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Directional Analysis of Vehicle Travel Desire

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● AN urban area is characterized by a complex pattern of daily movements of persons and goods between a wide variety of land activities. A primary purpose of the metropolitan origin destination survey is to find out what this pattern of interchange is, based on a sample of all trips made on an average weekday in the particular metropolitan study area. Thus the ability of the existing transportation system to serve these movements can be measured; strengths and weaknesses can be determined; requirements for new facilities in terms of location, type, and capacity can be estimated.

To accomplish these ends the data must be organized so that the movement patterns are evident and so that comparisons between supply and demand can be made and quantified. Clearly, one dimension of such analysis and interpretation is spatial.

This paper is concerned with the techniques of organizing and displaying origin-destination data on maps so that the movement patterns can be analyzed, interpreted, and brought to bear on the job of improving the transportation system Because the fundamental pattern underlying the travel within the urban structure is composed of the links between origins and destinations, straight line connections between origins and destinations have been referred to as "desire lines." Thus the pattern of desire is separated from the actual over-the-road travel pattern which results from a large number of existing situations.

Zone to Zone Desire Charts

For purposes of organizing the data, O. D. study areas are subdivided into areas usually called zones. Different surveys have established zones according to different criteria. Whatever the criteria, however, the subdivision has usually produced small zones near the center where trip volumes are high and where detail is necessary, and zones of large size at the periphery where volumes are low, sample reliability therefore less, and detail less important. Intermediate zones are of increasing size from center to cordon.

For spatial analysis the components of daily urban travel are, for all practical purposes, trip length and trip direction. First attempts to analyze the spatial pattern were therefore based on a simple graphic connection of zones, between which travel occurred, by desire lines, usually drawn from zone center to zone center. By establishing a simple scale on which line width (or height) was related to trip volume, a pattern of zonal interchanges weighted according to trip volume was the result. This result appeared as a great number of straight lines of varying length, direction, and width, the pattern increasing in complexity as the central business district was approached. When total daily travel was so displayed on a zone to zone base, such charts were generally illegible.

In order to increase legibility, zones have frequently been accumulated into groups, thus reducing the number of lines, but also reducing the precision of the presentation. At the sacrifice of the total pattern, map series have been made, each map portraying a part of the pattern.

Except for portrayal of a limited number of the most important desire lines, or for portrayal of through movements only, these zone to zone desire line charts are a crude tool of limited value to the analyst seeking to understand the total pattern.

Coordinate Isoline Desire Charts

A different approach to the display of trip data on maps was developed by the Division of Highways, Department of Public Works, State of California. The method has been described in a previous publication of the Highway Research Board (1). They laid out a rectangular system of coordinates on the area of study thus providing a uniform reference system for location. Where zones were desired, as for example to describe the central business district for certain analyses, the coordinates falling within the area

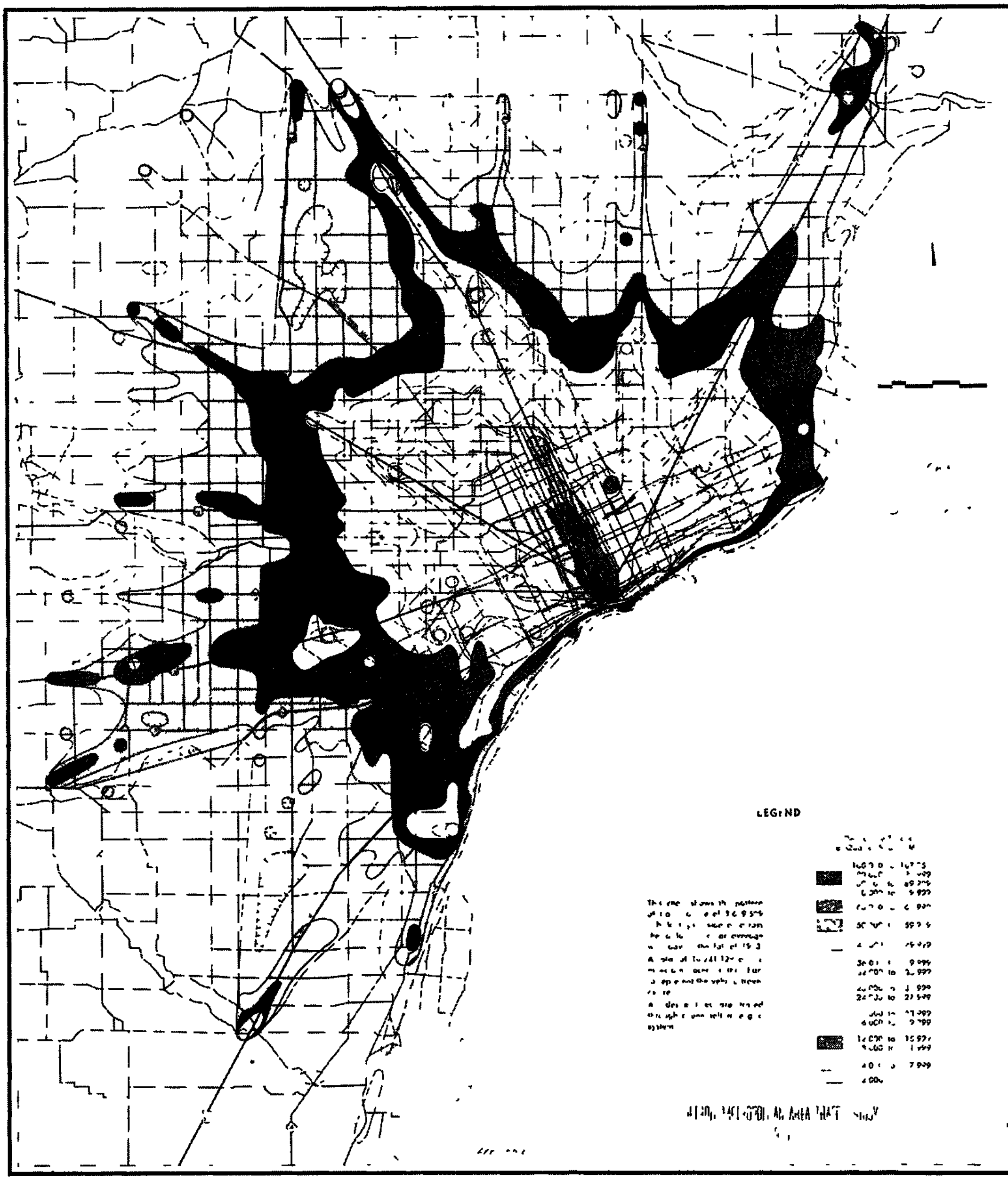

Figure 1. Trip desire chart - all vehicles.

could be grouped. But for purposes of setting forth the desire pattern of travel the trip data were processed directly on the grid system. Although different in some ways from the California procedure, the principles adopted by the Detroit Study were the same.

Stated simply, and for this purpose without reference to the machine procedures which are described in the appendix to this paper, the system consists of the following. A one-tenth mile rectangular grid, running north-south and east-west, was laid out. Each trip origin and destination was coded to a specific block as defined by the U. S. Bureau of the Census. Each block was then assigned to its appropriate tenth mile co-ordinate value in the grid system. All trip origins and destinations were thus given X and Y coordinate codes. In tracing the trips across the grid all origins and destinations were summarized to half mile coordinates to reduce the work involved. Destinations were of course similarly coded. Each group of trips with like coordinates of origin and of destination were then traced across the grid in a straight line. They were registered at each set of coordinates through which they passed between origin and destination. After all the trips had been so traced, the accumulated trace values (trip volumes) at each X, Y coordinate were transferred to a map on which the grid system had been laid down. In accordance with a predetermined scale, areas of like volume were isolined.

The result of such a process is a map of the relative densities of the desire movements, sometimes referred to as a contour map of trip desire.

Several advances over the earlier described zone to zone desire line chart are evident in the coordinate isoline chart. Figure 1 is a reproduction of the All Vehicle Trips chart prepared in the Detroit Metropolitan Area Traffic Study, showing the tracing of all vehicle trips on a one half mile grid (2). Similar charts have been made for several other areas by different state highway departments. Figure 1 clearly shows the main pattern of trip desire. Note how sharply the radial pattern stands out and how the very heavy demand lies between the northwesterly radials. Points of high origin or destination concentration are also very clear. Note the well-defined subpatterns around outlying town centers and shopping centers. Because the reports of the Detroit Study interpret the chart in considerable detail, it is unnecessary to do more than state these main points.

The problem of displaying graphically a summary picture of the total pattern of daily travel on a straight line desire basis is well met by the summary isoline chart. The complex pattern of daily movement is reduced to terms that the analyst can grasp. It is reduced to terms that permit comparisons with the land use pattern, the pattern of population distribution, of employment distribution.

It was stated at the outset that origin destination data should be organized so that the patterns are evident, but additionally so that comparisons between supply and demand can be made, and so that requirements for new facilities in terms of location, type, and capacity can be estimated. The summary chart meets the first of these criteria reasonably well. It does not meet the remainder except in the grossest terms. The major radial flows are apparent from Figure 1 and in some cases their volume and direction can be read directly from the chart. But crosstown flows are not generally apparent, (although with practice some of them can be picked out) and where they are apparent, for example between the northeast radial and the northwest radial, they are so mixed up in the radial flow itself that neither direction nor volume is clear.

Directional Isoline Charts

Breaking out the directional components of the pattern is of course a logical next step because direction is built into the process of tracing trips across the rectangular grid.[1] Simply stated, all trips traced across the grid were oriented either generally north-south or generally east-west. Each of these primary directions was further divided in two so that groups of trips were identified in directions within an arc of 45 deg. Thus four

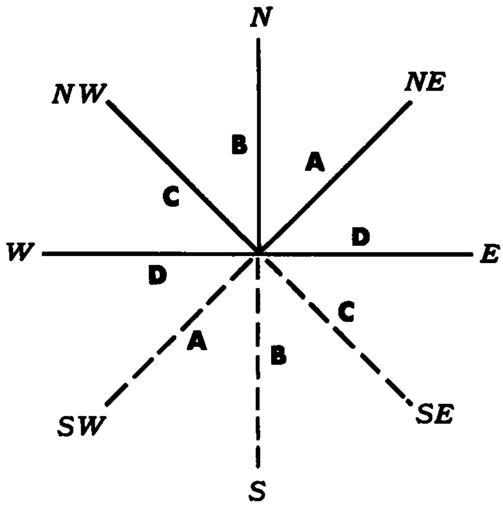

Figure 2. Directional codes. Trips whose course lies along a cardinal direction are coded in the directional area counterclockwise to that line. Example: trips running due north and south are coded in Direction B.

[1] Credit should be acknowledged to M. Earl Campbell of the Highway Research Board who suggested analyzing what he called "traffic sheds" and of determining what he called the "centroid of desire."

