THE COORDINATE METHOD OF O AND D ANALYSIS

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SYNOPSIS

This paper presents a substitute for the standard desire line method of analyzing O and D data. The method is based upon identifying all trip ends to a tenth-mile grid superimposed over an area so that punch card tabulating machines may be used to the utmost advantage in arranging and rearranging material. Aside from customary data being presented more readily, other departures are made possible.

The basic travel desire picture of an area in the form of a "Trip Desire Contour Chart" is one of these departures This is accomplished by causing each trip to leave its effect on each point within a field of points across which or close to which it might pass in its straight line journey from beginning to end When the total effect of all trips of an area is taken, the result is a field of values representing the number of trips wishing to pass through the various points Many trips desiring to traverse similar routes would leave many values along their common desire route. When these registered quantities are separated into groups of like value in the contour sense, a "Trip Desire Chart" results. This Trip Desire Chart can be restrictive and embrace the effect of any selected length of trip, the long or the short, and it can be used likewise to present trips of selected types, the auto trips, the mass transit trips, the truck trips, etc

Another feature made possible by the coordinate system of O and D analysis is the partial assignment, mechanically, of traffic on a proposed alignment Based upon the advantage that an "improved facility" travel has over the normal street travel, a mechanical assignment to this facility can be made from all the trips of the area This assignment is based upon the assumption that the grid established be considered to replace the existing streets and that trips will be attracted to the improved facility in some proportion to the amount of time they could save by its use The selection of interchange locations is provided for as well as the extra distance certain trips might travel due to their imposition

In addition to the Trip Contour Chart and the mechanical assignment of traffic to a proposed facility, other information is readily disclosed

1 Angular (or grid) trip lengths are obtained
2 Straight line or shortest distance trip lengths are computed mechanically
3 Resulting vehicle-miles are made available.
4. Various areas can be selected for special analysis and study
5 Densities of origins in a selected or overall area are easily established

The coordinate method of O and D analysis primarily gives a lucid and concise representation of true desire movement, provides a method of evaluating traffic on a freeway, and speeds up analytical results

The system of interviewing people in their homes to determine their daily travel has been followed in many of the metropolitan areas of the country. By this time, the technique of collecting information to be used in determining the entire traffic flow within an area is fairly well perfected. Studies can be run on schedule and the accuracy of the results obtained is good.

Progress in assembling and analyzing the data still presents many problems This is due not so much to the fact that the aims of the studies differ from city to city as it is to the difficulty in processing large quantities of data. The root of much of the trouble seems to lie in the current method of zoning. The vast number of combinations resulting from the multiplicity of zones is perplexing and so are their irregular shapes and areas.

There are other difficulties. Once a zone is established it may be impracticable to further subdivide it and some of the accuracy of the original data is sacrificed It has also been observed that zones set up for one purpose frequently are unsuited for another. In setting up zone borders in advance of the analysis, we may be introducing a possible error into the resulting traffic picture.

With the thought of overcoming this last objection and of lessening some of the other difficulties mentioned, an alternate procedure has been tried in California The procedure requires that a regular grid system be substituted for the customary irregular zones, and all origins and destinations of trips referenced to it. Some examples drawn from studies in Sacramento and the San Francisco Bay Area will serve to outline the method

the grid, a log was made of all traversable roads and streets in the area so that the intersections of streets and the numbers within the street blocks might be referenced to the grid system. A sample of the road log is shown in Figure 1. Field work was at the rate of 30 mi. per day. Pertinent data from the log were then transferred to tabulating cards, Figure 2, and following this, a street index for use in coding was prepared, Figure 3.

Street Index Form #1
WARREN
Chief of Party
Date 10/3/47

Metropolitan Traffic Surveys
STREET INDEXING
(Logs read up the page)

State of California
Department of Public Works
Division of Highways
Serial No 192

	2	3	4	5	6	7	8	9	10	11
City	Major Street	Card* Type	Intersecting Street	Begin End No	Area Limits		Odometer Reading Beg - End	Int Dist	Multiple Inter No.	Zone
1	S St	1	39th St		3800	3930				068025
1	S St	1	37th St		3700	3799	548			066073
1	37th St	3	dead end				548	01		066074
1		1	S St		1800	1914				066073
1	37th St	1	T St		1915	1950	547			066072
1	U St	1	Stockton Blvd		3750	3809	546	1 2		066072
1		1	39th St		3810	3999				068072
1		1	42nd St		4000	4299				070072
1		1	45th St		4300	4599				071072
1		1	48th St		4600	4899				073072
1		1	51st St		4900	5199				075072
1		1	53rd St		5200	5399				077072
1	U St	1	55th St		5400	5450	534			078072
1	T St	2	S St		5768	5799	533	0.2	44	079073

*1 Normal Streets & Addresses
2 Multiple Intersection
3 Dead end or city limits
4 Even Numbers Only
5 Odd Numbers Only
6 Intersections on city limits
7 Special Cases (addresses in wrong int area, etc)
8 No numbers on either side.

#77

Figure 1. Street Index Form

Development of a Trip Desire Chart—In Sacramento a grid system was chosen so that its ordinates could be as nearly in conformity with the general street pattern as possible in order that there would be high correlation between the route that a trip might be expected to take on existing streets and the route that it would take if it were placed along the coordinate system A $\frac{1}{10}$-mile interval on each of the ordinates and an approximate north-south, east-west orientation, based upon the layout of the streets in the older portion of Sacramento, was judged the most desirable.

Immediately following the laying out of

An important by-product of this logging operation is the determination of the total street mileage.

All origins and destinations were then coded to the coordinate point which lay to the lower left of the unit square in which they occurred. The west-east distance (X Distance) is always recorded first, with the south-north distance (Y Distance) second In general, origins and destinations respectively are expressed as X_oY_o, X_dY_d.

The next step is to trace desire lines and to incorporate them into a chart to show the contribution of each trip to the daily traffic flow. A Desire Line may be defined as a

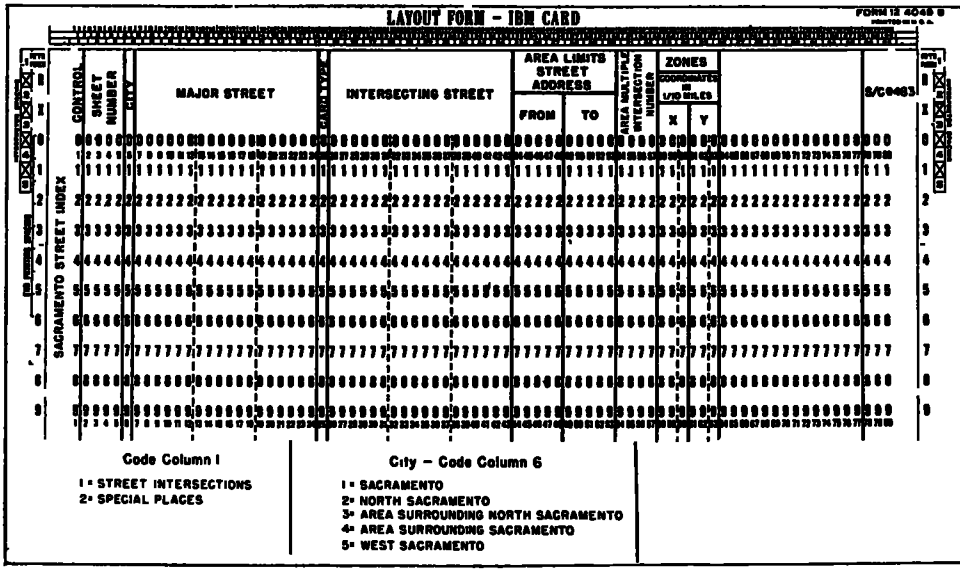


Figure 2. Tabulating Card for Street Index

CITY CODE	MAJOR STREET	INTERSECTING STREET	ADDRESS From	ADDRESS To	COORDINATES X	COORDINATES Y
1	V	24	2316	2415	056	072
		25	2416	2515	057	072
		26	2516	2615	057	072
		27	2616	2715	058	072
		28	2716	2815	059	072
		29	2816	2915	060	072
		30	2916	3015	060	072
		ALHAMBRA BLVD	3016	3199	061	072
		34	3200	3399	063	072
		STOCKTON BLVD	3750	3809	066	072
		39	3810	3999	068	072
		42	4000	4299	070	072
		45	4300	4599	071	072
		48	4600	4899	073	072
		51	4900	5199	075	072
		53	5200	5399	077	072
		55	5400	5450	078	072
		58	5800	5815	080	072
		59	5816	5850	080	072
1	UNION AUTO FRT	4 8			041	073
1	UNION OIL	FRONT BROADWAY			038	069
1	UNITED GROC LTD	NORTH 016 A			050	087
1	V	FRONT	100	115	038	071
		2	116	215	039	071
		3	216	315	040	071
		4	316	415	041	071
		5	416	515	041	071
		6	516	599	042	071
		8	800	815	044	071

Figure 3. Sample of Sacramento Street Index

straight line between the origin and destination of a trip without regard to the existing street pattern or any physical obstacle. The connecting line is then defined by the general formula of a straight line, $Y = A + BX$, where A is the Y intercept and B is the slope of the line. Interest in the equation lies within the limits of the Y_o and Y_d values for Y and X_o and X_d values for X for any given combination of origins and destinations.

