Travel Time—A Measure of Service and A Criterion for Improvement Priorities

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•TRAVEL time has been used as an indication of traffic congestion for some time in the Phoenix area which has grown tremendously in recent years. The first travel time study was conducted by the Arizona Highway Department in 1947. In 1956 Phoenix was selected as a pilot city by the National Committee on Urban Transportation. Evening peak-hour time data were gathered in 1957 and 1962 as a part of the continuing fact gathering effort. Travel time was obtained in accordance with national standards on all major arterial streets and selected collector streets of major importance.

The purpose of this report is to demonstrate that travel time offers a sound measure of the level of urban traffic service and can be a basic criterion for a major street improvement priority formula.

This paper compares the overall level of service as obtained by peak-hour travel time studies in 1947, 1957 and 1962. Comparison of the Phoenix street system for these years also related the level of service to population growth, increase in vehicle registration, city size and traffic volumes. Selected route segments are compared for change in average speed, vehicle delay and average daily traffic. In making these comparisons, street improvements that increased capacity are identified. Examples of these improvements are street widening, intersection widening and provision of left-turn lanes, channelization, and removal of parking.

This paper also recognizes the need to develop a simple priority formula that would aid in determining major street construction priorities in urban areas. The test formula used in Phoenix assigns major emphasis to delay rate, but also considers collisions, traffic volume and structural condition of the pavement. The formula was evaluated by comparing the relative priority rating for selected major arterial street segments, as determined by the formula, to the judgment rating of individuals. The various public works, planning, and management officials who served as raters were chosen for their familiarity and knowledge of the Phoenix street system.

This improvement priority formula is not intended to replace judgment, but could be used as an aid to develop recommended capital improvement priorities for major arterial street construction programs.

A MEASURE OF URBAN SERVICE

Travel time studies have been used for decades to show the time required to travel from one location to another. This information was useful in scheduling individual movements and later applied to the operation of mass transportation. The early traffic engineer commonly used travel time studies to show that an engineering improvement reduced the time required to go from point A to point B. Travel time studies of entire urban areas became commonplace and isochronic maps of urban areas were shown in the earliest text books concerned with traffic studies.

Travel time is easily understood by the average motorist and the "quickest way home" is a topic of conversation over the backyard fence. The motorist's desire has produced the traffic assignment diversion curves that are in widespread use. The speed of mobility for people and goods is the reason for the motor vehicle's being and travel time is a measure of service afforded by the street net.

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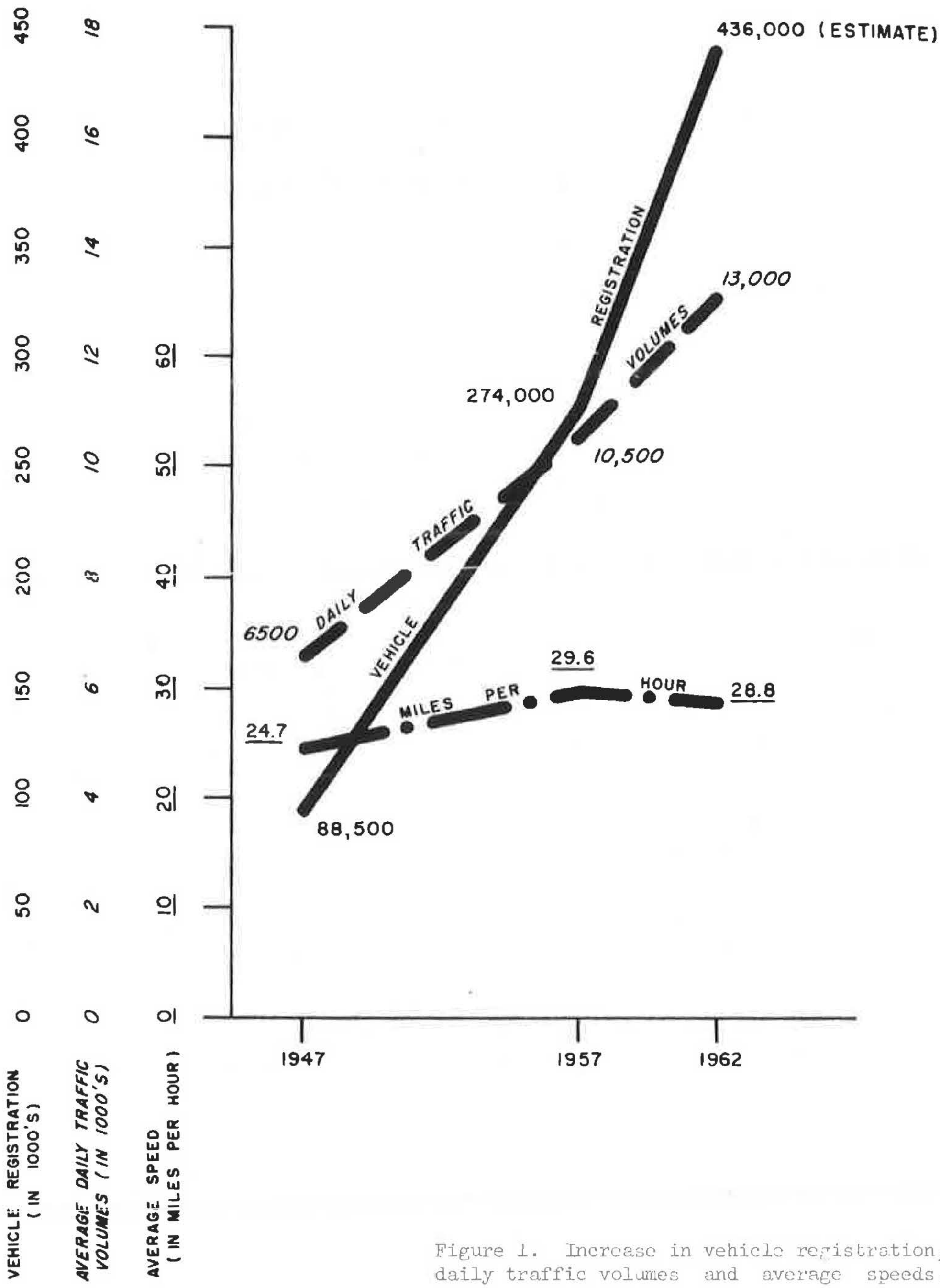


Figure 1. Increase in vehicle registration, daily traffic volumes and average speeds.