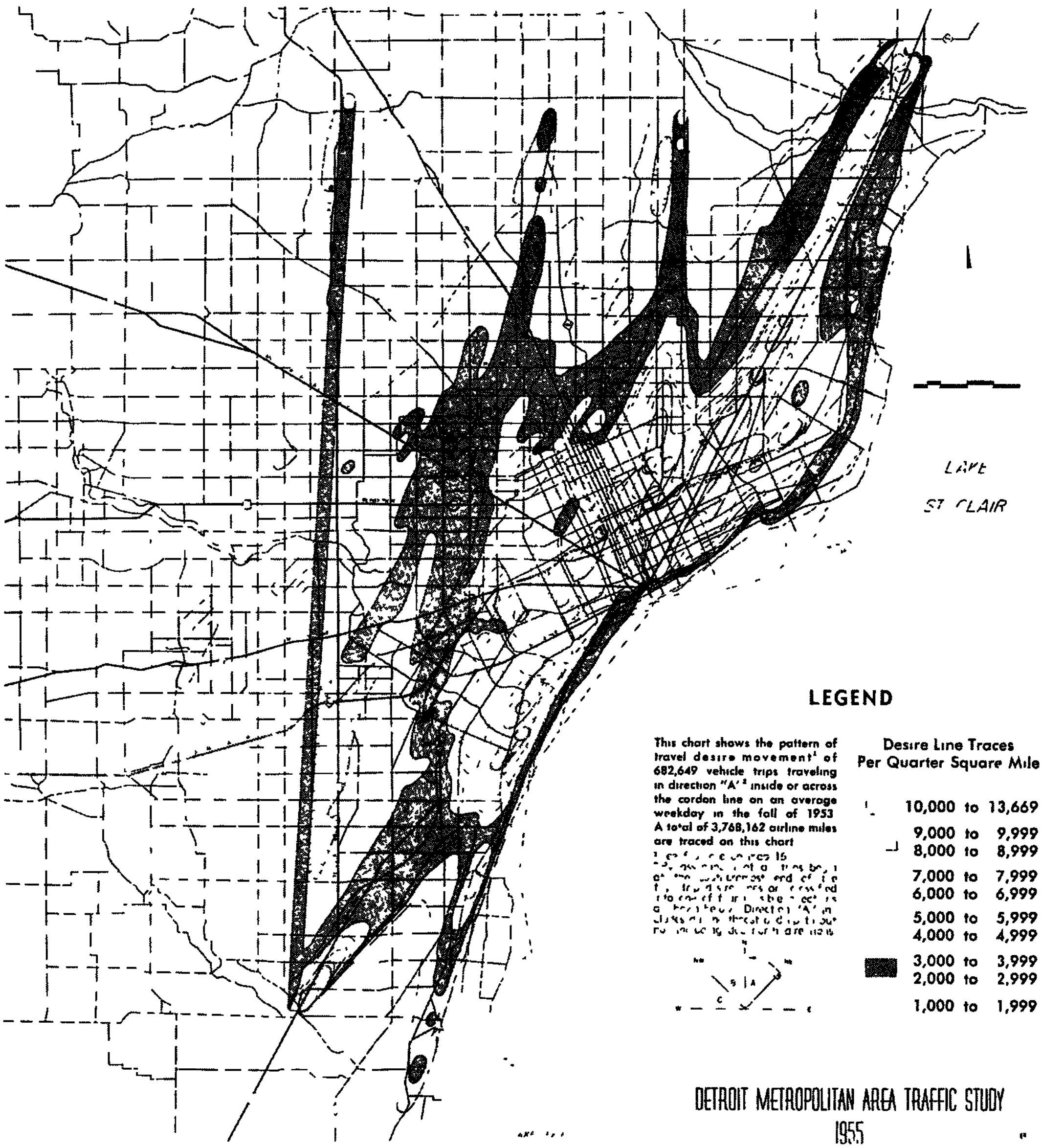

Figure 3. Trip desire chart - vehicle movement - Direction A.

main directions of travel desire were separated out. It should be obvious that concern here is with the directional alinement of a trip, not with compass direction. Thus a trip going northwest is alined in the same way as a trip going southeast and they are considered as one direction. Figure 2 shows the directional groupings used. The machine procedures are described in the appendix.

It has been said that a trip in space has two components, length and direction. Trip length is important because it affects the type of highway facility used. In order to build this component into the chart, the traces registered by the trip at its origin and its destination were omitted. Thus very short trips are eliminated from consideration and the terminal sections of trips are omitted. Most of the trip remaining on the chart would then be made on the arterial street system.

Figure 3 is one of the directional charts prepared in the Detroit Study (3). The clarity in this particular chart is excellent. Note how the major desire line groupings vary in direction within the arc. The heaviest travel lies directly along the axis of the major northeast radial. To the west of this line is an almost due north-south ridge extending out to the cordon. To the far west the north-south through traffic is sharply defined.

Along the northeast radial (Gratiot Avenue) maximum desire volumes on this chart are between 10,000 and 14,000 per quarter square mile between the central business district and Seven Mile Road. The decrease in volume just north of this point and the increase again at Eight Mile Road is probably due to the attraction of the shopping center at Gratiot and Seven Mile. Remember that the traces at the origin and destination are omitted. Thus on directional charts points of high attraction appear as breaks in lines of high density approaching from either side.

It should not be construed from the preceding paragraph that the demand for service along Gratiot Avenue can be directly translated as 10,000 to 14,000 vehicles per day. If the chart is likened to a topographic map then the ridge along Gratiot Avenue represents a mass roughly centered along the axis of the highway. All the vehicle desire traced in this ridge is the volume of this mass It is possible to construct a scale which permits reading the volumes within given distances from an estimated center line. The point is that in reading the chart both "height" and "width" of the deisre lines must be considered. With these considerations in mind the desire volumes can be estimated.

The sharply defined desire line running north-south on the western periphery of the study area is a simple case. Desire can be read directly as 2,000 to 3,000 vehicles per day throughout most of its length. A complicated case is the north-south desire line just westerly of Gratiot Avenue, the Mound Road — Van Dyke axis to those who know Detroit. There is a merging of different desire lines with peak destination areas within this mass centering around industrial development in this area. Probably in this case there is an overlapping of central business district oriented travel and industrial area oriented travel.

In reading the chart it should be remembered that lines of desire are composed of trips of different lengths. Thus the heavy desire pattern along Gratiot Avenue does not mean that all the trips represented are destined for the central business district. In this case both CBD destined trips and trips with origins and destinations along this commercialized artery are included. A base of long trips underlies them as can be seen by the ridge of lower density running all the way to the cordon line.

The contrasting broken pattern between the central business district and the south is due partly to the fact that the trip patterns are more localized. It is also due to the fact that the bend in the river traces the long trips from the cordon along a different line, thus preventing them from being combined on the chart with the shorter trips near the center. Finally, in the particular direction represented by this chart, there is no major heavily commercialized straight line artery to the south of the central business district.

Interpretation of this chart has been undertaken in some detail in order to show how the directional chart clarifies the movement pattern in a way that the summary chart can not. After the directional charts have been analyzed in this way the summary chart becomes much more meaningful. In the first volume of the report on the Detroit Study all of the directions have been similarly analyzed (4).

In applying the directional charts to a working situation it should be obvious that charts of the adjacent directions should also be referred to. Thus the chart for direction "B," not reproduced in this paper, includes some north-south movement whose demand must be added to that evident in direction "A" in order to arrive at a thumb rule estimate of demand. Such joint considerations apply of course only to those movements which are alined close to the periphery of the arc of direction being analyzed.

After having worked with these charts the staff of the Detroit Metropolitan Area Traffic Study was convinced of their value in understanding the vehicle desire pattern. They were brought directly to bear in first sketching the proposed expressway system, although the idea of constructing "centroids of desire" as suggested by M. Earl Campbell was not pursued.

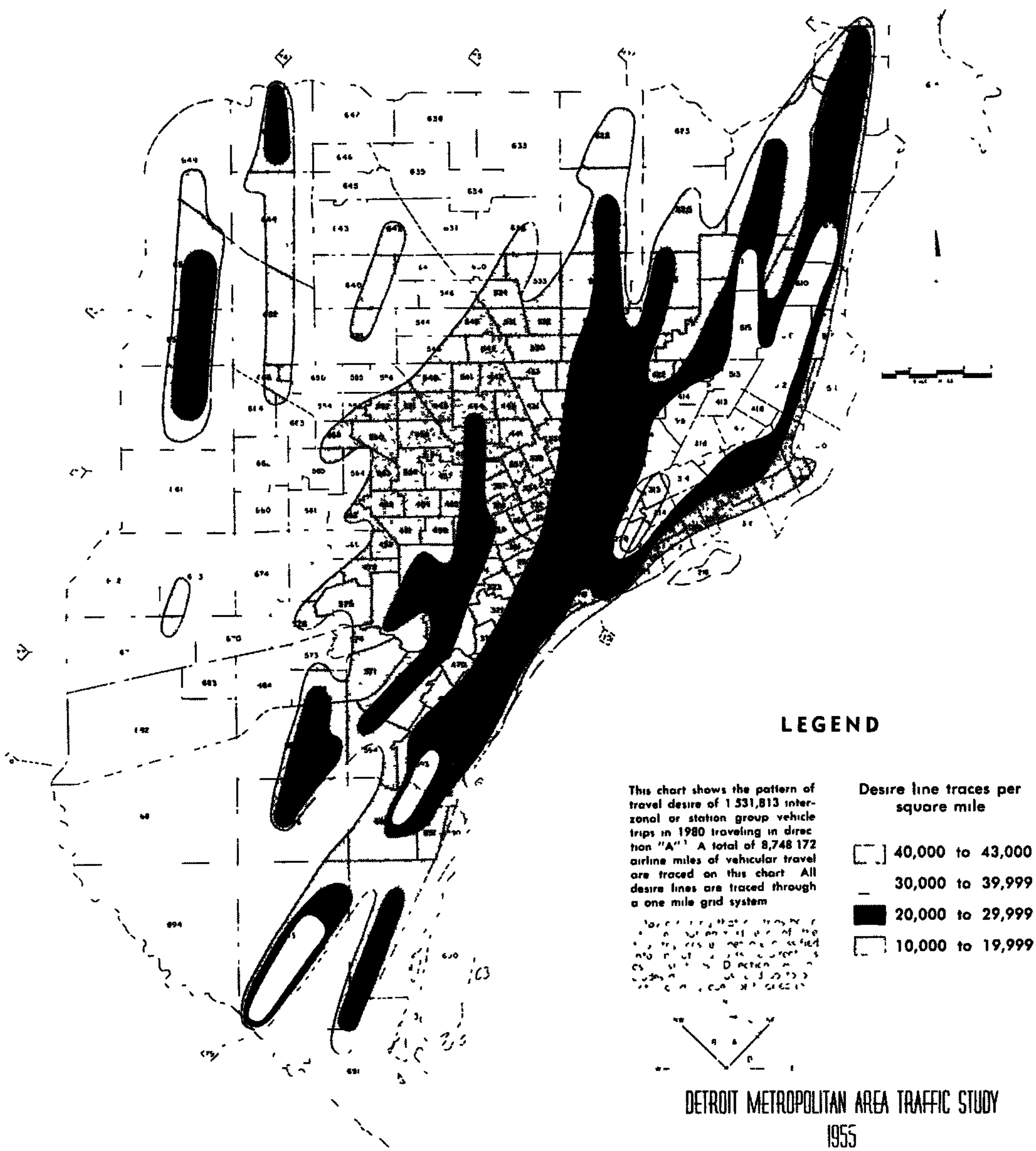

Figure 4. Trip desire chart - 1980 vehicular desire line densities - Direction A.