The solution of the formula mechanically can be accomplished by dealing with increments of X and Y (ΔX and ΔY) (See Fig. 4). To obtain Y for any value greater than Y_o, the formula becomes $Y = B\Delta X$ where

$$Y = Y_o + \Delta Y$$

and

$$X = X_o + \Delta X$$

This calculation has to be done and a tabulating card prepared for each value of ΔX be-

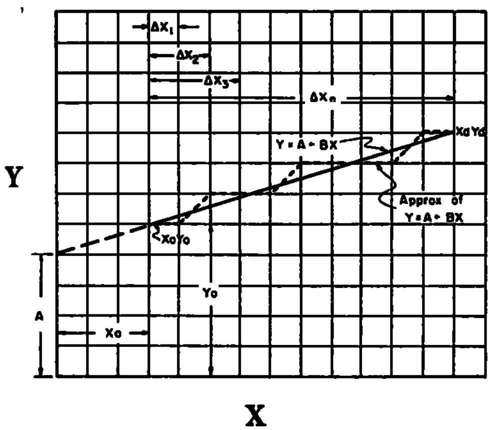


Figure 4. Chart Showing Items Required in Solving $\Delta Y = B\Delta X$ and the Approximation of the Straight Line Obtained

tween X_o and X_d (Note that in Figure 4 the absolute value of ΔX_2 is one unit, in this case $\frac{1}{10}$ mile, greater than ΔX_1)

The solved values of Y are adjusted to the closest $\frac{1}{10}$ mile since the data are to be collected to a $\frac{1}{10}$-mile grid. Plotting of these points on the grid system will approximate a straight line (Fig 4) It is possible to have the same Y values for two or more consecutive X values Several methods for accomplishing the necessary tabulating machine work are available.

When cards upon which the Y coordinate is calculated for each X coordinate between origin and destination have been obtained, a major portion of the work has been accomplished for all modes of travel. It only remains to gather and to total the trips passing through the several coordinate points With these totals giving the "elevation" for each coordinate point, a desire line contour chart may be prepared.

Figure 5 is a small section of such a contour chart. The recorded numbers represent a grouping in hundreds of all the trips desiring to pass in any direction through or near the various points. Thus, 2,700 trips daily can be said to desire to pass through the hundredth of a square mile of which the SW corner is $X = 5.0$, $Y = 9.0$. Traced through the field can be seen the lines separating like values.

Figure 6 is a Trip Desire Chart for autos and trucks for the entire Sacramento area. The chart approximates the aggregate effect of the movement of the 328,460 auto and truck trips that occur daily. The shapes of the contour lines reveal a picture of the traffic desires and form the basis for a general traffic analysis

Immediately attention is drawn to three main phenomena First, the area of high contour values above the 10,000 trip level defines the core of the central business district. Second, the major ridges, and particularly those from the cordon stations, generally point to this area Third, minor yet sharply marked ridges connect the major cordon stations. It is to be noted that the maximum through movement between any pair can never exceed the least value shown on the chart that lies nearest the straight line connecting the two stations concerned. Further attention is called to the fact that the location of the cordon stations is arbitrarily fixed and the ridges emanating from them must be considered with this fact in mind.

The effect at the intersection of two ridges is exemplified at the position $X = 9.1$ and $Y = 9.6$. A small peak occurs. It has a value roughly equal to the sum of the two streams. Small peaks, of course, also occur at points of traffic concentration such as at $X = 5.4$ and $Y = 5.8$ which happens to be the Junior College

Other Data—At the same time that data are tabulated to obtain the figures for the intersection of the several grid lines as illustrated on Figure 5, a first approximation is had of the desire line vehicle-miles within the area, (Table 1) To do this it is assumed that each recorded number of trips will travel a minimum of 0.1 mi. On this basis, the average length of the 328,460 auto and truck trips is 2 2 mi Further, since each intersection of grid lines represents 0 01 sq mi. it follows that a measure of area may also be obtained simply by counting squares within a given contour elevation, and thus the relative density of traffic can be established as shown in Table 1

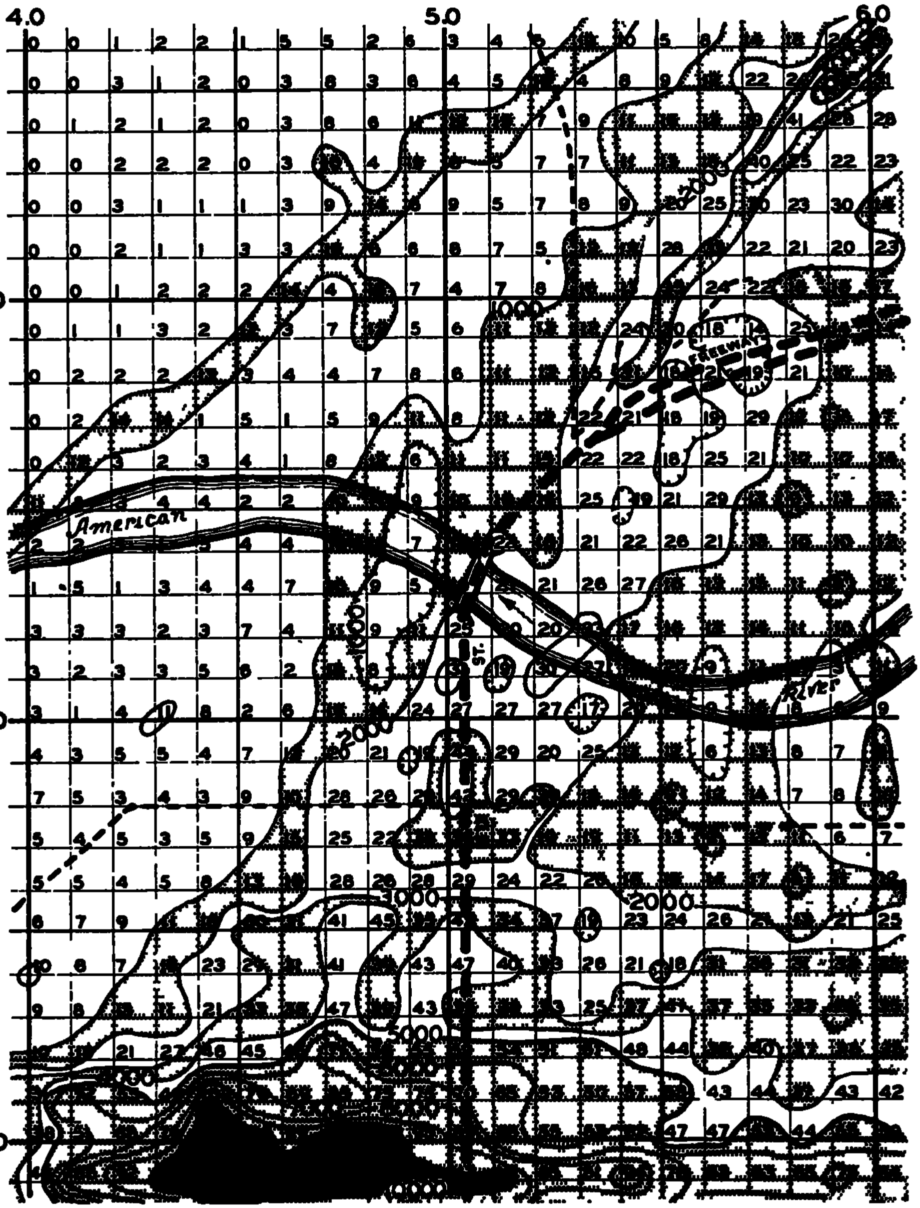


Figure 5. Sacramento Area Trip Desire Chart—Autos and Trucks Work Sheet Sample

There is obviously a weakness in the basic assumption that each trip will travel a minimum of 0.1 mi. but the justification for desire-line-vehicle-miles can be computed at a later time.