Travel time figures are easily obtainable. With a vehicle, a stop watch, and a half-hour's training, non-technical help can produce the desired study. However, because this tool is so old and so easily understood, travel time has been overlooked for more sophisticated and complicated applications. Travel time studies should be completed every two to three years for the major street and freeway network in an urban area. Thus, the trend in the overall level of service could become evident. Closer

TABLE 1

COMPARATIVE DATA FOR PHOENIX AND MARICOPA COUNTY

Year	Major Arterial Street: Peak-Hour Avg. Speed (mph)	Major Arterial Street: Avg. Daily Traffic	Maricopa County: Vehicle Registration	Maricopa County: Population	City of Phoenix: Population	City of Phoenix: Area (sq mi)
1947	24.7	6,500	88,500	270,000	95,000	12.2
1957	29.6	10,500	274,000	520,000	172,000	36.3
1962	28.8	13,000	436,000	750,000	496,400	220.3

appraisal of individual routes would result in more quickly taken remedial measures. Travel time figures can play a large part in determining construction priorities, enforcement assignments, surface mass transit routings, freeway locations and signal timing deficiencies. If travel time data were available for various urban areas, the level of service could be compared. Travel time then should become a factor in programming urban construction projects by state highway departments. It would aid in advertising street improvements, the excellence of a transportation system of a community, and could be used in support of needed legislation to obtain financing to improve and build a street and freeway system.

Phoenix Studies

Although much of the foregoing may be wishful thinking and oversimplification, certainly travel time is a sound engineering measure of the level of service of a street net. In Phoenix a comparison was made of the overall average evening peak-hour major arterial street speeds for 1947, 1957 and 1962.

The 1947 study was made by the Arizona Highway Department, Maricopa County and the Bureau of Public Roads as part of an origin and destination study. The average speed determined for the major arterial street system in 1947 was 24.7 mph. This compares with a speed of 29.6 mph after a 10-yr period of traffic engineering improvements (Table 1).

Thus, during a period of unprecedented growth, the average speed increased 4.9 mph (20%) while the major arterial average daily traffic increased from 6,500 to 10,500 vehicles. This is a 62 percent increase in traffic volume. Figure 1 shows the increases in vehicle registration, major arterial street average daily traffic, and average overall speeds found for the three travel time studies.

The average major arterial speed was slightly less in 1962 (0.8 mph) than in 1957. This is more significant in view of the continued traffic engineering improvements that have been made and even accelerated. During this period the average daily traffic volumes have increased from 10,500 to 13,000 vehicles. The present surface major arterial street system is reaching saturation.

This leads to one possible theory: when the central city of an urban area reaches a population somewhere between 400,000 and 500,000, a typical major arterial street system reaches its peak efficiency. At this point a freeway system has to be placed in operation if the downward trend in overall average street net speeds is to be prevented. The population range of this "hump" depends on many factors such as density of population, efficiency of mass transportation, the ratio of vehicle registration to population, adequacy of the street net, rights-of-way, and the ability of the city to operate an efficient street system. Figure 2 shows the isochronic drawings for the Phoenix metropolitan area for 1957 and 1962. Figure 3 shows the level of service

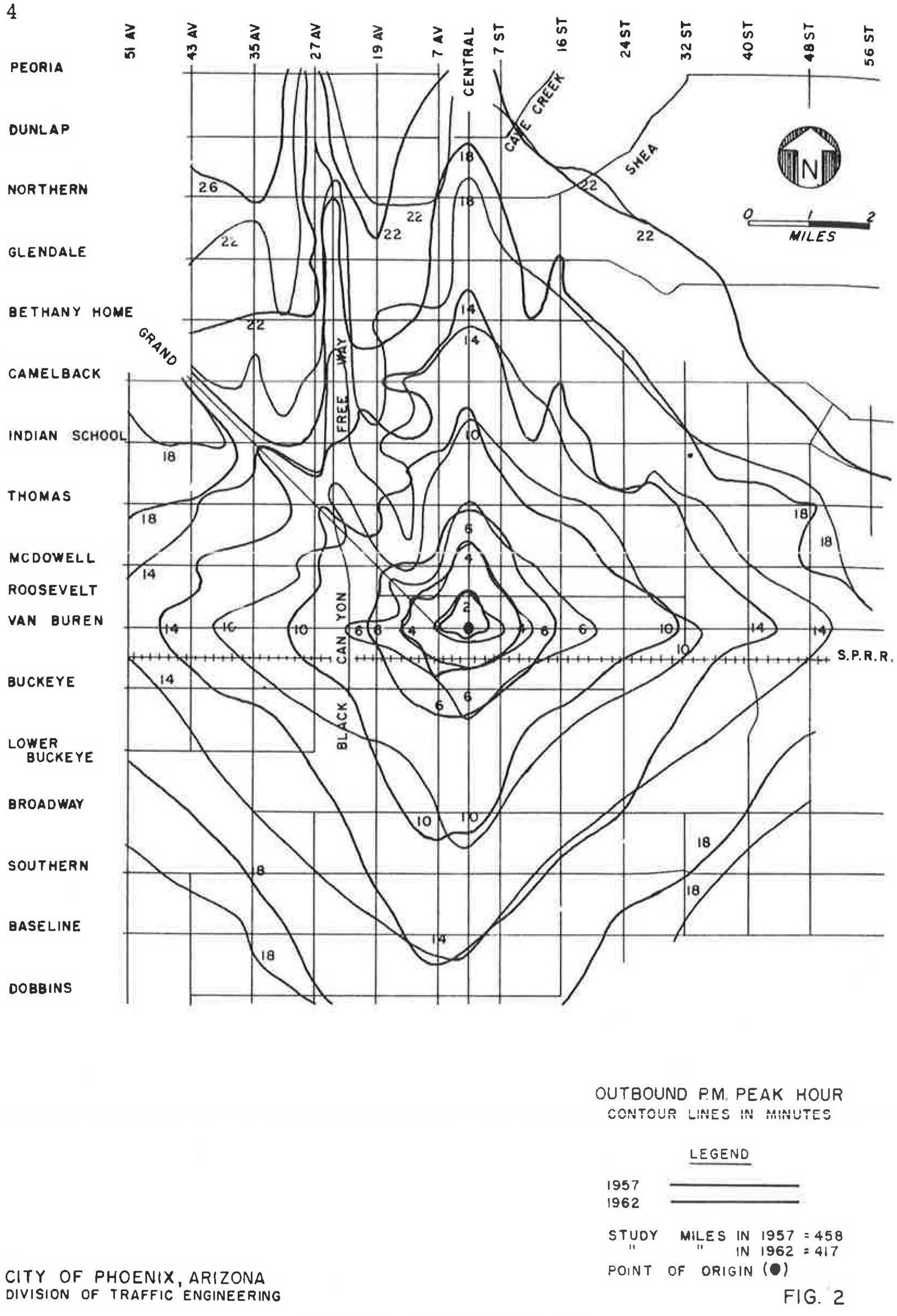


Figure 2. Time contour map.