Projected Traffic by Direction

Although planning improvements to a transportation system starts with the "here and now," it is axiomatic that it must be based upon estimates of future needs. Another set of desire charts was constructed on which were traced the projected 1980 movements. The method of making these projections is a subject beyond the scope of this paper (5), but the translation of these projections into visual form is pertinent.

The traffic projections were based upon population and land use projections by zone.[2]

[2] For certain kinds of analysis the study area was subdivided into districts, zones, and subzones in much the same way as has been done in most origin-destination surveys. Estimates of future land use and population were obtained for the zones from the City Plan Commission, City of Detroit and from the Detroit Metropolitan Area Regional Planning Commission.

Zonal interchanges were projected. These interchanges were then traced across a mile square grid. The use of the larger grid reflects a necessary compromise in scale between the small central zones and the large peripheral zones. The mile grid also provides a basis for comparison with arterial capacity to determine areas of deficiency as will be shown later.

Interzonal movements were traced from zone center to zone center, the coordinates of origin and destination being the mile square within which the zone center was located. It will be recalled that the traces in the terminal grid squares were omitted from the directional charts of 1953 travel. On a mile square grid such omission would affect the pattern considerably. On the first runs the termini were not excluded; this produced an artificial concentration in the zone centers of the larger zones. If the trip termini

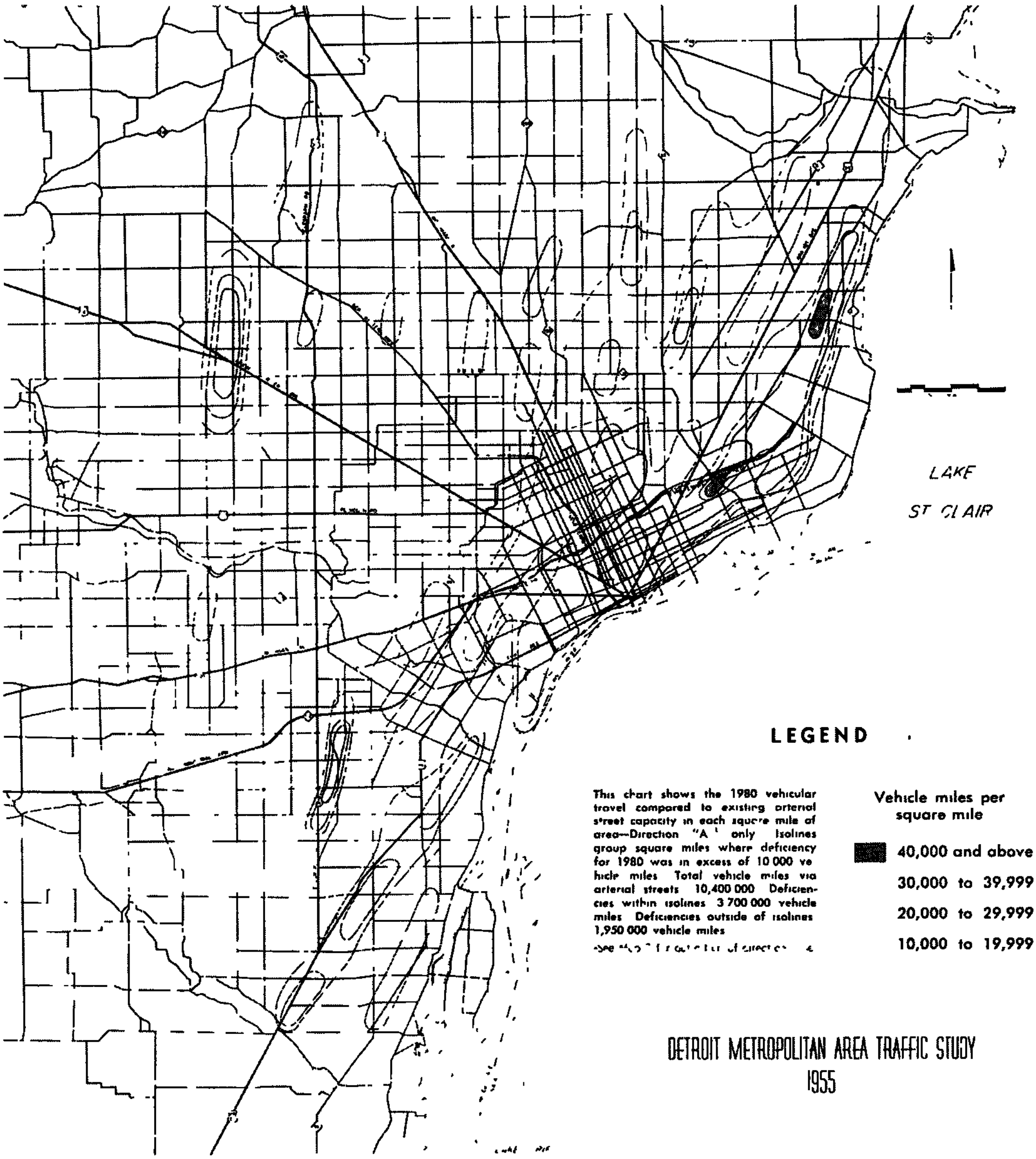

Figure 5. Deficiency in surface arterial street capacity by 1980 - Direction A.

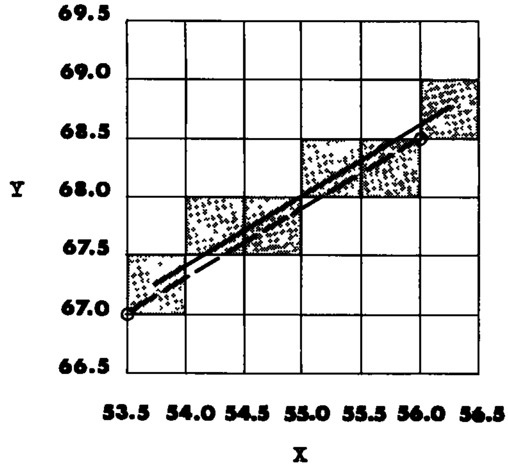

Figure 6. Trace of hypothetical trip across grid.

traces were excluded on the other hand, a large percentage of the trips would simply not appear on the chart because a trip would have to register in at least three mile squares to be represented: square of origin, square of destination and intermediate square. Thus not only would the portion of a trip generally made on local streets be omitted, but also some demand for arterial street capacity would not appear. It was therefore decided to omit one half the origins and destinations to prevent overweighting the terminal portions of the trip without undervaluing the trip demand requiring arterial service.

These limitations should be borne in mind in analyzing the projected 1980 patterns. Figure 4 shows the projected zonal interchange traced through the mile square

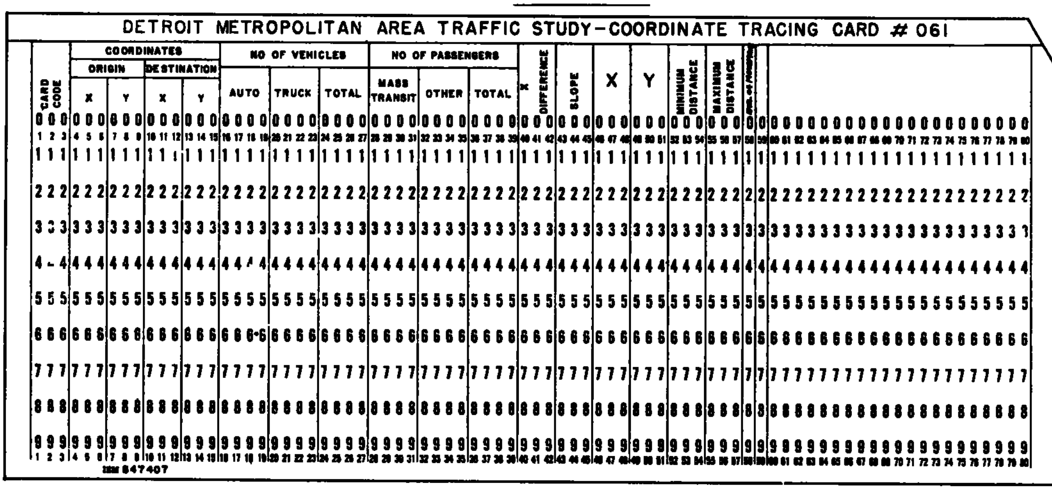

Figure 7. Card 061 - coordinate tracing card.

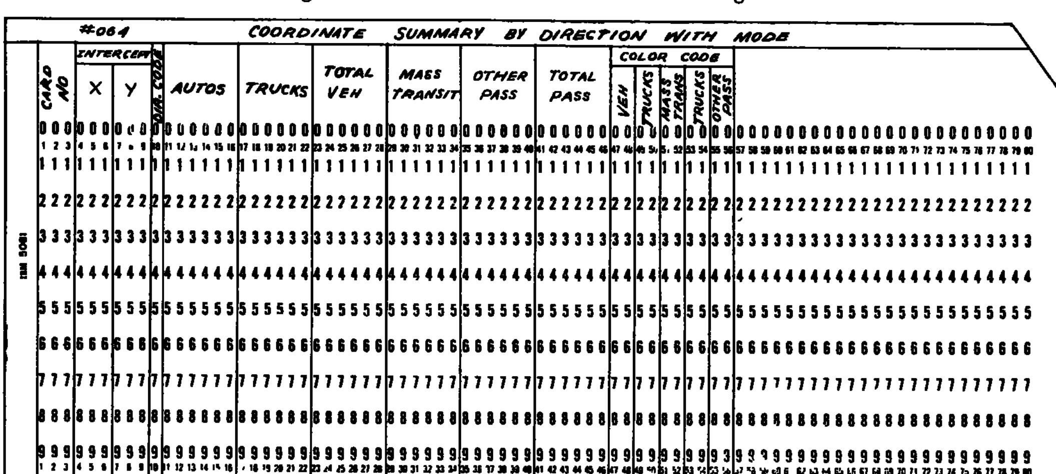

Figure 8. Card 064 - coordinate summary card.

grid. The pattern is of course more generalized than in the 1953 desire chart. But in estimating 1980 pattern and volume such generalization must be expected. The over-all pattern for this direction is quite similar to the earlier detail pattern but the volumes are higher as one would expect. The "flatter" pattern is partly due to the increase in grid size which smooths out the high points. It is also because the traffic increase was estimated from projected new land development; therefore the greatest increases would be expected to occur in areas still open for development. Hence traffic in outer areas would tend to approach the traffic density of the older areas although of course a gradient will always exist.

The increase to the north from the central city where high volumes are predicted well out to the periphery of the area is important. Where the two main lines divide into minor separate fingers, the volumes should be read together because the location of zone centers has artificially separated the main stream. Through movement is not apparent on the western edge of the chart because, compared to the accumulation of desire lines based on zonal interchanges, the through movement is too small to appear.