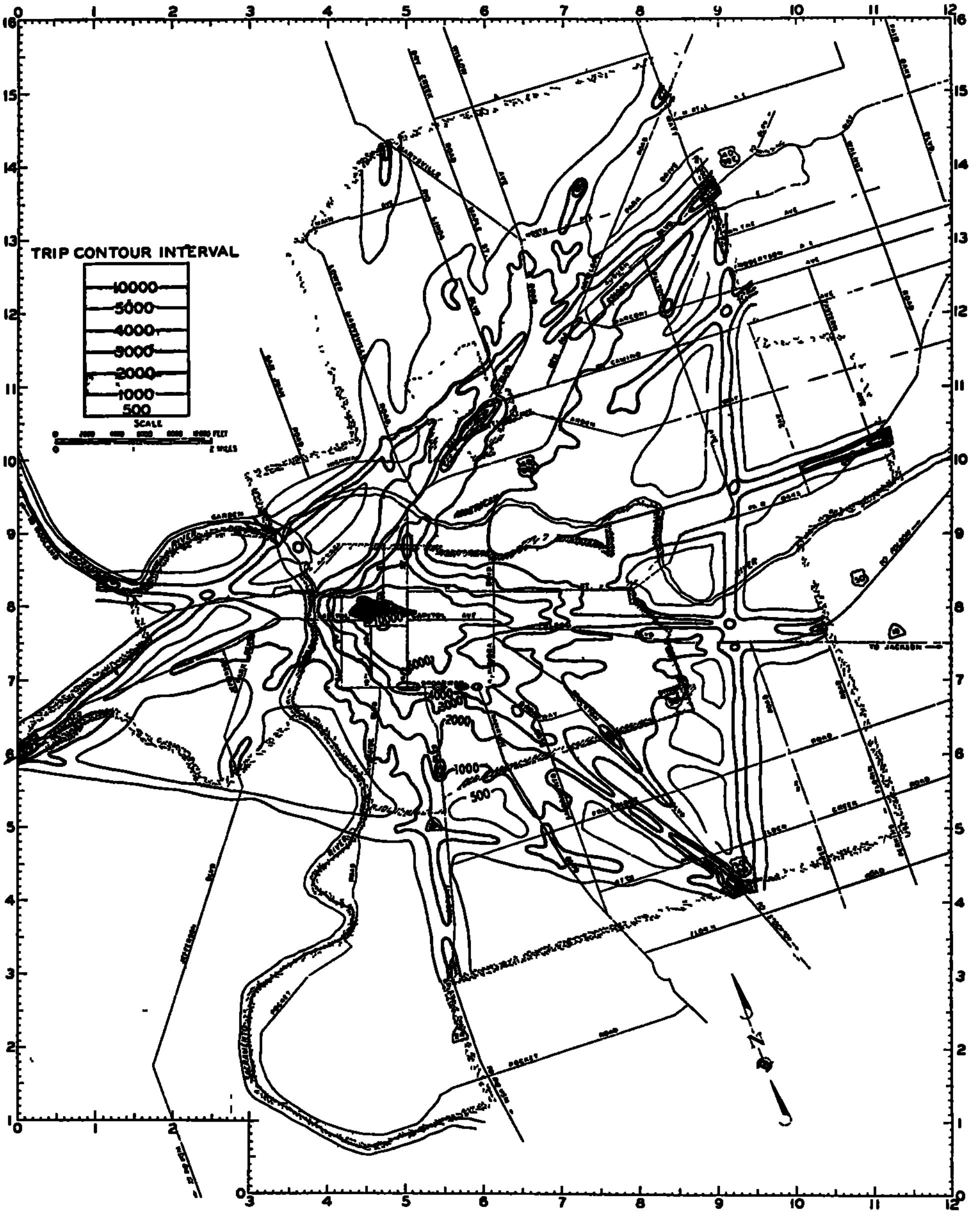


Figure 6. Contour Chart Sacramento

making it is that the average length of trip on a desire line basis is obtained incidentally at an early stage of the procedure. The true

Another piece of valuable information is also obtainable. Because of the high congruency of the grid pattern to the street pattern, the more probable length of a trip may be approximated by causing each trip to follow a grid line course. Thus in Sacramento it was found that there were 982,383 grid line vehicle miles. The average trip on this more realistic basis was close to 3 mi.

TABLE 1
VEHICLE MILES OF AUTOS AND TRUCKS BY AREA AND CONTOUR INTERVAL

Contour Interval	Area	Percent of Total Area	Vehicle Miles	Percent of Total Veh Miles
	sq mi			
0–499	47 98	55 49	80,411	11 37
500–999	16 69	19 30	120,707	17 06
1000–1999	13 01	15 05	179,490	25 37
2000–2999	4 26	4 93	103,749	14 67
3000–3999	1 90	2 20	65,427	9 25
4000–4999	1 16	1 34	51,678	7 31
5000–9999	1 30	1 50	84,402	11 93
10,000-and over	16	19	21,528	3 04
Totals	86 46	100 0	707,392	100 0

TABLE 2
NUMBER OF TRIPS AND VEHICLE MILES BY LENGTH OF TRIP—AUTOS, TRUCKS & TAXIS

Length of Trip	Trips		Vehicle Miles	
	No	Percent	No	Percent
Miles				
0 0– 0 9	95,702	29 3	47,850	4 9
1 0– 1 9	67,274	20 5	100,912	10 3
2 0– 2 9	47,414	14 5	118,534	12 1
3 0– 3 9	31,041	9 5	108,644	11 0
4 0– 4 9	19,620	6 0	88,290	9 0
5 0– 5 9	15,315	4 7	84,231	8 6
6 0– 6 9	14,993	4 6	97,453	9 9
7 0– 7 9	9,759	3 0	73,193	7 4
8 0– 8 9	8,041	2 5	68,348	7 0
9 0– 9 9	6,631	2 0	62,993	6 4
10 0–10 9	5,955	1 8	62,532	6 4
11 0–11 9	2,480	0 8	28,521	2 9
12 0–12 9	1,086	0 3	13,579	1 4
13 0–13 9	253	0 1	3,416	0 3
14 0–14 9	217	0 1	3,142	0 3
15 0–15 9	113	[a]	1,752	0 2
16 0–16 9	1,057	0 3	17,442	1 8
17 0–17 9	89	[a]	1,551	0 1
	327,040	100 0	982,383	100 0
Unknown	1,420			
Total	328,460			

[a] Less than 0 05.

Table 2 is a frequency distribution of trips by length. It is valuable on two counts First, in the ordinary method of analysis by zones, the short trips, of say less than a half mile, present trouble and lead to uncertainty in analysis. An approximation of their number and relationship to the entire array of trips obviously means that they can be studied and examined in detail. Second, and more important, the desirable minimum distance between interchange facilities of a freeway is a lively question in debate. The data available should be helpful in discussing it.

Special Considerations—If in preparing the desire-line contour chart all the trip cards had been used in the foregoing outline of procedure to solve mechanically the straight-line formula, the total volume of cards obtained would have been prohibitive. Consequently, after preliminary study a fraction of the cards (⅛) was selected in the following manner:

1. Cards were identified by direction so that in the Sacramento area only eastbound trips were taken. It was assumed that this could be done with negligible bias as in a 24-hr. day the travel in one direction would balance that in the opposite direction This reduced the cards by ½. They were further reduced by taking cards where the differences on the X axis and also on the Y axis ended in even numbers

2 For trips between cordon stations, ⅛ of the whole were taken regardless of even or odd differences. This was necessary because such trips otherwise would have been either included or excluded in their entirety. This same procedure was also followed to check on the possibility of there being a phenomenally high traffic interchange between two points within the area It was easily accomplished

Question naturally arises as to whether the use of this ⅛ fraction of the cards is valid Studies indicate that not only is it probably valid, but that still smaller fractions subsequently may prove justified. Two criteria are available to judge as outlined in the succeeding paragraph.

Following production of the map shown in Figure 6, additional work was done to determine the desire line vehicle mileage for the entire array of trips It was found to be 715,515. Next, the remaining seven additional samples were drawn and the desire line vehicle mileage obtained for each sample The ratios of the vehicle miles of the respective samples to the total generated by the entire array of trips are given in Table 3. The maximum deviation from the true was −2 percent. This same process was followed with respect to the true straight line vehicle mile

TABLE 3
VALIDITY OF SAMPLING TEST

½ Sample Group No	Expanded ½ Sample Value as Percent of True Value	
	Desire Line Contour Chart—Vehicle Miles	Straight Line Vehicle Miles
1[a]	98 9	99 0
2	99 4	99 6
3	101 8	102 7
4	98 8	98 9
5	100 8	100 9
6	101 4	100 8
7	98 0	96 9
8	100 9	101 2
	100% = 715,515	100% = 754,140

[a] Sample used in preparing Fig 6

determination. Here again the results were close While these data are inconclusive, they give good grounds for supposing that there exists some further possibility of reducing the amount of work required in preparing a desire line contour chart.