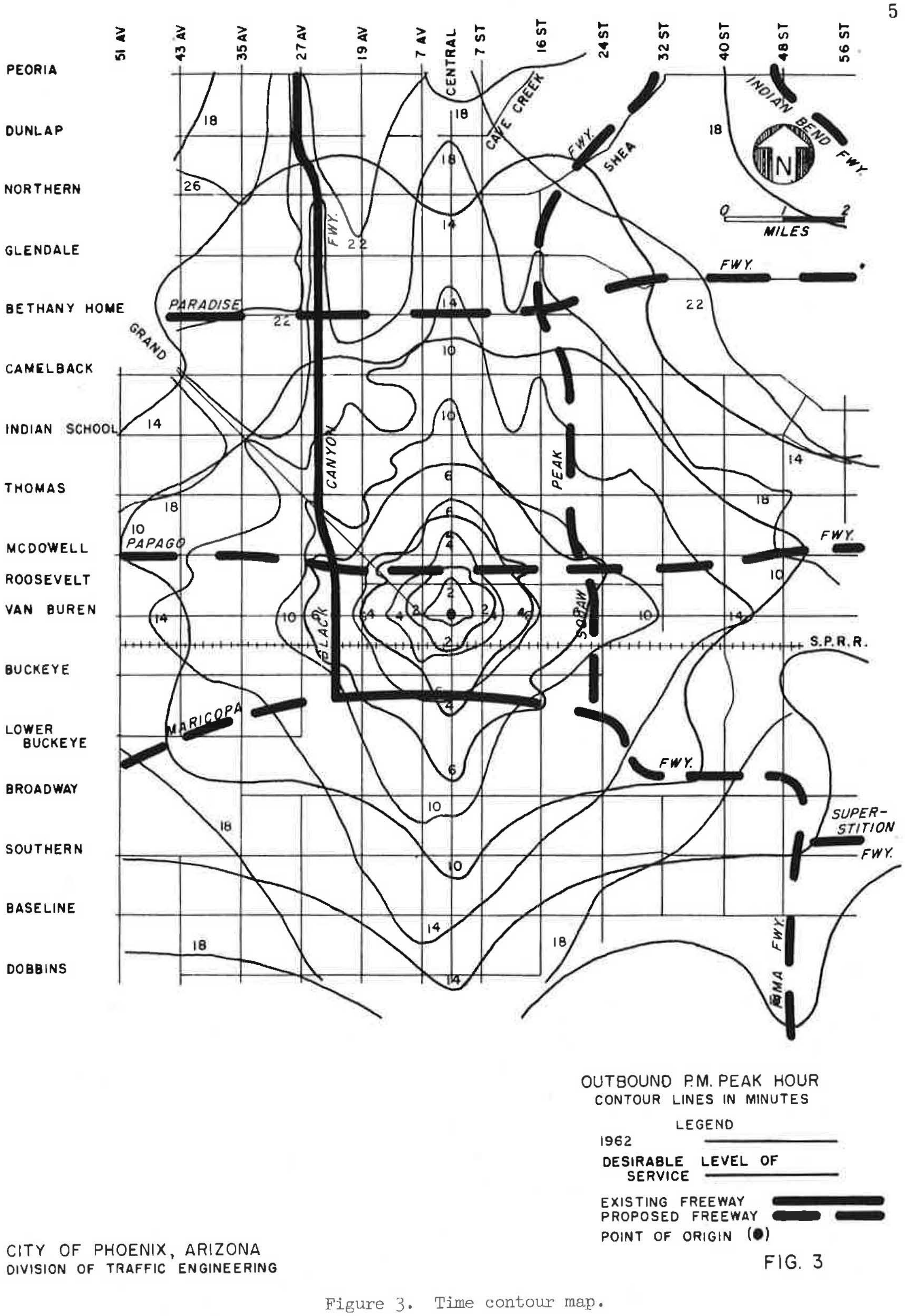


Figure 3. Time contour map.

TABLE 2

TRAVEL TIME RELATED TO ENGINEERING IMPROVEMENTS FOR SELECTED MAJOR ARTERIALS

Street Section	Average Speed		PM Peak-Hour Volume		Veh.-Min.Delay Per Hour Per Mile		Engineering Improvements
	1957	1962	1957	1962	1957	1962	
Indian School Road:							
15th Ave. to 7th Ave.	14.6	30.3	752	935	1,579	0	A, E, F
7th Ave. to 7th St.	13.4	16.3	859	1,239	2,113	2,043	C, D, E, F, G, J
7th St. to 16th St.	26.7	29.9	912	1,222	228	12	C, F, G
16th St. to 24th St.	23.2	26.5	863	1,066	509	277	C, E, F, G
24th St. to 32nd St.	23.5	29.1	774	1,175	426	71	C, D, E, F, G
McDowell Road:							
19th Ave. to 7th Ave.	14.0	24.8	587	672	111	12	A, D, E, F
7th Ave. to 7th St.	10.2	17.2	934	1,040	3,222	1,134	A, E, F, G, H
19th Avenue:							
McDowell to Thomas	22.0	32.1	421	410	139	0	A, E
Thomas to Indian School	21.1	27.3	396	503	337	101	A, E
Grand Avenue:							
7th Ave. to 19th Ave.	13.3	18.7	939	1,064	1,931	862	C, E, I
Washington Street:							
28th St. to 32nd St.	26.4	28.8	865	1,200	208	96	B, F, G

A—Street widened from 2 to 4 lanes.
B—Street channelized from 2 to 3 lanes.
C—Intersectional widening.
D—Signals installed.
E—Changed signal timing or cycle.
F—Painted left-turn channels.
G—Removed parking.
H—Raised speed limit.
I—Prohibited left turns.
J—Added right-turn lane.

which would be attained if the deficiencies in the existing major arterial system were corrected and the freeway system was completed. This desirable level of service determined for Phoenix is as follows:

Street Classification	Avg. Speed (mph)
Urban freeway	50
Major arterial:	
Normal	30
Intermediate	25
CBD	20

Definitive Travel Time Studies

In 1950 Phoenix realized that as it increased in size there was a need for a single agency to handle traffic matters. In July 1950, the division of traffic engineering was established under the direction of a traffic engineer. This division was responsible for the operation of the street system and for the propagation of traffic studies and design recommendations. The usual tools of the trade were employed: improved signal design, one-way street system, a program of parking removal, a through-street system, reversible-lane movements and channelization.