In addition to providing the planner with a visual picture of the estimated major directional flows, these 1980 charts serve another useful purpose. They represent the effects of readjustments in the travel pattern due to estimates of new trip generation and changed interzonal movements that have been predicted by a variety of statistical and mathematical means. Thus they are a kind of visual check of reasonableness.

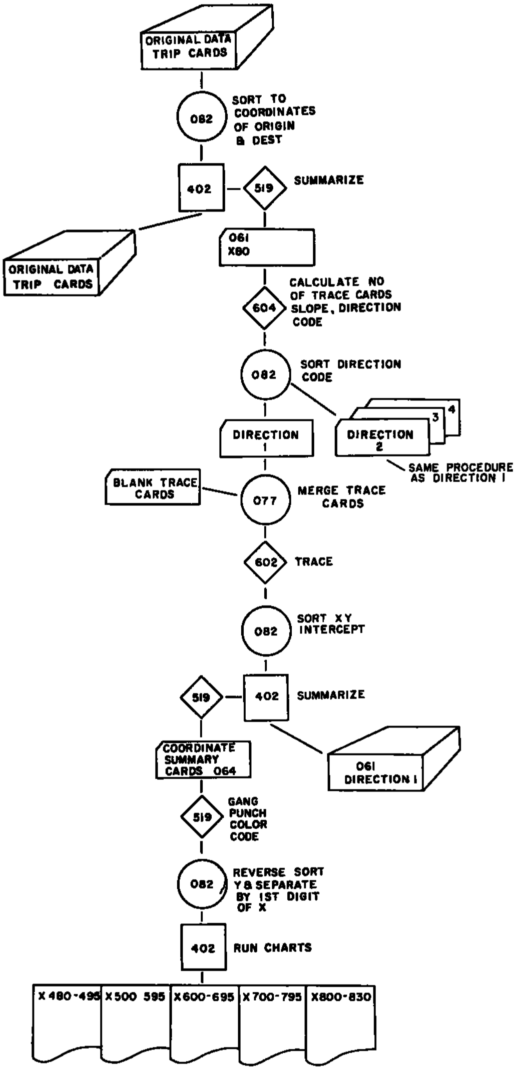

Figure 9. Flow diagram for trip desire charts.

Estimated Deficiencies by Direction

Another criterion of origin-destination data preparation is that they should be organized so that they can be used in measuring the ability of the existing transportation system to meet the observed and projected needs. This requires the preparation of the travel data on the one hand and street capacity data on the other in such a way that they can be compared. Just as trips can be registered by direction in the grid squares of the coordinate system, street capacity of the arterial street system can also be registered. Each primary street can be classified in terms of the major direction it serves; if it serves two directions then its capacity is divided between these two. Because the street has length within the square, and because these lengths vary depending on the location and alinement within the square, each street capacity is expressed in vehicle miles. Thus each grid square has an estimated street capacity in vehicle miles in each of the four directions used for trip analysis. By translating the trip registrations in each square into vehicle miles of desire in each of the four directions, a direct com-

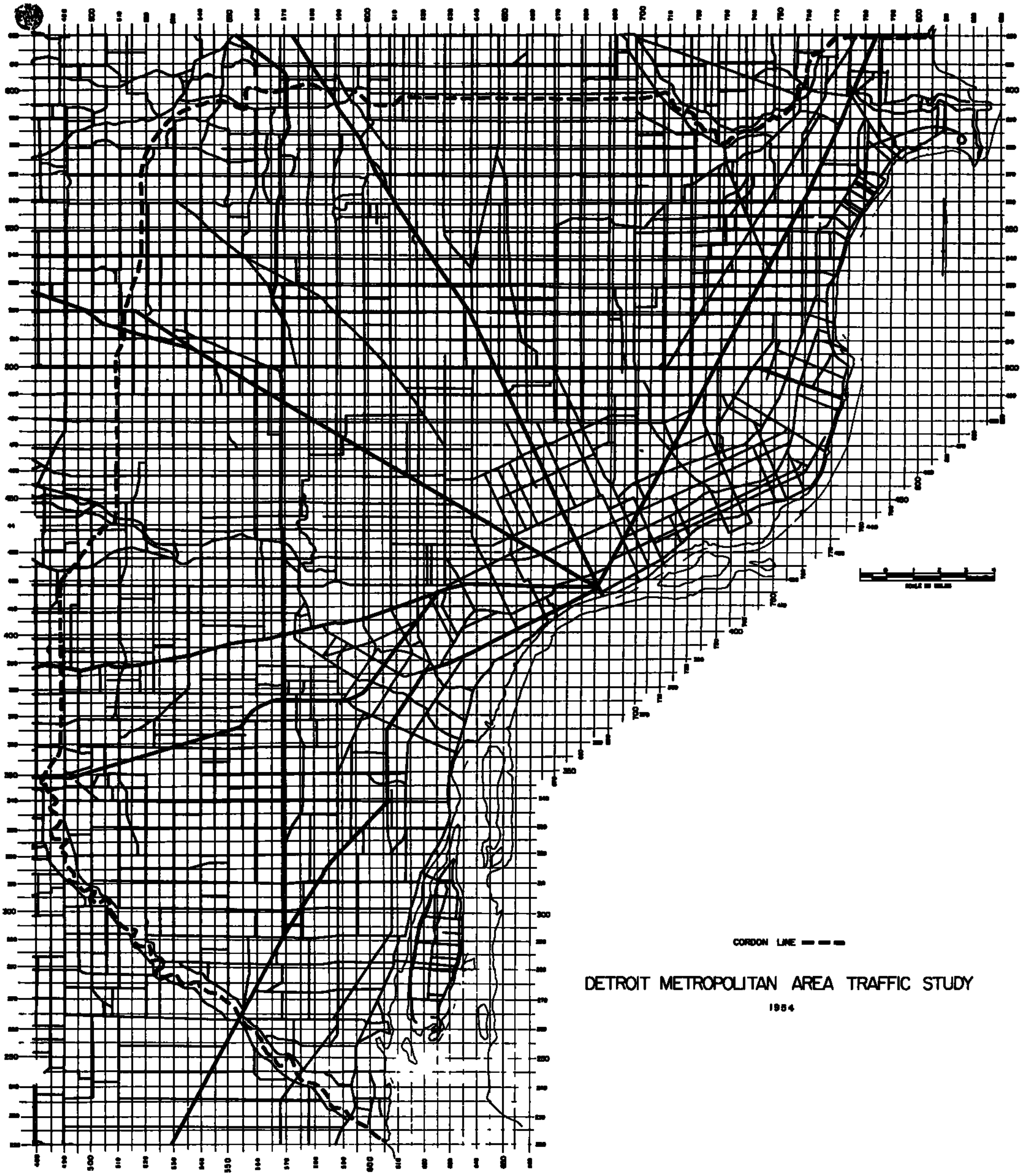

Figure 10. Grid coordinate system.

parison is available. For this purpose the data were expressed by square mile rather than by quarter square mile, both to reduce the manual operation of coding street capacity and in recognition of the fact that the comparison between primary street capacity and straight line desire travel cannot be reduced to such small units of area as a quarter square mile, particularly in those parts of the study area where the primary street system consisted largely of the mile roads.

The method used for measuring street capacity by direction is discussed at greater length in the Detroit Study report (6), and in a paper by Howard Bevis of the staff (7). Again, although discussion of the method is beyond the scope of this paper, the translation of the comparisons into visual form is pertinent.

Figure 5 is a graphic presentation of the comparison of estimated 1980 vehicle travel desire with the capacity of the 1953 arterial street system for Direction A. It is unnecessary to interpret this chart at length. Clearly there are deficiency areas of a magnitude to suggest expressway solutions. Most of the deficiency appears in the areas where Figures 3 and 4 have shown heavy present and future demands to exist.

One particular point, however, should be noted. It was pointed out in the discussion of the summary isoline chart (Figure 1) that the heavy radial pattern of the summary chart obscured crosstown desire. But this directional deficiency chart shows clearly two areas of crosstown deficiency lying athwart the city's main artery, Woodward Avenue running northwest. Each of these deficiency areas is in the vicinity of 30,000 to 40,000 vehicle miles per square mile.

Conclusion

The use of directional charts in the Detroit Study unquestionably advanced staff understanding of the travel patterns of the area, and indeed, of the very structure of the area. The techniques can undoubtedly be improved, but there is no doubt on the part of the staff of the validity of tackling the directional component of travel through the coordinate system of data analysis.

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4. Ibid,. pp 67-76.
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7. A Method for Determining the Adequacy of the Arterial Street System for the Detroit Area, Howard W. Bevis, 15 pp, mimeo.

Appendix[3]

To understand the process of construction of the isoline chart, let a particular case be assumed.

Assume a case in which the origin is X53.5 and Y67.0 and the destination is X56.0 and Y68.5. Since all blocks were coded to the closest tenth of a mile value, X53.5 includes all points from X53.5 to X 53.9 inclusive and Y67.0 all points from Y67.0 to Y67.4 inclusive. Accordingly the notation X53.5 and Y67.0 refers to all territory within the quarter square mile of which the note point is actually the lower left hand corner as shown in Figure 6.

Remembering the distinction between points and areas, the trip is traced as follows:

(a) The X and Y differences are computed to determine which is greater. The greater difference determines the axis which serves as the longer side of the right triangle, that is, the axis along which the trip crosses the greater number of grid lines. In this case the X axis is greater.

Origin:	X53.5, Y67.0
Destination:	X56.0, Y68.5
X Difference =	56.0 - 53.5 = 2.5
Y Difference =	68.5 - 67.0 = 1.5

(b) Determine the points on the Y axis through which the hypotenuse would pass for

[3] This section was originally prepared by Robert E. Vanderford, Machine Supervisor of the Detroit Study. Part of this was published in the appendix to Part I of the Detroit Study Report, op. cit. p. 105.

each half mile increment on the X axis. For each point this is obtained by multiplying the tangent of the angle between the hypotenuse and the X axis by the X distance from origin to the particular grid line, and then adding the result to the Y origin value. In this case, the tangent is 1. 5/2. 5 or 0. 6. The X distance from origin to next grid line is 0. 5. Multiplying 0. 5 by 0. 6 = 0. 3 which, added to the Y origin value of 67. 0 yields 67. 3. The first pair of coordinates through which the trip would pass after leaving the origin then would be X54. 0, Y67. 3. Since the coordinate values used in the trace are half miles, this would be rounded to X54. 0, Y67. 5. In Figure 6 it can be seen that the dotted line passes through X54. 0, Y67. 3 but that the shaded square is X54. 0, Y67. 5. The complete set of points for the example are shown below. The graphic results are shown in Figure 6.

