											3	94		
Light Trucks											1	25		
Heavy Trucks												6		
Total											4	125		
11. Passenger cars												192		
Light Trucks												66		
Heavy Trucks												9		
Total												267		
12. Passenger cars													397	277
Light Trucks													100	75
Heavy Trucks													6	8
Total													303	360

Each trip was assigned to the most practicable route, and the mileage of the trip was scaled on the proposed route and measured on existing roads. Because of the geography and road patterns involved, there was no doubt in the assignment of trips. The time on existing roads was obtained by cruising with traffic between control points. The time on the proposed route was computed at 58 mph., which is the speed above which very few cars travel but below which many cars travel in each speed increment, on open level tangents in Arizona.

trucks, and heavy trucks or combinations. The latter included all vehicles or combinations having more than two axles.

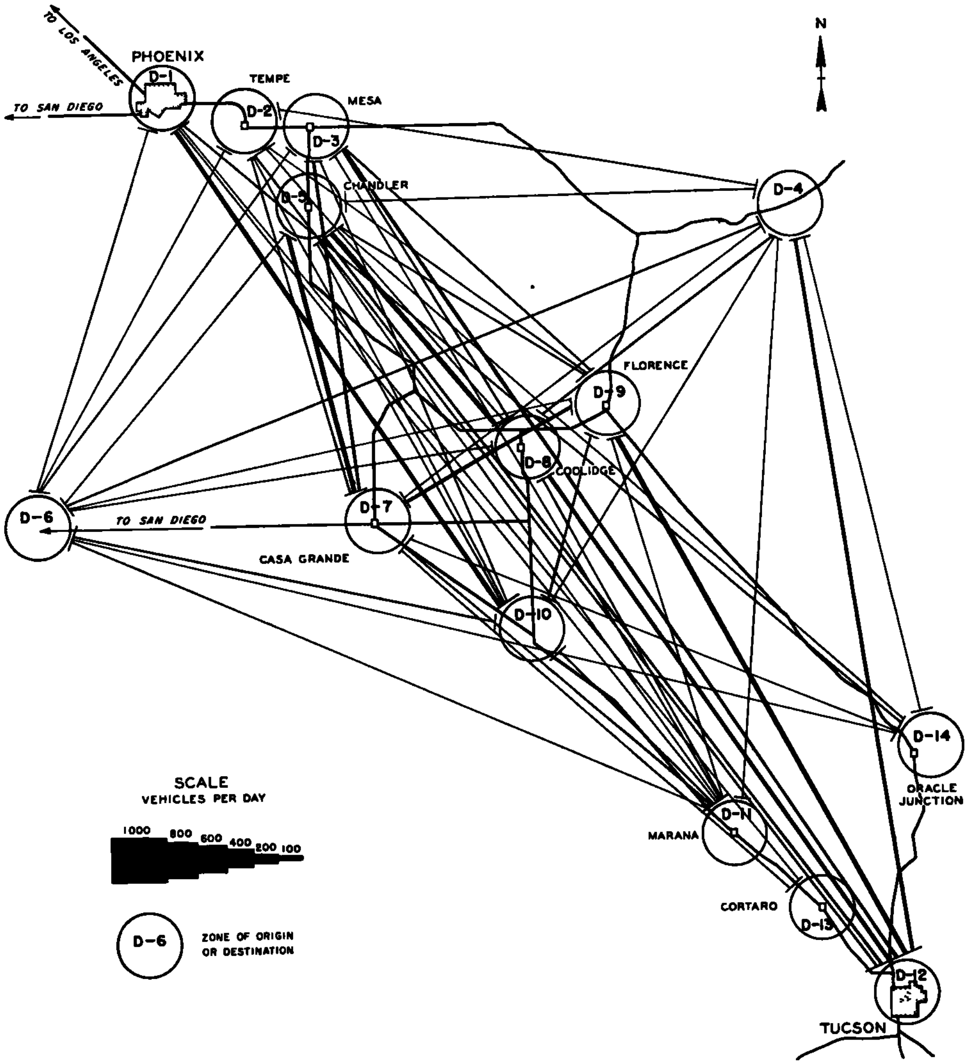

Figure 5. Total Daily Trips of All Vehicles where Trips are Less Than 100 per Day