It may be remarked, before passing to the subject of estimating traffic volume on a projected alignment, that the question of using a fraction of trips for such purpose has not been studied

Estimating Traffic on a Projected Line—The substitution of a grid coordinate for the existing city street pattern is likewise one of the

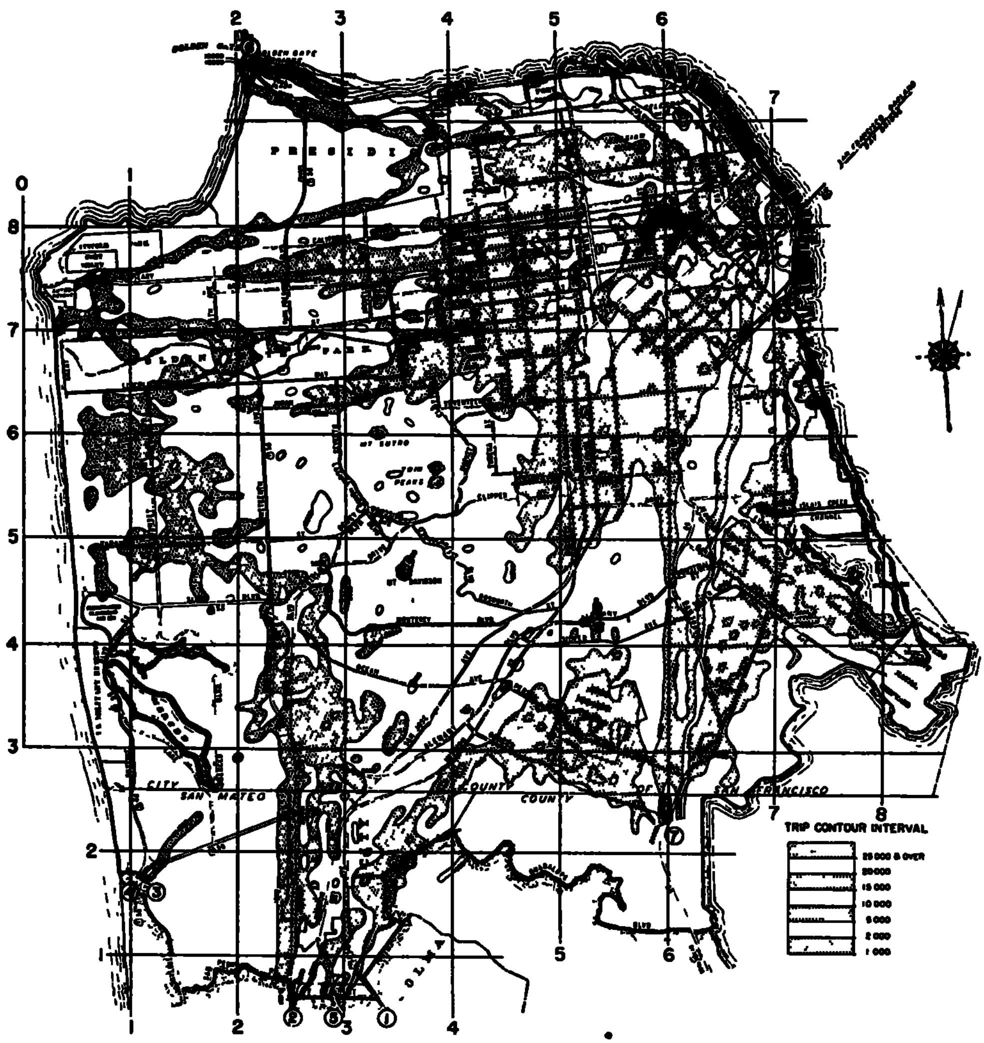


Figure 7. Contour Chart San Francisco

key points that makes it possible to process mechanically many of the data for subsequent studies of traffic on particular lines The general technique may be sketched by considering the San Francisco Bayshore Freeway Figure 7 is a desire contour chart for San Francisco. A pronounced concentration of traffic is seen running north to south along the general line $X = 6.1$ The proposed Bayshore Freeway, extending from the south city limits of San Francisco to a connection with the San Francisco-Oakland Bay Bridge, follows pretty much this straight line It will be considered between the limits $Y = 2.5$ and 7.1 in the mechanical evaluation procedures that follow

of things Some, like time or speed, are readily measurable Others, like safety differential, economy of vehicle operation, and comfort and convenience are only measured with difficulty, if at all. Nonetheless these latter elements may conceivably exert as great an influence on a motorist's choice of route as does the more easily determined element of time saving It is considered desirable to recognize that possibility even though the ratio is based substantially on speed In the present case it is assumed that 2:1 could be a practical ratio of advantage for a freeway. This factor could, of course, be altered to suit any particular set of conditions or freeway locations.

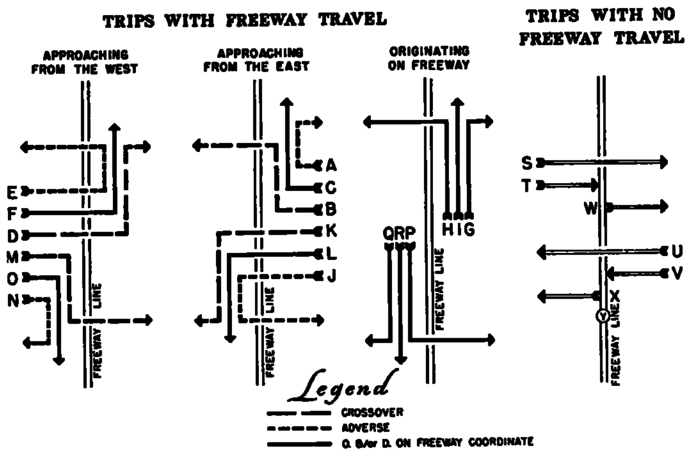


Figure 8. Trip Types

Once the alignment has been chosen, analysis hinges upon the following major steps:

1. Establishing an advantage ratio for the proposed line.
2. Subjecting all trips in the area to mechanical investigation with regard to the line, upon which it is initially assumed that traffic may enter at any point.
3. Refining the results of the initial investigation to account for the effect of interchanges on traffic, for length of trip considerations, for amount of time saved by reason of the improved routing, and for the ratio of freeway portion of trip to total length of trip.

The establishment of the "advantage ratio" poses a problem. It is called "advantage ratio" because in it are included a multitude

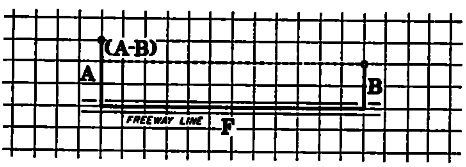
In order to subject all trips of an area to mechanical manipulations, a trip-type code has been established that takes into account every possible move (25 in all) that a trip could make from beginning to end with respect to a chosen line. This code is shown in Figure 8.

Once this classification is established something can soon be known about how much service a given line will provide. All crossover trips that have movement in the freeway direction could accrue advantage by utilizing a portion of the proposed line, and the amount of advantage would be in direct proportion to the distance they would travel on the freeway. These trips are shown on Figure 8 as codes D, M, B, K.

Other trips that could obtain advantage

are those of codes F, O, C, L, and Q, R, P, H, I, G Trips of the latter group are not numerous as a rule, as one of their classifying conditions is that they must have at least one end with a value the same as that of the freeway

There is a trip-type that depends entirely upon the advantage ratio for its selection as one that would or would not utilize the freeway. That is the trip that has both end points on the same side of the freeway line. For convenience, this trip is called the "adverse" trip as compared to the cross-over type trip Out of the whole area there must be selected those trips of the adverse type that could obtain advantage by approaching



Let **A** = Distance to Freeway of End of Trip farthest removed from Freeway Line
B = Distance to Freeway of End of Trip nearest the Freeway Line
F = Portion of Adverse Trip on Freeway
R = Ratio of Advantage Freeway Travel to "Off" Freeway Travel

DERIVATION–

Let–Direct Route = Adverse Route

Or $(A-B)+F = A + \frac{F}{R} + B$

Then $F = \frac{2RB}{R-1}$

When $R=2$ Then $F = 4B$

Figure 9. Derivation of Formula for Determining the Route of Advantage for the Adverse Type Trips

the freeway, traversing some portion of it, and then receding to their destinations on the same side as that from which they came

The distance to the freeway of that end of the trip that lies the closer is the determining factor of whether or not the trip would use the freeway. Consider Figure 9.

The equation $F = 4B$ in effect says that "when four times the distance from the freeway line to the closer end point of an adverse trip is less than the desired freeway travel distance, then the trip route via the freeway is the advantageous one" This $F = 4B$ is called the attraction formula for a freeway line with a 2:1 advantage ratio

At this stage all trips in the area of the survey are subjected to mechanical test and the results, shown in Table 4, are the number of trips that would theoretically use the chosen line, the extent and portion of the line they would traverse, their desired turning movements, and their points of entry to and exit from the line They yield in Figure 10 the maximum potential traffic profile of the proposed facility. The 208,649 trips indicate a maximum peak traffic of 132,673 vehicles daily.