	X	Y
Origin	53. 5	67. 0 rounded to 67. 0
Next point	54. 0	67. 3 rounded to 67. 5
Next point	54. 5	67. 6 rounded to 67. 5
Next point	55. 0	67. 9 rounded to 68. 0
Next point	55. 5	68. 2 rounded to 68. 0
Destination	56. 0	68. 5 rounded to 68. 5

Thus, the hypotenuse of this triangle or straight line distance from origin to destination is traced according to the table above. If it is remembered that each origin and destination falls within a square, then the trip is traced through the shaded squares from the origin to destination. The dotted line shows the trip hypotenuse or desire line drawn from coordinate point of origin to coordinate point of destination. The solid line shows the desire line which would go from the center of the quarter square mile of origin to that of destination. The shaded squares then show the actual representation of this trip as it would be plotted on study maps.

A trace card is made for each trip (or group of trips) for each square through which it is traced. Travel desire lines thus traced can be summarized at each square and the entire density of straight lines readily displayed on maps to make up the representation of traffic desire volumes.

In the process, control on direction, mode of travel, trip distances and other factors is made so that many different kinds of summary maps are possible.

Machine Procedures

To accumulate the volume of traffic passing through any quarter square mile, it is necessary, on limited storage equipment, in tracing each trip, to punch a card for each square through which the trip passes. The IBM 604 was the calculator used on the Detroit Study. The first pass through the machine was used to calculate the number of trace cards to follow, direction code and the slope of the straight line trip. Slope is the tangent as explained above. Direction codes are prepared based on the following conditions which involve determining the X difference, the Y difference and the comparison of these two items.

TABLE 1

BASIS FOR DETERMINING TRIP DIRECTION

Direction Code	Conditions Which Decide Directional Code
A	$Y_o < Y_d$ and X difference < or = Y difference
B	$X_o = X_d$, or $Y_o > Y_d$ and X difference < Y difference
C	$Y_o > Y_d$ and X difference > or = Y difference
D	$Y_o <$ or $= Y_d$ and X difference > Y difference

It was found best to use the collator to compare X_o to X_d. Equals were immediately punched as Direction B. All cards with high origin had the O and D reversed so that the X value of the origin would always be less than the X value of the destination. This cut in half the number of possible cases without affecting the result because whether a trip was headed northwest or southeast was immaterial. Direction codes were determined by the 604 which could compare Y_o to Y_d and also compute and compare the X difference to the Y difference (i. e. Y_o-Y_d to X_d-X_o).

For Directions A and B the Y difference gives the number of cards to follow when multiplied by two. For Directions C and D, the X difference times two was used. In the example the trip falls in Direction B. The X difference is 2. 5. Multiplied by two because the trip is traced on a one half mile grid, the number of cards to follow is five.

The slope is obtained by using the larger difference as the divisor and the smaller difference as the dividend as shown in the earlier example.

The No. 061 card, (Figure 7) at this point contained all the information needed for the trace. These cards were sorted on direction, and each direction put through an 077 collator with a counting device. The collator merged the proper number of blank trace cards behind each No. 061 card.

To illustrate the trace method used, reference is again made to the example shown graphically in Figure 6.

The difference between the origin and destination is 2. 5 on the X axis, and 1. 5 on the Y axis. Dividing the smaller difference by the larger makes the tangent or slope 0. 6. To trace by hand methods, add one-half the slope to the origin on the smaller axis, in this case Y 67. 0 plus 0. 3 equals 67. 3. Add one-half mile to the larger axis; X 53. 5 plus 0. 5 equals 54. 0. This is the first point on the straight line trip. To adjust to the nearest intercept is simple because the point is obviously closer to Y 67. 5 than to Y 67. 0, so the intercept would be X 54. 0, Y 67. 5. For the second point, add one-half the slope to Y 67. 3 for Y 67. 6. Add one-half mile to the X 54. 0 for X 54. 5. Adjusting to the nearest intercept, X 54. 5, Y 67. 5.

Next, add one-half the slope to Y 67. 6 for 67. 9. Add 0. 5 of a mile to X 54. 5 for X 55. 0. Adjusting to the nearest intercept, X 55. 0, Y 68. 0. Add one-half the slope to Y 67. 9 for 68. 2. Add 0. 5 to the 55. 0 for X 55. 5. Adjusting to nearest intercept, X 55. 5, Y 68. 0.

The IBM 604 can handle the above problem very easily except for adjusting to the nearest intercept. However, if the factors are doubled before calculation and divided by two afterward, it becomes a simple problem of rounding to the nearest whole number. For example:

Y 67. 0 times 2 plus slope equals 134. 6 which rounds to 135. 0. Divided by two it becomes 67. 5.

134. 6 plus slope equals 135. 2 rounded to 135. 0 and divided by two equals Y 67. 5.
135. 2 plus slope equals 135. 8 rounded to 136. 0 and divided by two equals Y 68. 0.
135. 8 plus slope equals 136. 4 rounded to 136. 0 and divided by two equals Y 68. 0.
136. 4 plus slope equals 137. 0 rounded to 137. 0 and divided by two equals Y 68. 5.

For the longer axis, of course, it makes no difference which method is used so in this case the X still comes out X 54. 0, X 54. 5, X 55. 0, X 55. 5 and X 56. 0.

When the last card of a trace is reached, the intercept must agree with the coordinates of the destination. If they do not agree, the machine can be wired to stop, thus eliminating the need for a second run through the 604 for checking the accuracy of the trace.

The No. 061 cards and the trace cards were then sorted to XY intercept within direction code and a new summary card cut for each XY within each direction. This card contained total volumes for each mode of travel passing through a square in one of the four directions.

These coordinate summary cards for each direction were then sorted on the total vehicles field and arranged in descending rank order. A listing was made and the volumes examined by personnel of the cartographic department in order to establish the best isoline intervals. Color codes were assigned to these intervals and gang punched into the coordinate summary cards, card No. 064, Figure 8.

The entire process is shown graphically in Figure 9.

The cards for each direction were then broken down on the first digit of the X coordinate. Since the Detroit grid ran from X480 in the west to X830 in the east, this breakdown produced five groups. Each group was then further sorted on Y. Because the grid ran from Y620 in the north to Y220 in the south these groups were arranged in reverse sequence in order to print from north to south.

The 402 Accounting Machine was wired to print the Y coordinate vertically at half inch intervals and to print the color codes at half inch intervals horizontally by spreading on the last two positions of the X coordinates. A separate tabulation was run for each group. When these tabulations were placed side by side they formed a grid of the area at a scale of one half mile to one half inch. The working base map of the study area was at this scale so that the tabulations of traffic desire volumes per quarter square mile were run at the scale of the map and the transfer to the map using a light table was a simple process.

Directional Contour Maps of Travel Desire

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● IN 1950-51 the City of Dallas, with the cooperation of the Texas Highway Department and the U. S. Bureau of Public Roads, conducted an origin and destination survey of Dallas County traffic. Using the findings of this survey, showing zone to zone movement of all vehicular trips, traffic was allocated to an existing major thoroughfare system. The allocated usage (based entirely on origin and destination) when compared with actual usage, as determined from existing traffic volumes, pointed out deficiencies in the existing thoroughfare system. Considerable use was made of this information in programing capital improvement projects. This, in itself, was an improvement over previous methods of formulating a capital improvement program and assured the city that current deficiencies were being given consideration.

In order to plan properly for a highway system that would be adequate for the future, however, it was necessary to expand the 1950-51 data to the higher level of a future date, giving consideration to such factors as would have a direct bearing on the increased traffic volumes to be expected. The year 1980 was selected, for it was felt that this date was about as far in the future as highway planning could be developed with any degree of reliability. In conjunction with this expansion it was decided to construct traffic contour maps which would depict graphically the traffic desire for the year 1980. This type of map had already been experimented with in Sacramento, California,[2] and it appeared from results obtained there that such presentation had some advantages over the straight line method of showing major travel desire lines.

Expansion of the Data

The 1950 population was known for each survey zone. In addition, the number of dwelling units in each zone was determined during the time the sample selection for the O-D survey was made. The anticipated population of Dallas County for 1980 was derived by carefully extending the curve of the 1890-1950 population trend as charted on semi-log graph paper.

The City Plan Department distributed the projected increment of population increase from 1952 to 1980 by zones, based on anticipated population shifts influenced by future water and sewer facilities. For each zone the Plan Department computed the total dwelling units anticipated, based on zoning and deducting areas for schools, churches, parks, shopping centers, industrial areas, etc.

There, 1980 population was destributed to each zone. The number of dwellings estimated for each zone in 1980 was computed on the basis of the average 3. 2 persons per dwelling unit in 1980.

Vehicle registration since 1910 was obtained from the state highway department statistics for the state and county. Using this data vehicle registration per thousand population for both the state and the county was computed, graphed, and the curve extended to 1980. Thus, passenger vehicle forecasts beyond 1950 for both the state and the county were derived from data obtained from curves showing vehicles per thousand population and a curve showing the population trend.

Forecasts of the number of trucks for 1980 was computed using a curve showing trucks per thousand population as a percentage of total vehicles per thousand population.

Gasoline consumption was projected on the basis of statewide gallons per vehicle per year from 1924 to 1952 (as obtained from the "18th Biennial Report" of the Texas Highway Department). No comparable data for the county was available. Gasoline consumption for the state beyond 1952, was computed using the derived motor vehicle registration

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[1] Now General Manager, Department of Traffic, Los Angeles.

[2] "Coordinate Method of Origin and Destination Analysis." K. A. McLachlan, Proceedings, Highway Research Board, Vol 29, pp 349-367, 1949.

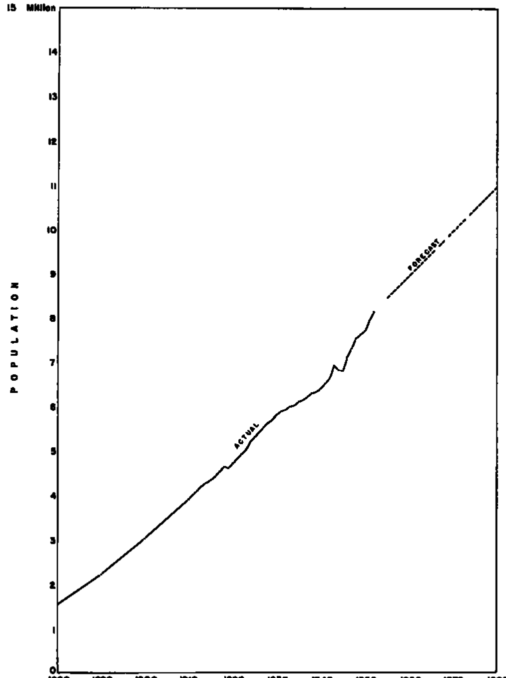


Figure 1. Population forecast for Texas.