Due to the statistical uncertainty of the breakdown of truck types in weight groups, as well as the crude cost accounting behind the calculation of unit operating costs of various sizes of trucks, only three classes of vehicles were used; namely, passenger cars, light

The vehicle miles which were attracted to the new route were extended separately from those which would continue using old roads, for two reasons · first, it was considered that in case of a close decision the route which would be busiest should be preferred; second, the new route is to be of controlled access design and the time costs as well as accident costs per vehicle mile would be less.

by post-war prices to obtain the cost per mile at various speeds. The cost per mile for each speed was weighted according to speed distri-

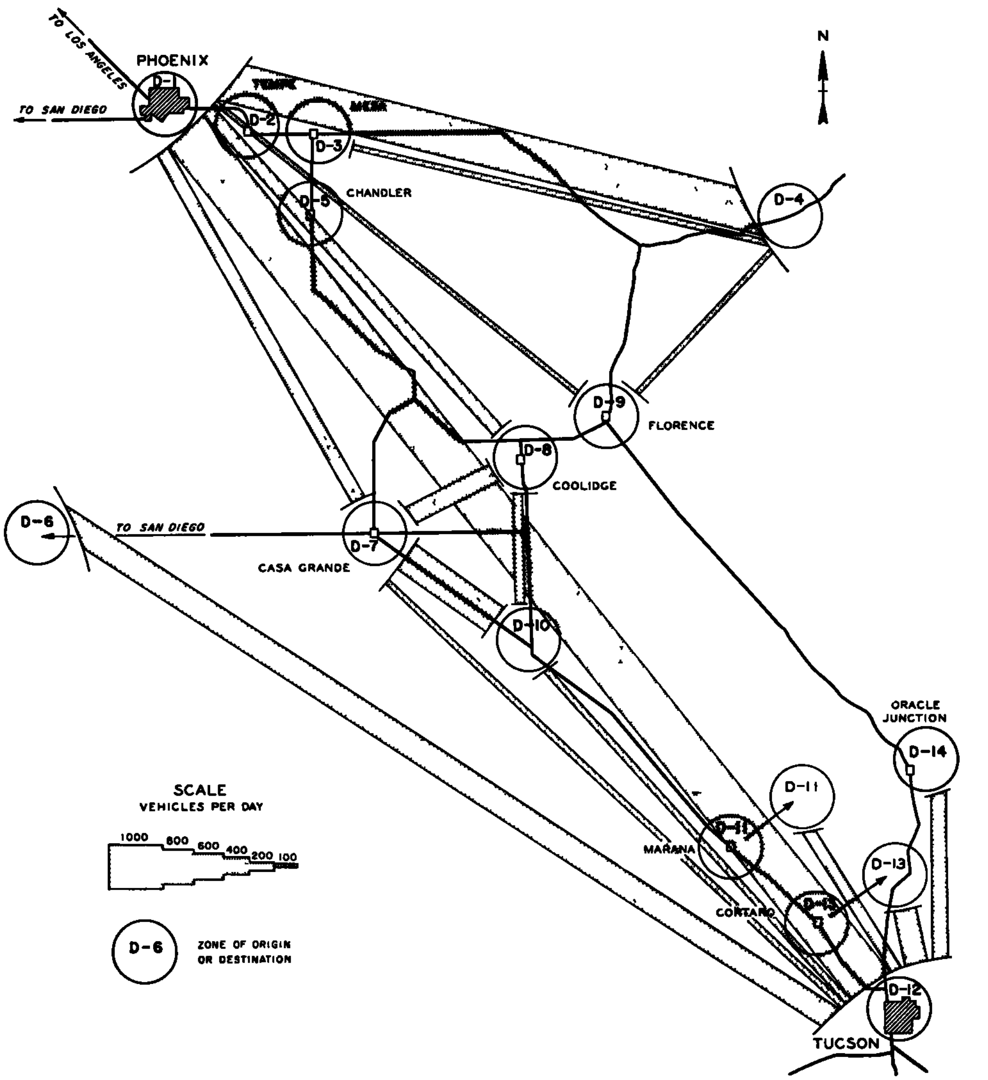

Figure 6. Total Daily Trips of All Vehicles where Trips Exceed 100 per Day

Unit costs for passenger cars were obtained by interpreting the data developed in Prof. R. A. Moyer's paper, "Motor Vehicle Operating Costs and Pavement Texture," *Proceedings* Highway Research Board, Vol. 22 (1942). These data were reduced to physical consumption per mile at various speeds, then multiplied

bution curves on open level tangents, with a result of 2½¢ per mile. This includes gasoline, oil, tires, lubrication, and repairs. It was held that other costs do not vary with distance. The same cost—2½¢—was used on all sections of the new road and remaining roads.

It is realized that the unit cost varies somewhat with quality of surface, grades, and congestion, but it was decided that the variation was of smaller magnitude than the error in other estimates made throughout the analysis, particularly the error in forecasting 20 years of traffic on the basis of a two-day sample.

Unit costs for trucks were 30¢ per mile for heavy trucks—that is 3 axles or more—and 12¢ per mile for light trucks, including pickup and panel. Six fleet operators in Phoenix were consulted but the cost accounting of only one operator was adequate for determining actual vehicle operation costs. This firm, which operates 30 tractor-truck semitrailers of approximately 40,000 lbs. gross weight, segregates time costs, which