Consideration of the maximum potential profile leads directly to the question of interchange locations The mechanical selection of any particular points for interchanges can at best be only an approximation because junctions the freeway might have with main contributing arteries, topographic conditions, economic factors, etc., weigh heavily in such a selection However, an entirely objective method of selection is presented. It is based on the frequency of desires of entry or exit at the various grid intersections within the limits of the freeway The method of selection outlined is probably only one of several that could be employed By making a table of half-mile progressive totals, as shown in the Activity column of Table 4, and observing maximum points, certain locations are suggested Due to the fact that the effect of an interchange often extends for a half-mile of freeway distance, the selected locations could vary somewhat from the maximum points of the curve of progressive totals.

However chosen, once interchange locations are established, it follows that movement is restricted and certain trips of the "maximum potential" will find it more profitable now to not negotiate the freeway, but to stay on the surface streets. This is particularly true of the shorter trips as the extra time taken to go out of their way to find an entry or exit point weighs heavily against the advantage offered by the freeway. The new element thus added to the trip route via the freeway applies to the crossover type trip as well as to the adverse type trip It is called the "back-tracing element" Consider Figure 11

Then, as before, equating the adverse route to the direct or city street route, it is found that $F = 4(B + C + D)$. The attraction equation when backtracking is considered, now states. "When the distance of the freeway portion of a trip is greater than four times the sum of the back-tracking and adverse distances, the trip would accrue an advantage by taking the freeway route." (Adverse as used here means that distance which must be made up)

TABLE 4
MAXIMUM POTENTIAL TRAFFIC

Y Coordinate	Number of Trips				Total Traffic	Activity	
	Southbound		Northbound			Per Coordinate	Progressive ½ Mi Totals
	Entering	Leaving	Entering	Leaving			
71 & Over	67,619 9	2,773 0	2,492 5	70,318 6	132,673 0	143,204 0	
70	2,106 1	2,457 1	2,475 1	2,374 7	132,221 6	9,413 0	
69	1,215 1	1,750 5	1,903 9	1,137 9	130,920 2	6,007 4	
68	1,720 6	1,341 9	1,588 7	1,702 9	131,413 1	6,354 1	34,265 9
67	1,285 1	1,705 7	2,071 0	1,370 0	130,291 5	6,431 8	31,713 7
66	1,440 3	1,619 4	1,541 7	1,458 2	130,028 9	6,059 6	33,206 1
65	1,453 6	2,096 8	1,998 5	1,311 9	128,699 1	6,860 8	34,571 2
64	1,830 0	1,729 3	2,026 9	1,913 6	128,686 5	7,499 8	34,394 7
63	1,414 6	2,541 7	2,418 9	1,344 0	126,484 5	7,719 2	37,054 1
62	1,158 8	1,803 9	1,927 1	1,365 5	125,277 8	6,255 3	35,188 4
61	1,643 4	2,498 5	2,808 3	1,768 8	123,383 2	8,719 0	32,624 4
60	857 4	1,452 5	1,688 9	996 3	122,095 5	4,995 1	29,933 2
59	802 4	1,595 6	1,664 5	873 3	120,511 1	4,935 8	29,631 9
58	1,030 9	1,468 3	1,396 3	1,132 5	119,809 9	5,028 0	28,564 5
57	991 8	1,920 1	2,066 0	976 1	117,791 7	5,954 0	29,825 1
56	1,235 3	2,345 7	2,581 4	1,489 2	115,589 1	7,651 6	30,951 7
55	1,092 2	1,922 6	2,200 3	1,040 6	113,599 0	6,255 7	31,054 7
54	1,185 3	1,975 2	1,901 7	1,000 2	111,907 6	6,062 4	29,786 5
53	953 6	1,633 7	1,476 0	1,067 7	110,819 2	5,131 0	24,524 8
52	562 0	1,742 3	1,784 6	596 9	108,451 2	4,685 8	23,560 6
51	263 4	1,010 0	917 6	198 9	106,985 9	2,389 9	21,253 3
50	788 7	1 818 5	1,878 0	806 3	104,884 4	5,291 5	18,693 6
49	498 2	1,482 9	1,373 2	400 8	102,927 3	3,755 1	18,405 7
48	187 1	1,103 2	1,065 4	215 6	101,161 4	2,571 3	19,498 8
47	613 5	1,679 8	1,569 1	535 5	99,061 5	4,397 9	17,775 8
46	406 8	1,160 5	1,388 0	527 7	97,447 5	3,483 0	18,892 0
45	363 5	1,525 6	1,394 9	284 5	95,175 0	3,568 5	20,916 4
44	444 7	2,003 7	1,920 3	502 6	92,198 3	4,871 3	22,857 4
43	620 2	1,541 9	1,802 5	631 1	90,105 2	4,595 7	24,836 0
42	973 1	2,275 0	2,204 1	886 7	87,485 9	6,338 9	25,836 9
41	511 2	2,300 0	2,185 1	465 3	83,977 3	5,461 6	30,591 4
40	443 3	1,720 4	1,911 9	493 8	81,282 1	4,569 4	29,143 1
39	1,189 8	3,563 3	3,629 7	1,242 8	76,521 5	9,625 8	25,653 9
38	324 6	1,197 2	1,255 6	370 0	74,763 3	3,147 4	24,373 1
37	292 1	1,100 5	1,154 2	302 9	73,103 6	2,849 7	23,157 3
36	213 9	1,871 0	1,887 0	208 9	69,768 4	4,180 8	15,893 4
35	197 5	1,434 1	1,589 3	132 7	67,075 2	3,353 6	14,238 0
34	127 9	1,031 9	1,126 1	76 0	65,121 1	2,361 9	13,942 6
33	80 6	587 2	709 7	114 5	64,019 3	1,492 0	14,142 9
32	286 3	969 5	1,070 3	228 2	62,494 0	2,554 3	12,457 9
31	300 7	1,912 0	1,979 0	189 4	59,093 1	4,381 1	12,766 1
30	128 8	708 7	711 0	120 1	57,922 3	1,668 6	15,981 5
29	293 0	1,048 5	1,001 8	326 8	56,491 8	2,670 1	16,976 0
28	442 4	1,964 1	1,930 4	370 5	53,410 2	4,707 4	14,098 6
27	147 5	1,630 8	1,655 0	115 5	50,387 4	3,548 8	
26	66 0	725 4	645 1	67 2	49,150 1	1,503 7	
0-25 incl		24,063 7	25,086 4				

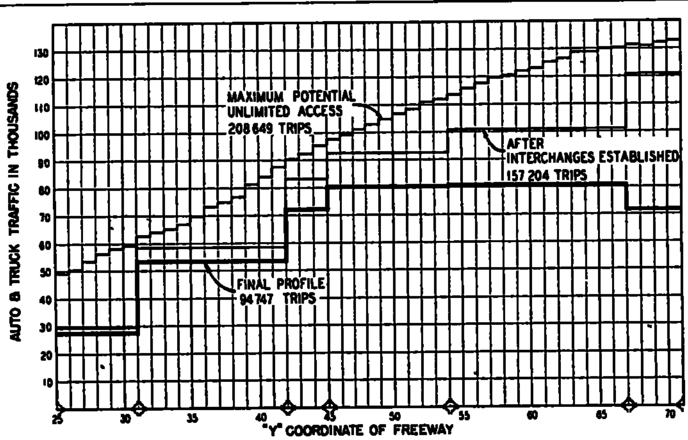
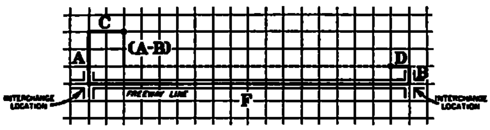


Figure 10. Traffic Profiles

Take for example two adjacent interchange positions, $Y = 31$ and $Y = 42$, shown on Figure 12. It now becomes possible for a trip moving in a northerly direction and originating at a point $Y = 33$ to return to interchange



Let A = Distance to Freeway of End of Trip farthest removed from Freeway Line
B = Distance to Freeway of End of Trip nearest the Freeway Line
C = Back tracking Distance at one end of trip to enter or leave at interchange location
D = Back tracking Distance at other end of trip to enter or leave at interchange location
F = Portion of Trip on Freeway
R = Ratio of Advantage Freeway Travel to "Off" Freeway Travel

DERIVATION–
Let Direct Route = Adverse and Back tracking Route

$$(A-B)+F-(C+D) = C+A+F/R+B+D$$

Then $F = \frac{2R(B+C+D)}{R-1}$

When $R=2$ Then $F = 4(B+C+D)$

Figure 11. Derivation of Formula for Determining the Route of Advantage for the Backtracking and (or) Adverse Type Trips

Applying this principle, then, each trip is assigned an interchange entry and exit. As to the mechanics of the operation, suffice it to say that, first, all trips are sorted by direction of travel. Second, they are routed over the city streets and also caused to back-track to get on the freeway Points of access are assigned accordingly. Trips are treated similarly in respect to destinations. Third, access and egress points now being assigned, each trip is routed via the freeway and also as if the entire trip were over city streets Net differences of distance and time via the two routes are obtained for use in subsequent analysis. Comparisons follow, and the advantageous freeway trips are separated from those whose net time would be less via the city streets.