In 1957 Phoenix became one of the pilot cities in the program sponsored by the National Committee on Urban Transportation. The travel time study, in particular, gave the city administrators an opportunity to evaluate the services of the division of traffic engineering. A total of 458 miles of street was studied in 1957 for travel time in the urban area. These studies showed that during the 10-yr period (1947 to 1957) when Phoenix was growing at a faster rate than any other city over 100,000 population, the overall arterial speed had increased. This improved level of service was attained through studies and observations made at congested locations and on critical streets that were translated into physical improvements construction in the field.

TABLE 3

GROWTH OF TRAFFIC ENGINEERING IMPROVEMENTS

Year	Left-Turn Channels	Signalized Intersections	One-Way Street Length (mi)	Prohibited Parking Length (mi)	Left-Turn Prohibitions
1951	0	82	0.75	7.9	2
1957	38	146	23.1	21.7	9
1962	180	307	25.5	55	10

As an example of the work accomplished during these years, Table 2 gives certain selected sections of major arterial streets, the increases in peak-hour traffic between 1957 and 1962, the vehicle minute delay per hour per mile, and engineering improvements. Table 3 gives the growth of traffic engineering improvements in service.

Summary

Travel time is a measure of the level of service of a street system. It can be useful in determining trends in a single area and has tremendous possibilities for comparing one geographic area with another. It can be a factor in determining signal timing, needed traffic improvements and street construction priorities. In some of these fields the methods of application have not yet been developed, but there is great potential use for this easily determined and universally understood measure.

A CRITERION FOR URBAN STREET PRIORITIES

The need for a simple formula that would aid in establishing the priority for streets to be constructed in urban areas has long been recognized. Certainly such a formula would not be intended to replace judgment, but would simply be a device by which urban projects could be listed as to their relative importance.

This section is solely confined to an urban major arterial street construction priority formula. In urban street and traffic work there are several areas where priority formulas will prove useful: resurfacing programs, traffic signal installations, and major arterial street construction.

A list of major street construction projects based on a priority formula could be a significant aid to the development of a recommended capital improvement program for urban areas. A major concept in the development of a formula has been to reduce judgment in the formula to the absolute minimum and thus make the formula as factual as possible. Judgment and budgetary elements would be brought into the final selection of the actual projects for the recommended program.

In September 1960, the Highway Research Board sponsored a workshop conference on formulating highway construction programs. The results of this conference have been published and are an important contribution of the Department of Economics, Finance and Administration. A similar conference directed primarily at problems of formulating construction programs in urban areas could be a significant contribution.

The American Public Works Association transportation committee is now engaged in the study of major street construction priorities for urban areas. It is the hope of this committee that it will be able to develop a useful publication. One objective is to include several priority formulas that have been developed for urban areas.

The subcommittee on developing project priorities for transportation improvement summarized its work in Procedure Manual 10-A of the National Committee on Urban Transportation series. This procedure manual developed a technique and a suggested form for the complete evaluation of a project, including street classification; time the project is needed; and administrative, budgetary, and service considerations. The

TABLE 4

PROPOSED GUIDING PRIORITY RATING METHOD[1]
(San Diego Metropolitan Area Transportation Study)

$$\text{Priority Index} = \frac{\text{Project Cost per Vehicle-Mile}}{\text{Project Benefit Index}}$$

Project Benefit Index		Relative Weight	
Community service:			
Pattern and continuity		15	
Coordinating and timing		15	
Roadbed condition		5	
Present capacity ratio		15	
Long-range future service		10	
Subtotal			60
User benefits:			
Time saving-delay rate:			
Present	5		
5-yr future	5		
Subtotal		10	
Duration of deficiency		5	
Distance saving of improvement, 5-yr avg.		5	
Accident rate, 2 year		15	
Time to amortize investment		5	
Subtotal			40
Total			100
Project Cost			
Right-of-way plus construction per vehicle-mile (10 yr)			

[1]Priority rating index should be based on the expected improvement in deficient conditions.

balance of this paper is concerned with an effort to formulate a simple factual analysis of service considerations. This is a continuation of programs undertaken by San Diego, Calif. and Phoenix.

San Diego Effort

San Diego has been publishing an annual 6-yr capital improvement program for many years. As a part of the pilot city program of the National Committee on Urban Transportation, several efforts were made to develop a capital improvement program priority formula for major street construction. Two of the earliest formulas were based primarily on traffic data. In one of these, priority was determined by the percent capacity overload; a second combined volume, speed and delay, and accident rates into a priority formula. Both efforts were helpful, but were not the desired formula.

Table 4 gives a guiding priority rating method developed in 1958. The basic philosophy of the formula was to weight community service 60 percent and user benefits 40 percent. The final priority index brought cost into the picture by dividing the cost per vehicle-mile by the project benefit index.

In an effort to test this formula 25 projects were selected. A group of eleven people having knowledge and responsibilities in administration, planning or engineering, and who participated in the capital improvement program project selection, were asked to order the 25 projects.

As this test proceeded, it became more and more obvious that the formula itself included judgment in all of the community service benefits as well as some of the user benefits. Actually, at least 70 points out of 100 in the formula were basically judgment

TABLE 5

PHOENIX MAJOR STREET IMPROVEMENT PRIORITY, FORMULA B
(Jan. 12, 1961)

Element		Relative Weight (points)	
Community Service			
Master plan-continuity of route development		10	
Coordination and timing in relation to other projects and jurisdictions		10	
Structural condition		15	
Surface	2		
Subsurface	8		
Drainage	5		
Ratio of $\frac{\text{future (design)}}{\text{present}}$ traffic volumes		10	
Present capacity ratio		10	
Subtotal			55
User Service			
2-yr accident rate/mile + accident/mile		10	
Duration of deficiency		10	
Time saving			
Delay rate "after" less delay rate "before"		15	
Time to amortize investment		10	
Subtotal			45
Possible points			100
Highest point value = most needed facility			

ratings. Thus, the proposed priority rating formula simply provided a judgment ordering of the projects. This is essentially no different from the results obtained by the capital improvement committee using the same basic data. Therefore, the formula was not considered satisfactory.