include license and taxes, storage, insurance, overhead, and wages, from distance costs, including fuel, lubrication, tires, maintenance and depreciation. The period taken was one-quarter year summary and covered 288,000 truck miles in 18,900 driver hours. The time costs were $2.17 per hour in addition to 20½¢ per mile of distance costs. Since data on truck time or speeds on the various types of roads involved in the study were not available, it was assumed at 30 mph. that the time costs would amount to 7¢ per mile. This truck is 10 percent lighter than the average vehicle of more than 2 axles in Arizona, so the 27¢ was increased by 10 percent and rounded off at 30¢. This all sounds pretty inexact, and it is, but accurate figures do not seem to be available. An extensive project, including the placing of accountants or engineers in the cabs of various sizes of trucks, probably will be necessary before a strictly rational truck cost can be developed. There is first of all the question of defining the unit for which the cost is determined. An hour of a truck rolling 50 mph. on level ground is probably equal in cost to an hour of the same truck crawling up a 5 percent grade at 11 mph. But either of these is more costly than an hour on level road at 25 mph. So the hour by itself is not the unit; neither is the mile. Had reliable time and speed data for trucks been available on Arizona roads, costs would have been computed at an amount per mile plus another amount per hour.

Time costs for passenger vehicles, which were added to the 2½¢ per mile, were computed at 57¢ per hour. This figure was derived by taking the difference in operating cost between 58 and 34 mph., and dividing by the time saved by the additional speed. There are flaws in this approach, since if the fast facility is credited with this money, and the motorist also has to pay in additional operating cost, the effect is a double charge. Nevertheless, it is a method of determining the value of time, which can be bought by driving fast. The amount paid for it, like any other commodity on a free market, is a good indication of its worth. Since this figure is so close to the 60¢ per hour adopted by several authorities, it was considered safe to use.