After subjecting all the trips to this test, which reduced their numbers from 208,649 to 157,204, the trips may be conveniently summarized as in Table 5 and a Limited Access Profile made, Figure 10.

NORTHBOUND ENTRIES OR SOUTHBOUND EXITS						SOUTHBOUND OR NORTHBO		
Time between interchange points via Freeway route	Backtrack Time on City Streets to get on, or after getting off Freeway	Time to travel adverse distance route to next interchange	Time on City Streets to next interchange	Access point to which north origins or south destinations are assigned	Y Coordinates Origin or Destination	Access point to which south origins or north destinations are assigned	Time on City Streets to next interchange	Time to travel adverse di-tance
					Beginning of Facility			
3 +	0 =	3	6	31	025	31	0	[illegible]
3 +	1 =	4	5	31	026	31	1	[illegible]
3 +	2 =	5	4	31	027	31	2	[illegible]
3 +	3 =	6	3	31	028	31	3	[illegible]
3 +	4 =	7	2	31	029	31	4	[illegible]
3 +	5 =	8	1	31	030	31	5	[illegible]
3 +	6 =	9	0	31	031	31	6	[illegible]
					Interchange			
5.5 +	0 =	5.5	11	31	031	31	0	16
5.5 +	1 =	6.5	10	31	032	31	1	15
5.5 +	2 =	7.5	9	31	033	31	2	14
5.5 +	3 =	8.5	8	42	034	31	3	13
5.5 +	4 =	9.5	7	42	035	31	4	12
5.5 +	5 =	10.5	6	42	036	31	5	11
5.5 +	6 =	11.5	5	42	037	31	6	10
5.5 +	7 =	12.5	4	42	038	31	7	[illegible]
5.5 +	8 =	13.5	3	42	039	31	8	[illegible]
5.5 +	9 =	14.5	2	42	040	42	9	7
5.5 +	10 =	15.5	1	42	041	42	10	6
5.5 +	11 =	16.5	0	42	042	42	11	5
					Interchange			
1.5 +	0 =	1.5	3	42	042	42	0	
					043	42	[illegible]	

Figure 12. Traffic Interchange Assignment Table

31 and then proceed along the freeway to 42 and still net a lesser time of travel than it would have had it proceeded directly to 42 via the city street. This would apply in a like manner to trips wishing to exit at $Y = 33$ coming from the North.

At this stage of the study, trips have been isolated mechanically as to whether they would use any portion of the freeway line based upon the two factors; the advantage ratio of two for freeway travel to one for city street travel, and the limitation imposed by interchanges Although this gives a fair degree of restriction and is a substantial approach to the traffic figure that might be expected, it does not take care of such questions as—"What is the minimum time saving an individual will strive to gain (a) if he has to trade distance for it, (b) if he does not?" "What might be the minimum freeway distance a trip should be credited with to make it definitely assignable to freeway use?"

It is permissible, too, to speculate on the probability that a trip would or would not use a facility depending upon whether the length of the freeway portion of the trip bears a high or low ratio to the total length. The working hypothesis here is that the farther removed the beginning or end point of a trip is from the facility, the greater the likelihood that an individual would select or happen upon an alternate route that would offer an acceptable substitute.

A direct answer to such questions by any source of authority is hard to find, but the data may be exploited to set forth some facts bearing on the situations. Without brief for the following assumptions, and merely for the sake of illustration, it will be supposed that trips would not use the freeway if·

(a) Less than 30 percent of their total length were freeway travel,

(b) If the total length of freeway travel were 0.6 mi. or less;

(c) If time saved by using the freeway were one minute or less.

Table 6 shows that eliminating 47,255 trips which would have less than 30 percent of their total travel on the freeway is largely a matter of excluding short trips.

In the final casting out, which is given in Table 7, 15,203 trips are found to be below the criteria assumed for distance of travel on the freeway or for time saved. Of these two criteria the latter exercises the greater force because most of the short trips have already been rejected.

The form in which Table 7 has been set up was adopted in order to permit making another observation. For convenience the table was developed for speeds of 18 and 36 mph. respectively on city streets and on freeways On this basis, 0.1 mi. of freeway travel nets 10 sec. of time saving. Increments on the time saved scale correspond to those on the scale for distance traveled Now, a trip that achieves

TABLE 5

TRAFFIC ON SAN FRANCISCO BAYSHORE FREEWAY AFTER INTERCHANGE LIMITATION

Point of Entry	North Movement — Number of Trips by Freeway Section						Total Number of Trips
	025 to 031	031 to 042	042 to 045	045 to 054	054 to 067	067 to 071	
025	15,217 2	14,468.1	13,966.9	13,311 7	10,839 0	9,518 0	15,217 2
031		15,273 4	14,450 8	13,506 1	11,622 9	10,373 4	15,273 4
042			14,244 8	13,649 5	11,232 4	9,892 8	14,244 8
045				6,852 4	5,484 3	4,764 1	6,852 4
054					12,184 7	10,819 2	12,184 7
067						16,859 5	16,859 5
Total North	15,217 2	29,741 5	42,662 5	47,319 7	51,363 3	62,227 0	80,632 0
	South Movement						
	031 to 025	042 to 031	045 to 042	054 to 045	067 to 054	071 to 067	
031	826 2						826 2
042	466.5	1,504 5					1,504 5
045	608.0	1,290 4	2,196 8				2,196 8
054	2,338 0	4,240 1	6,425 3	7,732 1			7,732 1
067	1,175 4	2,370 2	3,638 4	4,237 4	5,728 6		5,728 6
071	8,825 5	19,066 3	28,487 5	33,173 3	43,685 1	58,584 0	58,584 0
Total South	14,239 6	28,471 5	40,748 0	45,142 8	49,418 7	58,584.0	76,572.2
Total North & South	29,456 8	58,213 0	83,410 5	92,462 5	100,777.0	120,811 0	157,204 2

the maximum time saved is necessarily plotted on the true diagonal. Moreover, trips plotted on the true diagonal cannot involve either the adverse or the back-tracking element, for it is these elements that cut down the time saving built up by travel on the freeway.

Therefore, it follows that a new scale may be developed by constructing a series of diagonals parallel to the true. Such a scale is shown at the right hand of Table 7 It indicates the amount of additional distance incurred in order to save time. It is to be noted that this particular scale is ½ that of the freeway distance scale. This is easily understood when it is recalled that the speed differential equivalent of freeway travel vs street travel is 2:1

Now it can be stated that 75.6 percent of the trips have 0 6 mi. or less of back-tracking and adverse distance when the freeway route is used. Had space permitted the making of this table in tenths of miles rather than in six-tenth-mile units, it could be observed that 79,880 or 50.8 percent of trips lie on the true diagnonal and would have neither back-tracking nor adverse distance

At this point the number of trips involved in the study has progressively decreased from 1,740,038 to 94,746 as shown in Table 8. Rearrangement of the remaining 94,746 trip cards produces, in Figure 10, the profile which for the limited purpose at hand is referred to as "final".

TABLE 6

RATIO OF FREEWAY DISTANCE TO TOTAL TRIP DISTANCE AND MILES TRAVELED ON FREEWAY

Ratio Freeway Distance to Total Trip Distance	Miles Traveled on Freeway					Total Trips	Total Vehicle Miles	Average Length of Trip
	Less Than 1 0 Mile	1 0 to 1 9	2 0 to 2 9	3 0 to 3 9	4 0 to Over			
								mi
0 to 29	34,215	11,233	1,774		33	47,255	35,920	76
30 to 59	3,153	19,307	30,907	1,376	20,139	74,882	203,615	2 72
60 to 89	135	2,608	9,771	1,068	20,987	34,569	128,016	3 70
90 & Over	7	98	98		295	498	1,733	3 48
Totals	37,510	33,246	42,550	2,444	41,454	157,204	369,284	2 35

TABLE 7

TRIPS ON SAN FRANCISCO BAYSHORE BOULEVARD ARRANGED TO SHOW

1 Distance Traveled on Freeway
2 Amount of Time Saved by Having Used Freeway Route
3 Additional Distance Incurred to Save Time

Minutes Saved by Having Used Freeway Route	Distance Traveled on Freeway in Miles: 00-06	07-12	13-18	19-24	25-30	31-36	37-42	43-48	Total No. Trips	Percent Accum
0-1	1493	1764	5 504	627	4,166	299	1450		15 203	13 8
1-2		3 687	3 694	626	955	225	2 254		11 441	24.2
2-3			9 166	1,614	5 570	162	1 062		17574	40.2
3-4				2 788	3 718	504	1684		8 692	48.1
4-5					20 814	482	1 836		23,132	69 2
5-6						772	3 832		4 604	73 3
6-7							10 960	8 683	19,643	91 2
7-8								9,680	9,680	100 0
TOTALS	1493	5,451	18 364	5,565	35,221	2,444	23,078	18,343	109,949	
PERCENT ACCUM	1 4	6.3	23.0	28.1	60.1	62 3	83.3	100.0		