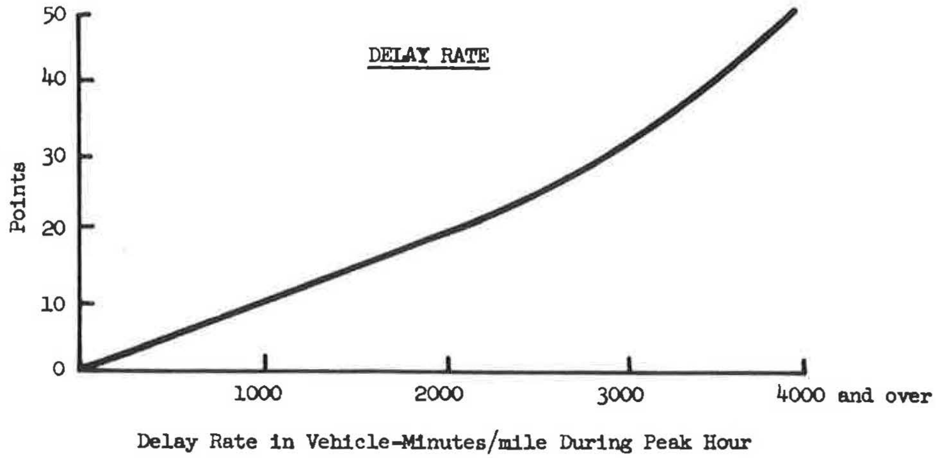
Phoenix Formula and Test

Phoenix completed a street deficiency study in December 1961 that found deficient approximately 152 out of 260 miles of major arterial streets. The estimated cost to correct the deficiencies was $54.2 million. The ever-present limitation of funds makes it essential that the priority of projects be carefully determined to insure the maximum benefit to the motoring public.

From the San Diego effort, Formula B was developed (Table 5). Again it is clear that there is a considerable amount of judgment in the elements to be rated. For this reason, Formula C (Table 6) was developed for test purposes.

Formula C reduces judgment to a minimum. In conjunction with the Major Street Improvement Priority Formula C, two rating scales were developed. These are to be used to determine the points for the delay rate and the collision index (Fig. 4). Curves were developed using existing data from Phoenix and San Diego combined with the following points of view:

1. The delay rate should give relatively few points in the lower scale of delay, but the number of points should increase more rapidly as greater delay rates are experienced.
2. Accident rates should be used but they should be tempered with the total number of accidents. If this is not done, erroneous conclusions can be drawn from either the accident rate or the use of total accidents.



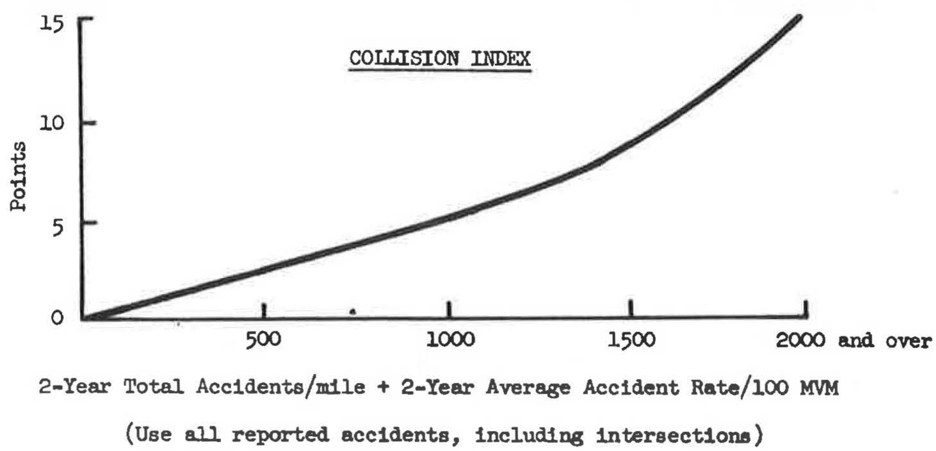


Figure 4. Major street improvement priority Formula C rating scales.

Twenty-five street segments (Fig. 5) were selected to test the formula. These segments were carefully selected to insure that they ranged from projects that had been recently completed through projects which were obviously extremely low on the priority scale. The projects that had been completed were to be rated as they existed prior to their recent improvement. Nineteen individuals having responsibility in the areas of administration, planning, public works-traffic engineering, engineering and street maintenance were asked to participate in the judgment ratings.

Test Results

Table 7 gives the result of the judgment ratings. Table 8 compares these ratings to the order of priority developed by the formula.

It is important to note that the largest deviation of 16 positions occurred on segment O, Van Buren Street, which is obviously in need of improvement. However, this 4-lane facility is presently in an intensively developed area and is fully improved. As a practical matter, significant relief will come from a nearby parallel freeway included in

TABLE 6

PHOENIX MAJOR STREET IMPROVEMENT PRIORITY, FORMULA C

Element		Relative Weight (points)
Delay rate per mile during peak hour		50
Collision index—2-yr accidents/mile plus accident rate/mile		15
Structural condition		15
Surface and subsurface	5	
Drainage	10	
Traffic - $\frac{\text{present ADT}}{2{,}000} + \frac{\text{future (5-yr forecast) ADT}}{\text{present ADT}}$		20
Possible points		100
Highest point value = most needed facility		

the adopted major street and highway plan. This is a situation where the priority formula gave a high rating but judgment would have removed it from the construction program. This demonstrates the judgment and budgetary considerations that must be applied in the development of a capital improvement program.

Table 9 gives the specific points for each element of the formula for the 25 projects. Review of this table gives insight into the other projects where there is a significant deviation between the formula and the judgment ratings as follows:

1. Segment C, 27th Avenue project, is ¼ mile away from a completed urban freeway and the poor structural condition of the facility combined with some delay produced a higher priority by the formula. As on segment O, judgment would tend to weigh the existence of the freeway and thus lower the priority.
2. Segment D, 19th Avenue, has a low delay but a considerably higher rating on structural condition. The various raters had a widespread opinion on the relative priority of this particular project. This may well be due to its being parallel to and approximately ¾ mile away from a completed freeway.
3. Segment H, 16th Street, received a low number of delay and traffic points but a number of structural condition points. Thus, the priority formula produced a somewhat lower rating than judgment.
4. Segment N, the Van Buren project, which judgment said should be among the very earliest, received zero points on the delay rate, relatively few points on traffic, but a high number of points on structural condition. As in segment H, judgment assigned a higher position than did the formula.
5. Segment S, Indian School, showed high by the priority formula due to the relatively high delay rate and traffic points received. Judgment lowered the priority because this segment had been improved to modern 4-lane standards within the last seven years.

Few of the street segments received a high number of points for delay rate. The cause of this is not fully understood. Certainly, it is possible that the delay rate curve (Fig. 4) could be adjusted. However, the curve is based on the philosophic point of view that the relative points should increase more rapidly as the delay increases. If the shape of the curve were varied, there might well be a relatively large number of points for a relatively small amount of delay. This is not considered proper rating. The second possible cause is that congestion in Phoenix has not yet reached the point where maximum delays are the norm rather than the exception. The shape of the curve deserves further research. Perhaps a family of curves for different urban characteristics is needed.