Because the mileage traveled on new road and existing roads varies between alternates, and the accident rate is likely to be lower on the new road, it was attempted to determine accident costs for each system. A tabulation of accidents occurring during the past year on about 100 miles of the existing network was made, using patrolmen's reported property damage and using $750 per injury and $15,000 per death. This cost was divided by the total travel, with a result of 0.36 cent per vehicle-mile. The tabulation was examined for causes, and it was determined that on a two-lane controlled access highway 60 percent of the accidents could not have happened. The accident cost on the new road was therefore taken as 0.14 cent per vehicle-mile. The figure of 0.36 cent is comparable with current insurance premiums, assuming a loss ratio of 0.4.

ROUTE COMPARISON

The final step was a tabulation in which all the costs were summarized for the existing system and for each alternate, and the ownership costs were added in. The alternate systems were arrayed side by side in columns, for quick appraisal (see Table 3).

The vehicle-miles previously derived, which were based on 1947 traffic volume, were expanded to an estimated average for the next thirty years, the amortization period of the improvement. This expansion had no effect upon the relative preference of the alternate routes since it was constant for all of them.

The most difficult phase of the whole study was deciding what method, and what values, to use for the determination of annual ownership costs of the roads remaining in service. This was finally resolved by estimating the actual replacement cost for each section which is below today's standards, adding re-surfacing every 20 years, and dividing the whole by 30, the number of years used for amortizing the new route.

As a matter of interest, for this report, the benefit quotient described by R. E. Jorgensen in "Origins and Destinations of Highway Traffic—The Basis For Connecticut Planning," *Proceedings*, Highway Research Board, Vol. 23 (1943), and the composite quotient described in "Economics of Highway Planning," by C. B. McCullough, *Bulletin No. 7*, Oregon State Highway Department (1937), is computed for each of the alternates.

The conclusion was confirmation that the shortest route (Route 19) is the best, notwithstanding traffic which will be obliged to continue using the existing roads to intermediate points, but could be handled on the new road if it were longer and more devious. Although this conclusion might have been drawn without benefit of an origin and destination survey, the dollars and cents proof removes doubt from the engineers' minds and will be a valuable factor in defending the selection before sectional groups.

TABLE 3
SUMMARY COMPARISON OF ROUTES BASED ON ANTICIPATED AVERAGE TRAFFIC VOLUMES (1947 + 51%)

	Existing System	Route 7	Route 10	Route 13	Route 18	Route 19
	(1000's)	(1000's)	(1000's)	(1000's)	(1000's)	(1000's)
Daily Vehicle Miles						
New Route,						
Passenger Cars		394	444	424	465	429
Light trucks		56	71	65	72	69
Heavy trucks		38	41	40	45	41
Subtotal New Route		(488)	(556)	(529)	(582)	(539)
Remaining Roads						
Pass. Cars	713	264	273	237	219	228
Light trucks	129	64	58	55	50	51
Heavy trucks	59	15	16	14	11	12
Subtotal Remaining Roads	(901)	(343)	(347)	(306)	(280)	(291)
Total Vehicle miles daily.	901	831	903	835	862	830
Annual Vehicle Operating Costs						
Excluding accidents	$22,141	$19,901	$21,488	$20,027	$20,678	$19,896
Accidents	1,184	699	740	673	666	657
Total operating cost	23,325	20,600	22,228	20,700	21,344	20,553
Annual Highway Ownership Costs						
New Route						
investment		535	360	519	477	505
maintenance		41	41	42	41	39
Remaining Roads						
renewal		269	393	268	268	277
maintenance		67	68	75	67	64
Total ownership costs		912	862	904	853	885
Operating plus ownership costs		$21,512	$23,090	$21,604	$22,197	$21,438
Benefit ratio		2.99	1.27	2.90	2 32	3.13
Oregon Composite Quotient		2.68	1.28	2.58	2.52	2.74

The work covered by this report was done by the Arizona Highway Department Division of Economics and Statistics working hand in hand with the Division of Surveys and Plans. Mr. O. L. Patterson made the prodigious trip and cost compilations, Mr. C. S. Benson was locating engineer, and Mr. Leslie McDougall compiled the construction estimates and computed the Oregon Quotients for each alternate.