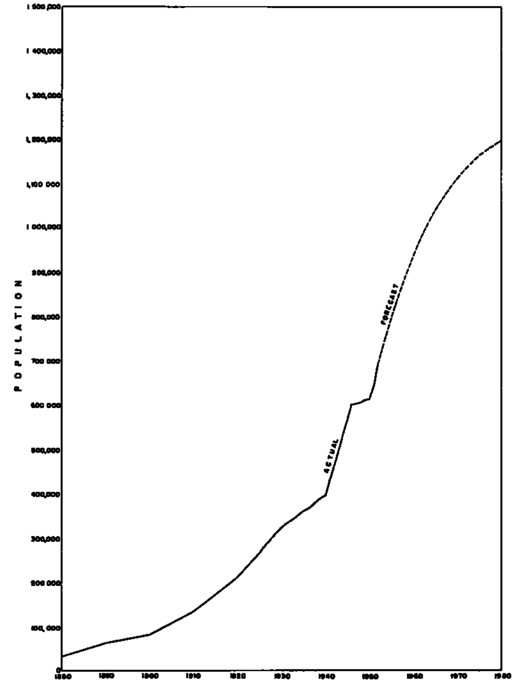


Figure 2. Population forecast for Dallas County.

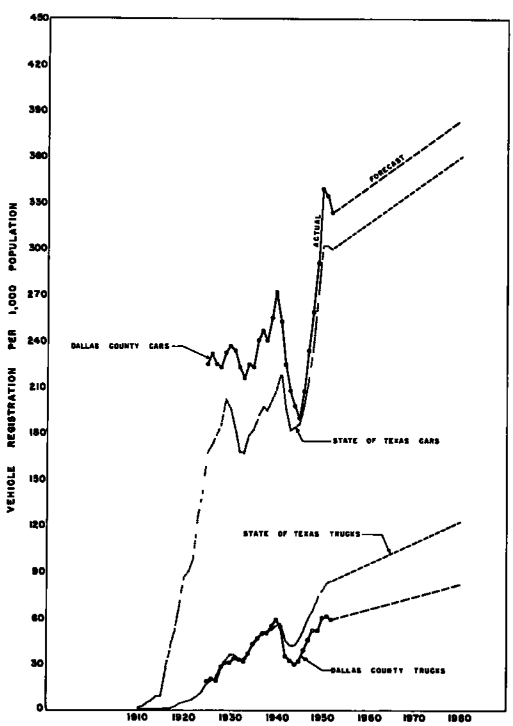


Figure 3. Trend of passenger vehicle and truck registration per 1,000 population.

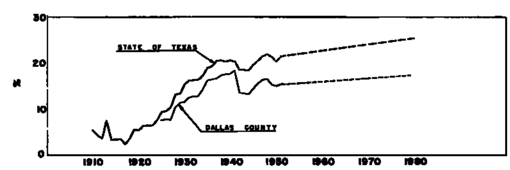


Figure 4. Percentage of trucks per 1,000 population to total vehicles per 1,000 population.

and the figure from the curve indicating the gallons per vehicle per year.

In order to expand the origin-destination figures to the 1980 level, it was determined that, in addition to the factor of increase occasioned by population increase "P," there would be a constant factor "C" because of the higher rate of vehicles per thousand population, as well as in the increased gasoline usage (miles) per year.

Thus, the final single expansion factor "T" used for each zone was a combination of the population factor, representing the ratio of the predicted 1980 population to that of 1950, and the constant factor, representing the increased vehicle registration and gasoline consumption, T = (P) x (C). Separate "T" factors for automobiles and trucks were computed.

In attempting to use the population expansion factor to convert the number of trips to or from any zone in 1950 to the number of trips in 1980, it was anticipated there would be a mathematical error if the trips from O to D, and D to O were combined to represent "trips between" zones. If expansion factors of both zones were practically equal and the number of vehicles in each direction were nearly equal, they could have been combined. However, if the factor for one zone remained fairly constant from 1950 to 1980 and the other zone had a very large expansion factor, it would be more desirable to use the trips from O to D by applying the factor for the origin zone, and the trips from D to O by using the factor for D.

A test of approximately 100 zones was made and it was found that because the number of trips from O to D could be radically different from those from D to O, and at the same time when the factors themselves were radically different, a mathematical error would present itself if the trips between zones were combined.

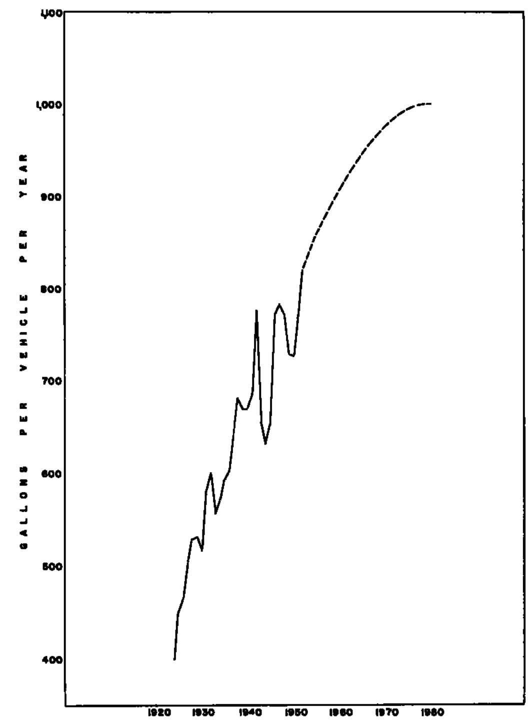


Figure 5. Trend of gasoline consumption - gallons per vehicle per year.

Some areas which were rural in 1950 were expected to be completely populated in 1980. In these instances the population factors ranged from 5.0 to 1,500. It was believed impractical to apply any factor for expansion purposes if the number were 5.0 or larger. In such instances it seemed appropriate to study several zones in that general vicinity of the city which in 1950 were fairly well developed and to use the general distribution from those areas as a guide toward the travel habits in the new area. The total number of trips out of that zone was based on the number of auto driver trips per dwelling per day experienced in the developed area and those total trips then distributed according to the pattern of the developed area.

Since the objective of this analysis was to determine future traffic usage on major thoroughfares and expressways, special attention had to be given to locations anticipated to become shopping villages, industrial areas, or other generators of traffic.

An analysis was made of four outlying shopping villages and three industrial areas to determine their zone of influence and volume of traffic attracted to each. The manner in which these special generators were treated and the methods used to calculate their effect on the over-all traffic pattern is thought to be beyond the scope of this paper, and the rather involved procedures used will not be discussed here.

Much of the actual expansion was accomplished by making extensive use of IBM facilities.

Preparation of Directional Traffic Contour Maps

The idea of contour maps probably brings to mind the familiar topographical type of map which shows the elevations of an area of land. In this type of map it may properly be assumed that the elevation of the land lying between two adjacent contour lines is somewhere between their values. With the traffic desire contour map, however, this is not quite the case. Here all terminals or zones are reduced from two-dimensional areas to points, and all vehicle travel is concentrated from bands to single lines connecting these points. Thus, it can be seen that technically the area between adjacent desire lines or between the adjacent contours constructed from points along these same desire lines, actually has no value and should be considered as zero. Consequently,

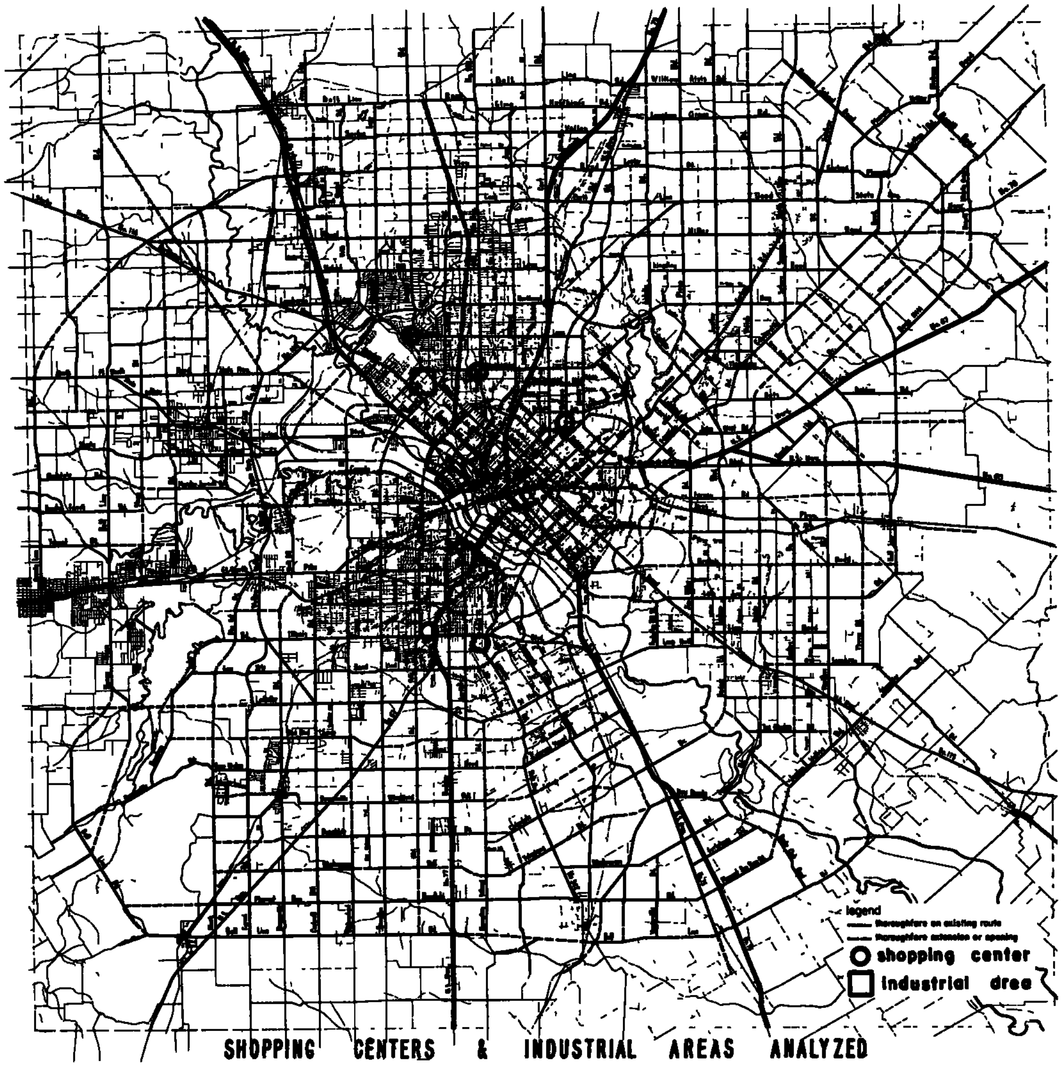


Figure 6. A preliminary major thoroughfare plan.

whenever lines are constructed by interpolation in these "zero" areas (a procedure necessary for proper presentation), interpolated lines show only relative volumes and do not permit the measurement of actual volumes.

The first step in the preparation of the contour map was the establishment of a regular grid system over the entire survey area so that trip terminals could be identified and so that regularly spaced points along the desire line connecting these terminals could be derived by use of the general formula of the straight line.

By selecting points along the desire line from the first terminal, each point being an additional whole increment of value along one axis or coordinate in the direction of the other terminal, the corresponding value of the other coordinate can be calculated for each point. It is obvious that the rate of change in the values of both coordinates for successive points along the desire line is in direct proportion to the slope of the line. Such computations were accomplished rapidly by use of mechanical equipment.