Table 9 indicates that a good spread was obtained by collision index and structural condition ratings. However, the spread of traffic volume rating was not as broad as expected. The highest rating was 15 of 20 points—the lowest 3½. The philosophy of the traffic volume component in Formula C is to place heavy value on present vol-

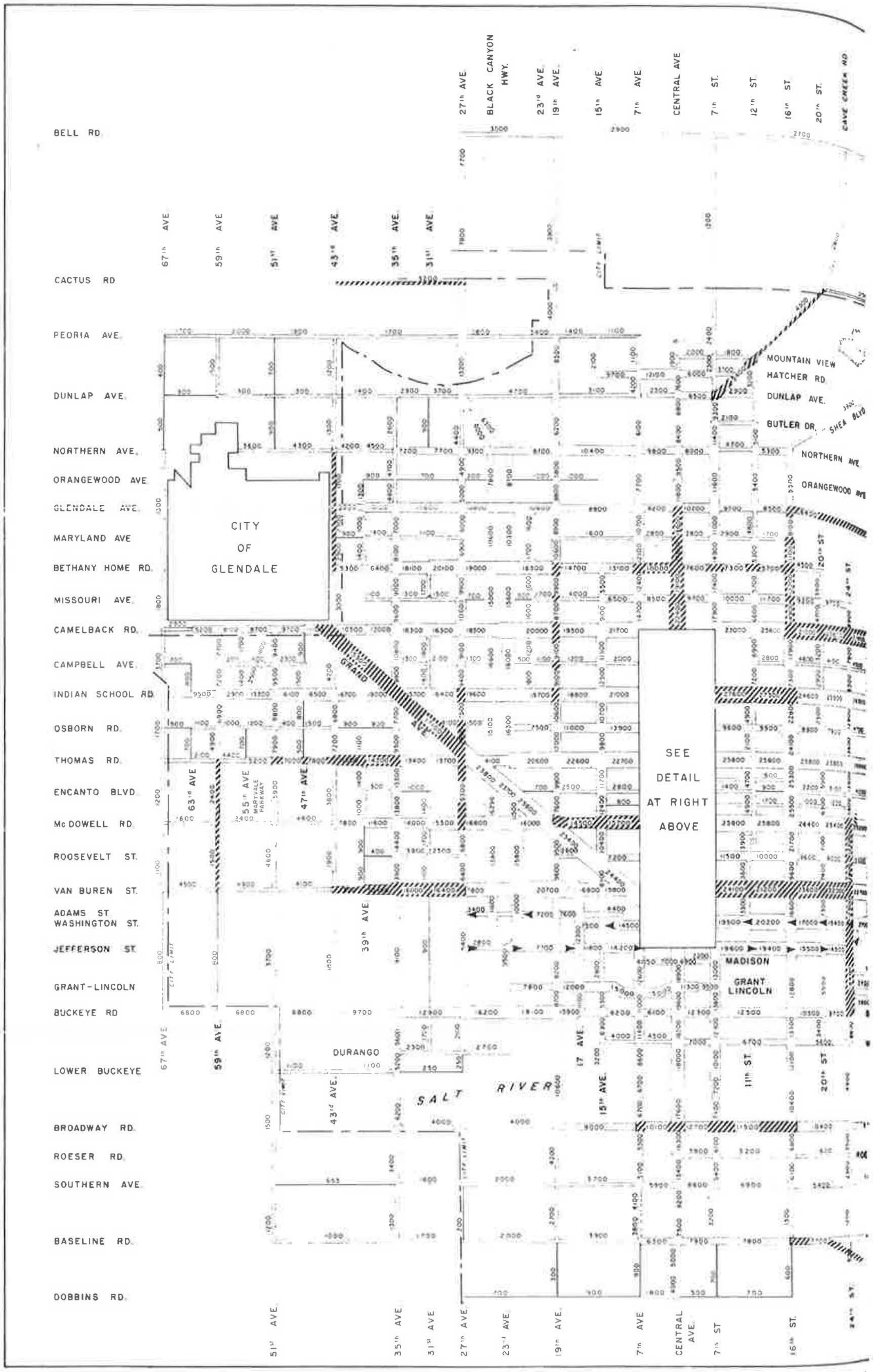
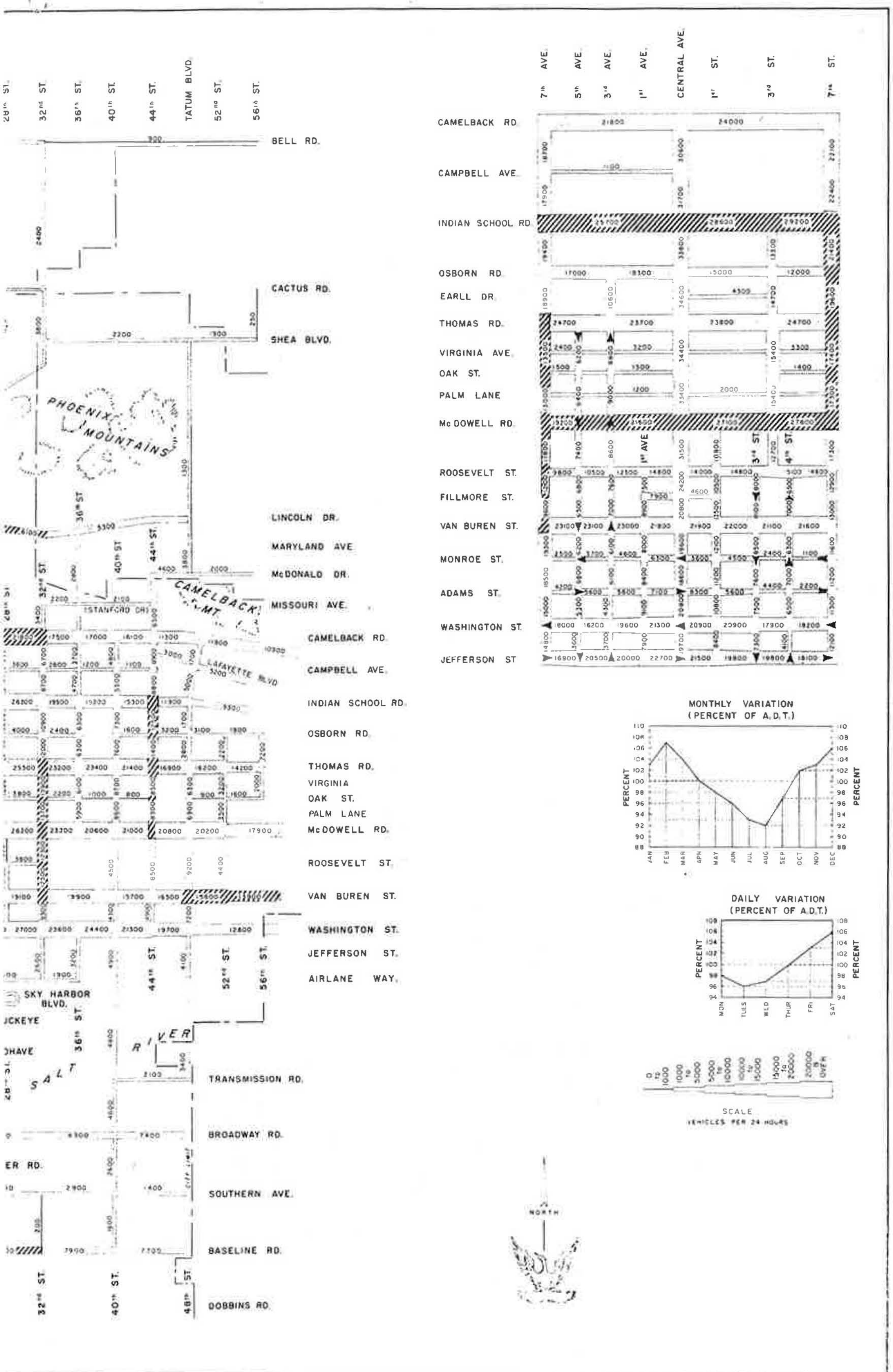