Additional Distance Incurred to Save Time	Number of Trips	Percent Accumulated
1 8-2 1	1 450	100 0
1 5-1 8	2 553	98 7
1 2-1 5	5 453	96 4
0 9-1 2	3 328	91 4
0.6-0.9	14,040	88 4
0.3-0.6	23 785	75.6
0.0-0.3	59 340	54.0
	109 949	

Finality in the sense that it is used here does not, of course, preclude making other arrangements of the data For instance, for those who prefer, a system of zones could be established, a triangular table made, and conventional desire lines constructed as in Figure 13 (This particular set of desire lines illustrates only a portion of the possible moves

TABLE 8

	Number of Trips Daily	Remaining No of Trips	Traffic Shown by Profile
On hand at start	1,740,038		
1st elimination	1,531,389	208,649	Maximum Potential
2nd elimination	51,445	157,204	After interchanges established
3rd elimination	47,255	109,949	
4th elimination	15,203	94,746	Final[a]

[a] Trips with (a) 30 per cent or more of total trip length on freeway
(b) 0 6 mi or more of freeway travel
(c) A saving of more than one min

—those from the tier of zones north of the facility to those that lie east and west of it).

Or again, a turning movement diagram could be prepared from the data of Table 4. Before and after comparisons of vehicle-miles or average length of trip might be made. Obviously, still other assumptions could be set up for study, but such matters are outside this report since its purpose is limited to outlining and attempting an evaluation of a method.

Conclusion—The coordinate method of analysis, like most methods, has its strength and

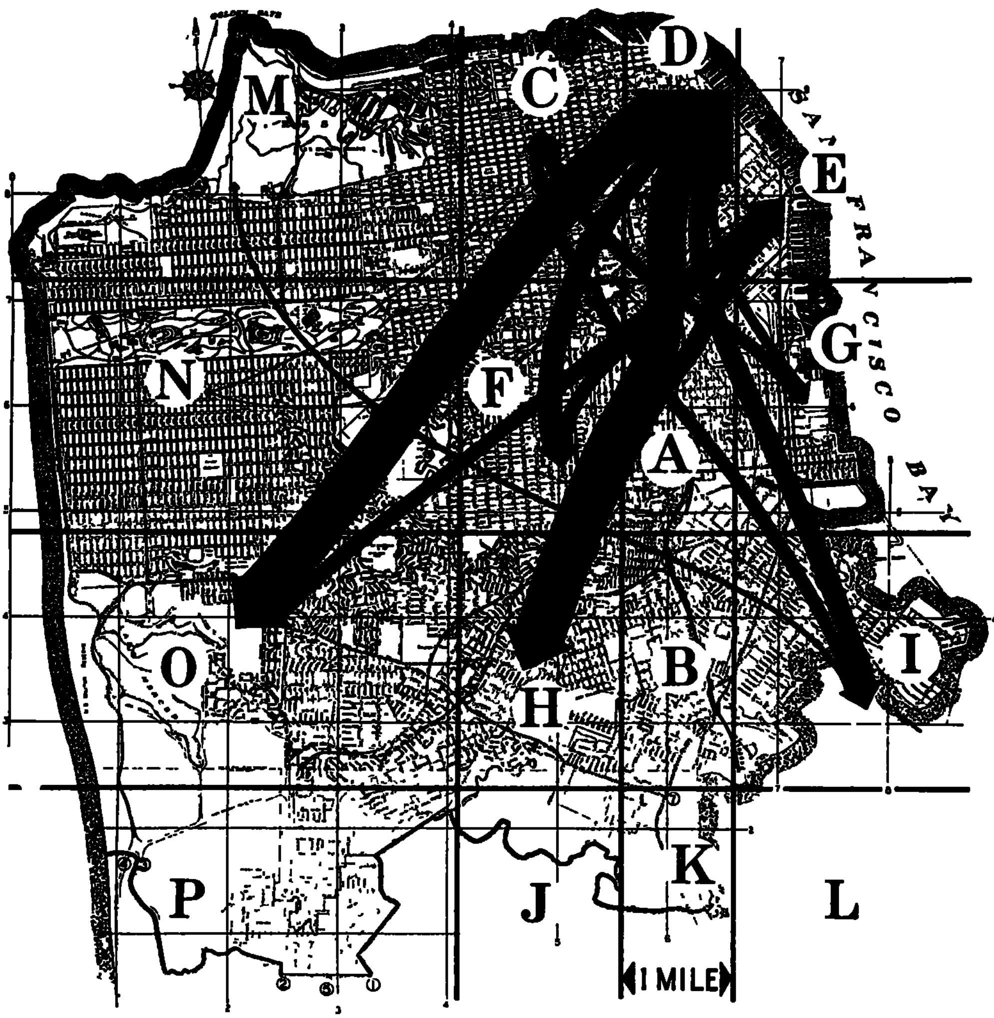


Figure 13. Desire Lines between Zones North of and Zones East and West of Freeway Line

weakness In respect to the traffic contour chart, the increase required in the volume of trip cards in order to trace the desire path of a vehicle might be considered objectionable Each of two expansions made thus far has been in the ratio of 28:1. In each case the grids have been exceedingly fine, possibly coarser grids could be used There is also a possibility that adequate contour charts may be constructed with still less than ⅛ of the total trips. Irrespective of either possibility, the disadvantages seem outweighed. The primary advantages are that.

1. The element of personal judgment is completely eliminated;

2 The basic conception is simple and the single chart is in a form with which engineers are familiar;

3. Engineering time is conserved because of the high degree of mechanization. In fact, total costs may be less than those under the conventional methods since the major computations are made simultaneously for all methods of travel.

As to route studies, the application of the method to a network of freeways has not been developed The difficulties to be solved involve the identification of all the alternate routes available for any given trip and, until this is done, the type of analysis demonstrated is unlikely to be of advantage. Also, in the case of certain diagonal routes the work may tend to be cumbersome although not impracticable. In each of the above instances portions of the process may be used to advantage.

The coordinate method is, however, of particular help where there is a high degree of correlation between the layout of streets and grid, and where, as is frequently the case, a single route is to be studied in detail.

In conclusion, it is desirable to call attention to a step which will always be necessary, though the taking of it here is outside the scope of this report. The step relates to what was just referred to as a final profile. Through an objective and highly mechanical process, a disorganized collection of trips has been classified and arranged in particular order. At the root of the method is the assumption that we are dealing with a plane surface. With the facts of the real world in mind this convenient fiction must now be discarded. The results must be scrutinized in the light of topography, or of local deviation of the existing street pattern from the established grid in order to check or to modify the traffic pattern No formula, no mechanical process, can obviate this step. However, the limitation is in reality no handicap because the number of trips that have to be scrutinized is small and much is known about them.

Highway location and design is an art in which shrewd observation, experience and study count heavily Furthermore, the process is a slow one which requires not merely the making of one estimate but the making of a series of estimates. Progress between establishment of a reconnaissance area and final plans is affected by various forces Topography may tend to put a line in one location while right-of-way costs or other economic or governmental concerns put it in another Now, although any purely mechanical process can merely be an aid in these circumstances it can be a useful one. As the designer reacts and modifies his plans, he must know also how the traffic pattern will be affected. Whether his need be for a rough approximation, sufficient to set up a reconnaissance, or for a fine one requiring turning movements at interchanges, the coordinate method, with its simplicity and close control of the data, shows promise.

DISCUSSION

JOHN T. LYNCH, *Bureau of Public Roads, U. S Department of Commerce*—The development of a trip-desire chart, which gives a clear picture of the desired routes of travel, is an important first step in the analysis of the data obtained in a comprehensive transportation study such as has been made in more than 70 metropolitan areas. Such a chart shows how traffic would move if it were permitted to go in a straight line from origin to destination and therefore indicates the general location of routes which would best serve traffic needs. Of course the actual route locations selected must depend upon topography, existing improvements, and the cost of right-of-way, but the trip-desire chart is an important aid in determining the general pattern and, particularly, in explaining the traffic needs to officials and laymen who do not have the time nor the technical knowledge to determine the over-all significance of the data contained in voluminous tables.