Selection of the ideal grid interval to be used in the construction of the grid map is largely dependent on the size of the area to which the expanded data are intended to apply. At the time of the 1950-51 survey the Dallas metropolitan area contained 215 sq mi, 24 percent of the county's area and 84 percent of the county's population. This 215 sq mi was divided into 346 zones of widely varying sizes and shapes averaging 0.62 sq mi each. The remaining 680 sq mi of the county outside of the metropolitan area was divided into 99 zones averaging approximately 6.8 sq mi each. In selection of the grid interval it must be remembered that too small a grid interval, although giving greater refinement, greatly increases the number of IBM increment cards needed in the desire line computation, possibly beyond all practical limits. Furthermore, in view of the fact that each of the zones had to be identified by a single grid square (which in every case was smaller than the zone it represented), some correlation had to be maintained between the two for reasons of desire line accuracy. It was something of a handicap that, unlike the Sacramento survey where the zones consisted of the exact squares formed by the pre-constructed coordinate lines, the Dallas survey zones had been determined before any possible use of the data for a contour map had even been considered. However, any such disadvantage can be greatly reduced, by careful selection of the grid interval and of the grid square to represent each of the survey zones.

After considering all the pertinent factors, a ⅓-mile grid interval was decided on as being the best possible to satisfy all requirements for sufficient refinement of the plotted values, number of IBM increment cards considered desirable, and the relation to the size of the zones to be represented by one each of the grid squares formed. The Dallas survey analysis required the use of 29,000 master cards which after machine processing, resulted in the use of over 500,000 increment cards.

Since it seemed quite likely that by 1980 the Dallas metropolitan area would in fact consist of the whole of Dallas County, this entire area was selected for analysis. Although the correlation between the size of the ⅓-mile grid interval selected and the 6.8 sq mi average size of the external or county zones seemingly is not good, the fact that 86.4 percent of the total of 862,223 trips studied in the original survey were made wholly within the metropolitan area (where the average zone size was just 0.62 sq mi) makes such a relationship less important. Just 12.7 percent of the total trips had one terminus outside the metropolitan area and only 0.9 percent had both termini there. It is fortunate that of the external zones, all of the more populated ones (such as those enclosing or representing the many small communities surrounding Dallas proper), were appreciably smaller than the average.

Any error in desire line alignment resulting from relating all the trips to or from a particular zone to one single point within that zone will occur with a relatively small percentage of the total trips and always at the external or county end of the line where such error may be more easily tolerated; if, in fact, an error actually does exist. By way of explanation, each zone was identified by the grid square within its boundaries that most closely represented either the zone's geographical or future population center-of-gravity. Each grid square was always identified by the X and Y coordinates of the point at the lower left-hand corner.

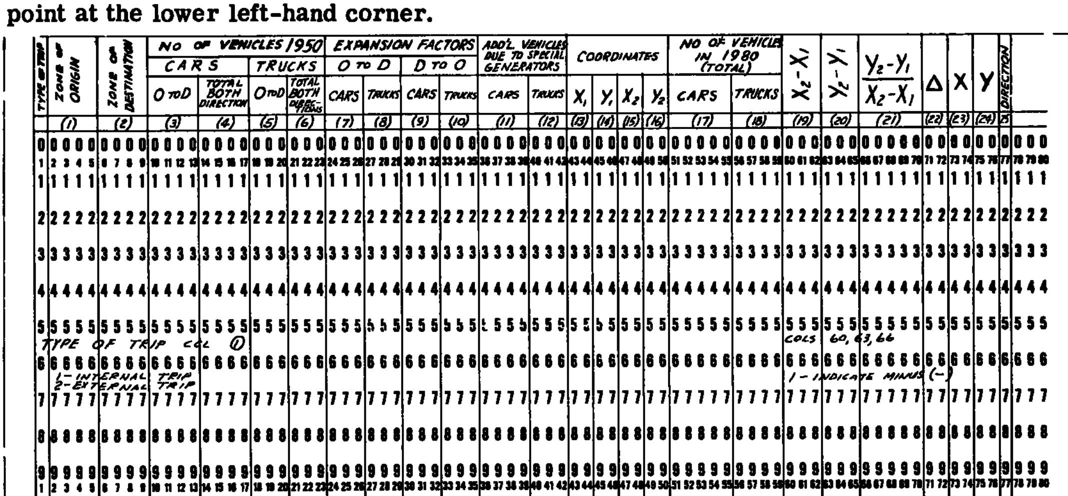
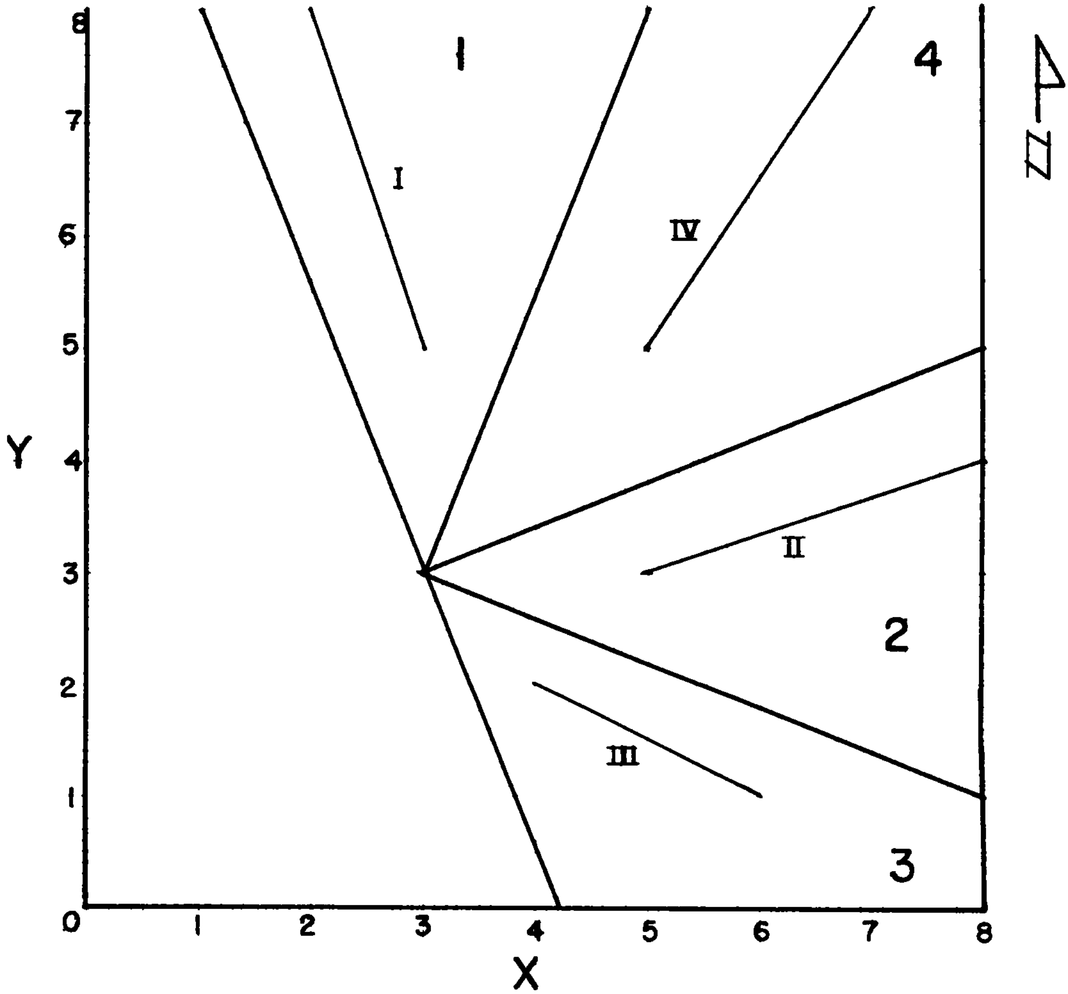


Figure 7. IBM card Type I, trip expansion and desire chart.



Sample Desire Line	X_1	Y_1	X_2	Y_2	X_2-X_1	Y_2-Y_1	TAN	DIR
I	2	8	3	5	1	-3	-.33	1
II	5	3	8	4	3	1	+.33	2
III	4	2	6	1	2	-1	-.5	3
IV	5	5	7	8	2	3	+.67	4

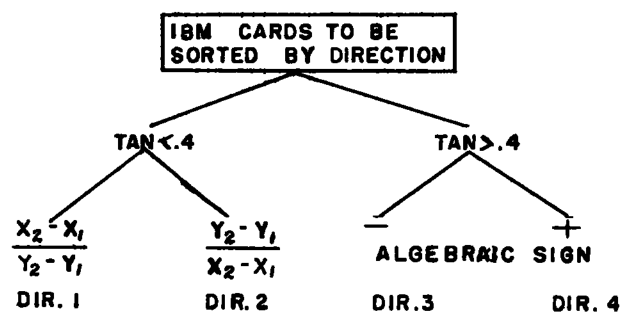


Figure 8. Directional movements.

With regard to the appropriateness of the grid interval selected, the manner in which the final results were tabulated provided a density point along all X and Y coordinates every sixth of a mile; this for an area that measured approximately 30 by 30 mi was certainly sufficiently refined.

Trip terminals located outside the limits of Dallas County were considered as points right at the county line. These points consisted of the actual location of the main high-

Assume that the machine calculation of desire lines gives the following actual solutions for the density points involved.

X	Y	Vehicles
4.0	31.0	10
4.4	31.0	2
4.6	31.0	2
5.0	31.0	6

The figures below demonstrate three possible ways in which these solutions would appear as punched on IBM increment cards and as plotted on a grid map. *

A

Solutions rounded to the nearest whole increment value of X

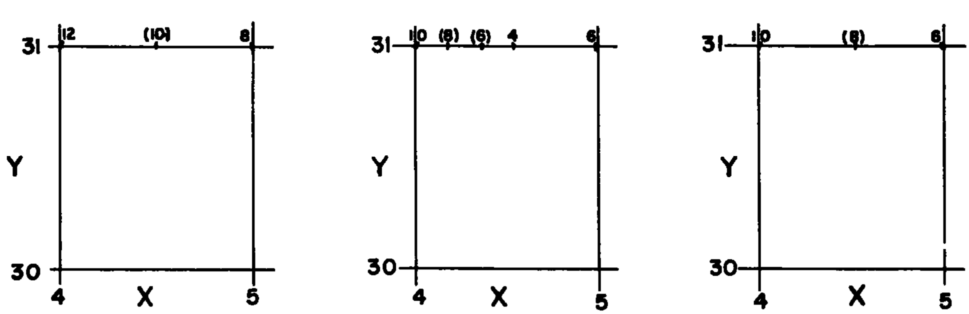
X	Y	Vehicles
4.0	31.0	10
4.0	31.0	2
5.0	31.0	2
5.0	31.0	6

B

Solutions rounded to the nearest half-increment value of X

X	Y	Vehicles
4.0	31.0	10
4.5	31.0	2
4.5	31.0	2
5.0	31.0	6

C



Compromise: half-increment values disregarded

* Values of interpolated density points appear in parentheses.