Figure 5. Selected



street segments.

TABLE 7

PHOENIX FORMULA C JUDGMENT RATINGS

Segment	Location	Relative Order by Individual Raters																			Priority (avg.)
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	
A	59th Ave. Van Buren–Thomas	22	25	23	24	24	25	25	23	22	25	20	24	25	18	19	19	24	25	25	25
B	43rd Ave. Bethany–Northern	18	20	24	20	23	24	20	18	21	17	19	23	23	24	9	22	21	21	17	22
C	27th Ave. McDowell–Ind. Sch.	17	14	8	19	14	17	13	10	16	13	10	16	15	17	4	16	16	15	9	14
D	19th Ave. Ind. Sch.–Bethany	6	5	5	7	12	12	10	7	6	21	18	15	13	13	8	3	6	13	16	8
E	7th Ave. Van Buren–Thomas	4	2	3	4	4	5	4	2	15	6	3	2	4	8	3	2	3	1	3	3
F	Central Camelback–Glendale	10	16	22	8	11	6	16	14	17	1	1	17	7	11	21	5	11	23	23	12
G	7th St. McDowell–Ind. Sch.	1	1	1	2	1	3	2	3	2	4	7	3	2	1	25	1	4	2	2	1
H	16th St. Camelback–Glendale	9	6	16	9	13	11	7	9	14	7	17	12	11	7	14	14	12	9	10	10
I	24th St. Buckeye–McDowell	7	4	4	3	5	4	5	5	3	2	2	5	3	5	2	17	5	5	5	4
J	32nd St. Van Buren–Thomas	12	15	19	5	6	18	8	11	7	5	8	7	6	6	12	13	17	8	8	7
K	44th St. McDowell–Ind. Sch.	14	9	11	18	15	19	15	12	20	9	9	21	8	12	11	12	18	11	12	13
L	Baseline 16th St.–32nd St.	24	24	21	12	22	16	23	24	13	24	21	22	21	22	13	20	25	19	22	23
M	Broadway 7th Ave.–16th St.	21	10	13	17	17	9	12	20	19	16	14	10	12	20	10	10	23	10	15	16
N	Van Buren 43rd Ave.–27th Ave.	13	11	6	14	7	7	6	15	12	19	4	8	5	14	5	11	14	7	6	6
O	Van Buren 7th St.–24th St.	23	22	20	23	20	20	18	6	4	8	13	11	17	4	24	9	19	17	20	19
P	Van Buren 48th St.–60th St.	19	19	18	22	21	8	22	17	23	18	23	20	20	23	22	21	8	16	21	20
Q	McDowell 19th Ave.–7th St.	2	3	2	1	2	1	3	1	1	3	6	4	1	3	23	7	1	4	1	2
R	Thomas 51st Ave.–35th Ave.	11	13	9	15	10	10	14	16	18	15	22	18	18	16	17	15	20	14	11	18
S	Ind. Sch. 7th Ave.–16th St.	5	17	15	21	16	21	1	4	10	12	12	6	22	2	20	6	2	6	7	9
T	Camelback 16th St.–32nd St.	25	18	10	10	9	15	19	8	11	11	11	14	9	21	16	18	10	18	19	15
U	Bethany 7th Ave.–16th St.	20	8	14	11	8	13	17	13	8	10	15	9	14	9	7	8	15	12	13	11
V	Glendale 16th St.–32nd St.	15	21	17	13	19	23	24	22	24	22	16	19	19	19	15	23	7	22	24	21
W	Cave Creek 7th St.–20th St.	8	12	12	16	18	14	9	21	9	23	24	13	16	10	1	25	13	20	14	17
X	"Q" Ave. 43rd Ave.–Black Canyon	16	23	25	25	25	22	21	25	25	20	25	20	24	25	18	24	22	24	18	24
Y	Grand Ave. Thomas–Camelback	3	7	7	6	3	2	11	19	5	14	5	2	10	15	6	4	9	3	4	5

TABLE 8

PHOENIX COMPARISON OF JUDGMENT AND FORMULA C RATINGS

Segment	Location	Judgment Priority	Formula Priority	Position Difference
A	59th Ave. Van Buren—Thomas	25	21	4
B	43rd Ave. Bethany Home—Northern	22	19	3
C	27th Ave. McDowell—Indian School	14	8	6*
D	19th Ave. Indian School—Bethany Home	8	17	9*
E	7th Ave. Van Buren—Thomas	3	6	3
F	Central Camelback—Glendale	12	12	0
G	7th St. McDowell—Indian School	1	5	4
H	16th St. Camelback—Glendale	10	15	5*
I	24th St. Buckeye—McDowell	4	7	3
J	32nd St. Van Buren—Thomas	7	9	2
K	44th St. McDowell—Indian School	13	10	3
L	Baseline 16th St.—32nd St.	23	25	2
M	Broadway 7th Ave.—16th St.	16	18	2
N	Van Buren 43rd Ave.—27th Ave.	6	11	5*
O	Van Buren 7th St.—24th St.	19	3	16*
P	Van Buren 48th St.—60th St.	20	23	3
Q	McDowell 19th Ave.—7th St.	2	1	1
R	Thomas 51st Ave.—35th Ave.	18	22	4
S	Indian School 7th Ave.—16th St.	9	4	5*
T	Camelback 16th St.—32nd St.	15	13	2
U	Bethany Home 7th Ave.—16th St.	11	14	3
V	Glendale 16th St.—32nd St.	21	24	3
W	Cave Creek 7th St.—20th St.	17	16	1
X	"Q" Ave. 43rd Ave.—Black Canyon	24	20	4
Y	Grand Ave. Thomas—Camelback	5	2	3

*Difference of 5 or more between judgment and formula order of priority.

umes and then to add the 5-yr forecast growth ratio. The 5-yr forecast is an effort to reach a balance between present and future needs in capital programming. Evidence indicates that the present volume element of the formula should be divided by 1,500 rather than 2,000. Thus, a better spread would be obtained.