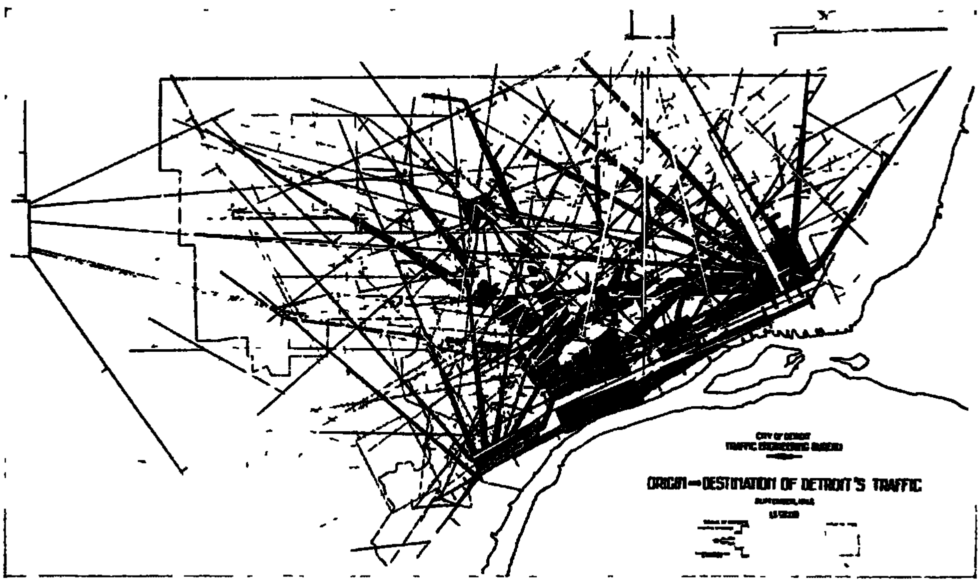


Figure A

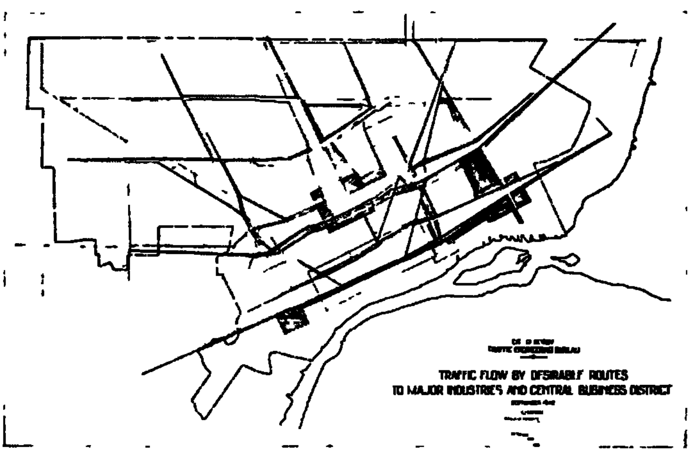


Figure B

The first trip-desire charts of which I have knowledge were constructed by Detroit in 1942 and were based on data obtained in connection with studies of wartime transportation needs through questionnaires filled out by workers in 10 important industrial areas, and in the central business district Desire-line charts were prepared for the 11 areas which constituted the most important traffic foci, showing trips to and from work. These charts, superimposed upon each other to give a general picture of the work-traffic needs of the area, are combined in Figure A.

The next step was to combine these innumerable traffic desire-bands into wider bands which were still fairly close to the desired routes of travel Figure B showing "traffic flow by desirable routes" is the result of this coordination. Using this chart as a basis and also taking into consideration terrain, existing improvements, and right-of-way costs, a network of expressways which approached the ideal with regard to service to work travel was developed. This network is shown in Figure C

Though only a portion of the trips in the area are included (work travel to and from 11 important traffic foci) the chart in Figure A is quite complex and is understood with difficulty, particularly by those lacking in technical knowledge of traffic studies Upon being shown this chart, the Mayor is said to have remarked "Anyway, that rules out the amateurs"

If all of the Kansas City trips had been presented in a single desire-line chart, the result would have been an unintelligible maze. On the other hand, the necessity of referring to a number of different charts makes the interpretation difficult Another objection which applies to the Detroit and Kansas City charts, as well as to all those for other cities which are similarly constructed, is that the method of consolidating the lines into a major directional desire-line chart (similar to Figure B) is somewhat arbitrary and subject to personal judgment or bias.

The California trip-desire chart, described in Mr. MacLachlan's paper, is not subject to the two objections cited All of the trip data are presented on a single chart of comparative simplicity and the method of construction is purely objective and not in any degree dependent upon judgment. Though the chart may be somewhat confusing when presented in black and white, the coloring of the areas between the trip "contour" lines makes it readily understood.

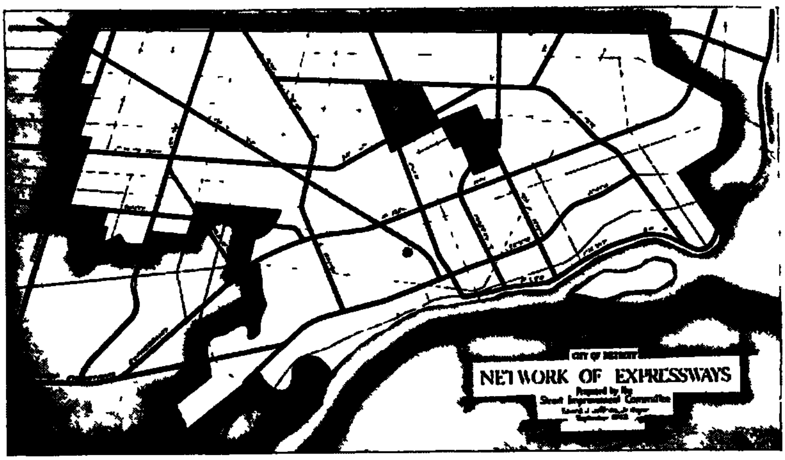


Figure C

Faced with a much more difficult problem, because the data included all of the trips within the area, Kansas City developed a method of presentation which is explained in detail by Mr John M Picton, Chief Planning Engineer, City Plan Commission, Kansas City, Missouri, in the 1945 *Proceedings* of the Highway Research Board (pp. 279–297). The procedure was to use different charts for interzone movements of different intensity. Thus, one chart shows only the trips which amount to more than 300 between any pair of zones Another shows those which aggregate from 150 to 299 between any pair of zones, and so on, so that a number of charts would have to be consulted to visualize the entire traffic flow. Ten desire-line charts of this character are presented in Mr Picton's paper

The first reaction, upon consideration of the method of construction of the chart, is to question the validity of the presentation because of the fact that trip direction is not considered in drawing the contour lines, yet the result is intended to show the desired directional traffic flow However, it is obvious that a concentration of trips with a common direction is bound to build up a "ridge" whereas scattered trips tend only to raise the general "contour" level "Peaks" on the chart represent business and industrial centers on which traffic converges. The more I have studied the chart, the more I have felt that important trip movements could not be missed or misinterpreted through its use, though experience is not yet at hand to demonstrate conclusively that it gives a complete and accurate picture of the desired directional traffic flow

The mechanical procedure for producing the chart is, I believe, somewhat complex and perhaps beyond the present abilities of those organizations that do not have available rather extensive tabulating equipment and skilled tabulating personnel However, if it does, indeed, present a simple and accurate picture of the extremely complex trip movements in a large metropolitan area, as regards desired directional flow, the chart is worth the effort required to prepare it and constitutes an important contribution to the analysis and presentation of urban origin and destination data. In any event, California is to be congratulated for their extensive and productive research in the field of trip analysis procedures.

A RURAL HIGHWAY CONGESTION INDEX AND ITS APPLICATION

K B Rykken, *Manager, Highway Planning Survey, Minnesota Department of Highways*

SYNOPSIS

The manual on highway capacity, recently completed by the Highway Research Board Committee on Highway Capacity, provides highway planners with an invaluable tool in the design of highway improvements. Its release will undoubtedly bring into even sharper focus the basic relationship between traffic volume and highway capacity.

This paper presents a simple method of rating a rural trunk highway system on the basis of its traffic carrying capacity. The congestion index is defined as a mathematical rating of highway capacity derived from the ratio of existing design hour traffic volumes to the practical hourly capacity of a rural highway system.

The development of the congestion index requires the following items of basic data

1. Fairly exact information concerning the relationship of the 30th highest hour in the year to the annual daily average traffic for a highway system.
2. Complete data on continuous restricted sights.
3 Detailed information as to the geometric design features of the complete rural highway system.

The practical application of a congestion index is not yet clearly defined. It is apparent that such an index provides a means of relating rural highway congestion to accident rate It also appears that the index can be valuable as an additional guide in the programming of projects for improvement. Its application in this respect may well be twofold; first, to assist in program development and, second, to assist in establishing priority of improvement within a program The application of the congestion index to design problems is at this stage more apparent. A low congestion rating indicates satisfactory geometric design. If improvements are required on routes of this character, they are dictated by other factors The low congestion index should be valuable in preventing overdesign Those sections of a rural highway system showing a high congestion index must, in their redesign, provide additional traffic carrying capacity. The extent to which a new design must provide such capacity can be accurately measured through the application of the principles involved in the calculation of a congestion index

This paper is a progress report It is evident that a great deal of additional work will be required, both to refine the methods of computation and to clarify the application of such an index.