The overall results from the test of Formula C are encouraging. The inconsistencies developed by the formula are either explainable or are not worse than the inconsistencies demonstrated by the spread in the individual judgment of the several raters. The lack of spread in the dalay rate point (Table 9) is cause for concern. However, it is possible that this can be explained.

Need for Broader Test

Phoenix is currently rating some 48 miles of major arterial streets included in a recently recommended capital improvement program. These streets will be rated by Formula C and combined with the 25 sections included in the first test. This broader base should provide a further evaluation of the formula's ability to differentiate between projects.

Judgment is not infallible, and therefore it is difficult at times to determine whether the formula is correct or whether the combined judgment of the raters is correct. Table 8 indicates that usually one or two raters were rather far off the mean. Several alternate efforts were made to reduce the spread of the judgment ratings. For example, the highest and lowest rater were eliminated, then the two high and two low. These efforts produced no significant difference in the judgment ratings. Table 8 also demonstrates that any one project may receive from nearly the highest to nearly the lowest

TABLE 9

PHOENIX FORMULA C

Segment	Location	Relative Weight (points): Delay Rate (50 max.)	Relative Weight (points): Collision Rate (15 max.)	Relative Weight (points): Structural Condition (15 max.)	Relative Weight (points): Traffic (20 max.)	Total Points (100 max.)	Formula Rank
A	59th Ave. Van Buren—Thomas	0	3	12	4	19	21
B	43rd Ave. Bethany—Northern	½	2	15	4½	22	19
C	27th Ave. McDowell—Ind. School	6	5	15	5	31	8
D	19th Ave. Ind. School—Bethany	1½	6	9	6	22½	17
E	7th Ave. Van Buren—Thomas	7	6	13	8	34	6
F	Central Ave. Camelback—Glendale	3½	6	7	8½	25	12
G	7th St. McDowell—Ind. School (as it was)	7½	6	13	9½	36	5
H	16th St. Camelback—Glendale	1½	6	9	7	23½	15
I	24th St. Buckeye—McDowell	7½	12	14	8½	32	7
J	32nd St. Van Buren—Thomas	2½	7	12	8	29½	9
K	44th St. McDowell—Ind. School	4	5	12	6½	27½	10
L	Baseline 16th St.—32nd St.	0	2	1	5½	8½	25
M	Broadway 7th Ave.—16th St	1	7	7	7	22	18
N	Van Buren 43rd Ave.—27th Ave.	0	6	13	7½	26½	11
O	Van Buren 7th St.—24th St.	9½	15	3	12½	40	3
P	Van Buren 48th St.—60th St.	0	2	3	9	14	23
Q	McDowell 19th Ave.—7th St. (as it was)	32	15	13	13	73	1
R	Thomas 51st Ave.—35th Ave.	0	4	8	6½	18½	22
S	Ind. School 7th Ave.—16th St.	11	8	4	15	38	4
T	Camelback 16th St.—32nd St.	3½	4	5	12	24½	13
U	Bethany 7th Ave.—16th St.	1	6	12	5½	24½	14
V	Glendale 16th St.—32nd St.	0	2	7	5	14	24
W	Cave Creek 7th St.—20th St.	½	4	15	4	23½	16
X	"Q" Ave. 43rd Ave.—Black Canyon	0	2	15	3½	20½	20
Y	Grand Ave. Thomas—Camelback	7½	15	13	9½	45	2

judgment rating. Perhaps this is the best argument of all for a major street improvement priority formula.

Summary

A major street improvement priority formula for urban areas is needed. Such a formula would be a useful tool to those responsible for developing a capital improvement program for major streets in cities. It would make possible the presentation of various projects in a relative priority list based on facts. At this point, judgment and budgetary considerations can most properly be applied to develop the capital improvement program that will provide maximum benefits to the public.

The results of the work in Phoenix and San Diego indicate that such a formula should not be too complex and should certainly minimize the judgment elements that go into it. However, this study demonstrates that one of the more difficult considerations for a priority formula to recognize and evaluate is a facility that has been improved to reasonable standards or that is near an existing or planned freeway.

It is difficult to evaluate a major street improvement priority formula because of the wide variances in judgment that have been obtained from the several studies. This emphasizes the need to develop a simple, easily applied, factual major street improvement priority formula for urban areas.

CONCLUSIONS

1. Travel time is an effective measure of level of service, both for individual routes and for urban streets and freeway systems.
2. Travel time studies of individual routes are a simple tool that can identify causes of congestion and thus lead more rapidly to needed improvements. A program of traffic engineering improvements resulted in an increase in the average speed on major arterial streets of 20 percent between 1947 and 1957, accomplished despite an increase of 62 percent in the average traffic volume.
3. Time contour maps offer a simple and reasonably accurate means of comparing the level of service of various urban areas.
4. A typical major arterial street system reaches saturation at some population level of the central city of a growing urban area. By the time this point is reached, a freeway system must be placed in operation if the overall level of service of the street system is to be prevented from declining. The population level of the central city may well be somewhere between 400,000 and 500,000 people. It appears that Phoenix has passed this "hump" as the average travel speed declined slightly between 1957 and 1962.
5. A major arterial street construction priority formula for urban areas is needed. Such a formula would not replace judgment but would be used to present various projects in a relative priority list based on factual studies. Judgment, timing and budgetary considerations can then best be applied to the priority list to develop a capital improvement program.
6. An urban major street improvement priority formula should be relatively simple and should minimize the judgment elements that go into it. A priority formula should be based on facts.
7. A major street improvement priority formula is difficult to test because of wide variances in judgment. Perhaps this conclusion is the strongest argument in favor of developing a simple, easily applied, factual major street improvement priority formula for urban areas.