Figure 9.

ways into the county where they crossed the line. External terminals were identified with whichever highway crossover would most logically be used in going to or coming from the particular terminal within the county for the trip in question. Thus, only the portions of such trips that lay within Dallas County were considered from the desire line standpoint, because all trips to or from outside the county were limited to crossing the county line at pre-determined points. Although this caused some distortion in alignment of the actual trip desire line, the resulting channeling of these trips through such control points had the advantage of showing more plainly the cumulative effect of their relatively fewer numbers.

In selecting the four general directions into which the trips were to be separated, the actual alignment and layout of the majority of the major thoroughfares were considered so that, if possible, the derived contours would run parallel to the appropriate existing streets in the system. In Dallas nearly every major street runs due north and south, east and west, northeast and southwest, or northwest and southeast; therefore, these were chosen as the four principal directions into which to separate the trips.

Figure 8 illustrates the principal directions selected and the trips that would be included or assigned to the respective directions.

It is obvious that with all the origin-destination zone combinations involved in the study, trip alignment could fall into any of the 360 degrees of the compass. In assigning the widely varied desire lines to the proper general direction, therefore, deviations up to approximately 22½ degrees to either side of each of these principal directions were included. The lines of these deviation limits form the boundaries of cones within each of which all trip slopes or alignments that fall are classified as having the same direction as the center line of the cone.

In order for the IBM machine to determine how many increment cards would be needed and to compute the slope of each desire line, it had first to obtain the mathematical difference between the X coordinates at each terminal of the line as well as the difference between the two Y coordinates. This was done for each combination by always subtracting algebraically the first terminal's coordinates from those of the second terminal (the first and second terminals may be referred to as the origin and destination respectively although actually each may be either or both, since volumes are two-way — having been combined, after expansion, from the original survey data in which volumes were expressed as one-way).

To find as many points along the desire line as possible, the axis was chosen, either X or Y, which would give the greater number of whole increments, and then, using each of these whole increments, the corresponding value of the other coordinate was calculated. In the machine procedure used to compute the tangent, the smaller absolute number of the two coordinate differences was always divided by the larger, giving a tangent that was based on either the X or the Y coordinate serving as the "side adjacent." The IBM machine automatically classified those lines with a tangent of less than 0.4 into directions north-south or east-west, depending upon which origin and destination coordinate difference, either the X or the Y, had been divided by the other in computing the tangent. The desire lines with tangents of more than 0.4 were divided into directions northwest-southeast, or northeast-southwest solely on the basis of the algebraic sign of the tangent. Tangents with a negative sign indicated a northwest-southeast direction (Figure 8). Trips which ran either absolutely north-south or east-west and which would therefore have a tangent of zero were machine sorted beforehand and classified.

Although the use of a tangent of 0.4 as the line of demarcation resulted in direction cones of unequal scope, the variation was not considered important. It will be noted that the north-south and east-west directions allow a divergence in desire line alignment of 21 deg 48 min to either side of the center line, whereas the diagonal directions allow a divergence of 23 deg 12 min.

In order not to overlook any possible major desire movement with a slope in the vicinity of 0.4, the finished maps must be examined in pairs and the volumes along the peripheries of adjacent directional cones combined. Due to the layout of the Dallas street system and the choice of direction division, there appeared to be no significant desire volume shared by any two maps.

The advantages of separate directional contour maps over a single composite non-directional map are several. Principally the plotted routes are much more meaningful in that not only are areas of high desire density located, but also the relative importance of the various specific directions of travel that go to make up such areas are at once made clear and available for easy comparison with one another. Obviously maps showing specific direction of travel desire in any area may be more readily related to the streets with the appropriate alignment to carry the traffic so represented. Furthermore, in the case of a thoroughfare commercially well developed for a considerable distance, the use of the directional type maps clearly shows how much of the desire density is due exclusively to travel along or parallel to the thoroughfare itself. On the other hand, a contour ridge along such a string development on a composite map would include travel to or from adjacent zones, which in interchanging at a right angle to the axis of the contour ridge, tends to build up the ridge in a misleading manner. Small, possibly non-conforming traffic flows which might go undetected on a composite map often become readily apparent on the individual directional maps.

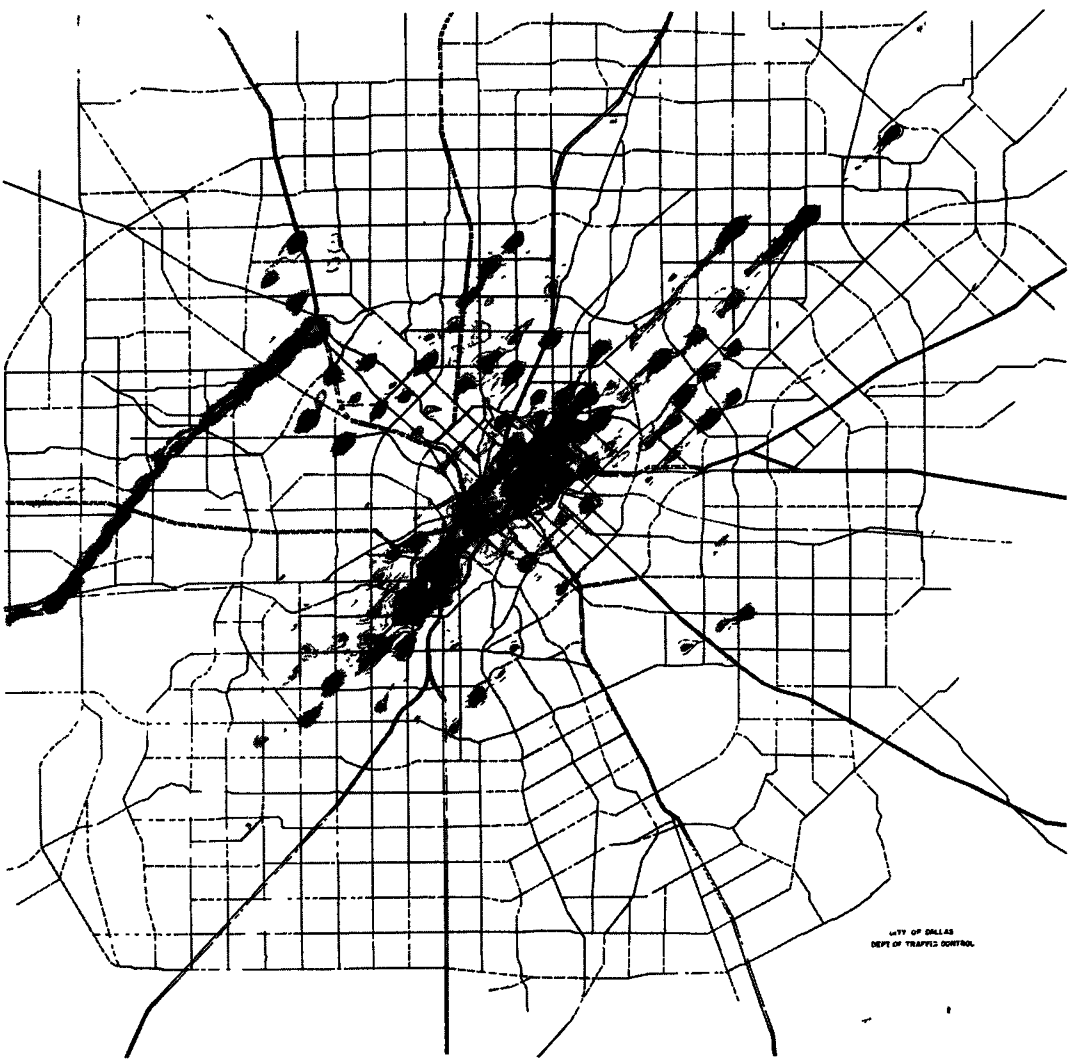


Figure 10. Directional contour map showing 1980 traffic desire - northeast-southwest direction.

No attempt was made to restrict the contour maps except as to direction. The maps were not broken down to show selected trips according to length or to vehicle type. The densities shown represent cars and trucks combined and are for all O-D combinations regardless of length.

It should be made clear that any extensive or extreme decimalization, except in the case of the expansion factors, is completely unnecessary. One decimal place is almost always more than sufficient. Furthermore, unusually small trip patterns, out-of-state trips, trips from other than immediately adjacent counties, etc., should be thrown out from the start as inconsequential and time and card wasting. The foregoing will be understood when it is realized that in plotting the final contours on the maps, point values were rounded to the nearest 500 whole vehicles and values of less than 2,000 vehicles were deleted altogether, except where they were needed for interpolation in conjunction with adjacent points with higher values. Considering the extreme range of point values that appear on any one map and the practical limit to the number of contour bands that may be used in view of the size of the map and the spacing between points, it can be seen why any greater refinement is impractical, if not impossible.

The manner in which the IBM results are tabulated is extremely important and upon it depends whether the plotting of the point values on the blank map (translucent paper overlaying the grid map) will be difficult or relatively easy. For purposes of transposing the volume densities from the tab to the map, it is far better to have completely separate tabs for each direction and for the total.

It was necessary, in arriving at the proper contour interval to be used, to examine the extremes in density of each of the four directions. For purposes of easier comparison of the four directional maps with each other, the same contour intervals were used on all.

The selection of intervals was difficult considering the extremes in values of the points on four maps. In fact, the differences between values in different areas on just one map made the choice difficult. It is probable that no one particular set of contour intervals can serve all areas of all four directional maps. The intervals should be small enough to give a reasonably fine set of lines, but not so small as to make it difficult to distinguish between the many interpolated points that must be plotted on the map before the drawing of the contour lines can begin.

Contour lines were constructed for the following volume densities in units of 1,000 vehicles: 2, 3, 4, 5, 6, 8, 10, 15, and 20. The resulting contour bands were then colored, starting with yellow for the 2,000-3,000 range and using gradually darker shades of color for each succeeding band. Black was used to represent values of 20,000 vehicles and over. The combination of contour lines plus color made unmistakable and crystal clear the location and intensity of the major desire lines. It bears repeating that measurement of actual volumes is not permitted.

In solving for the corresponding coordinate values of the points along the desire line for each whole increment of X or Y, answers were rounded to the nearest half increment of the derived coordinate. Although this procedure did not increase the number of increment cards used, it did greatly increase the amount of sorting needed to list the results. It also resulted in the map having from two to four times as many density points on it as it would have had if the answers had been rounded to the nearest whole increment instead. The procedure followed was worth the extra sorting, etc. because of the greater accuracy obtained.

The immediate effect of using half increments was to level some of the peak values resting on grid line crossings of whole coordinates and to place part of such amounts on the half-way points between such highs, thereby producing a map of more precisely located and more correctly valued density points. It should be realized that whole values of X and Y had a much better chance of being registered than half-way values. Two reasons for this are the following:

1. The fact that every zone was identified by coordinates of whole X and Y values guaranteed these points a heavier registration simply because any origin or destination involving a particular zone had to begin or terminate on the identifying coordinates, thus giving emphasis to such point at the expense of surrounding points — whole increment as well as half.

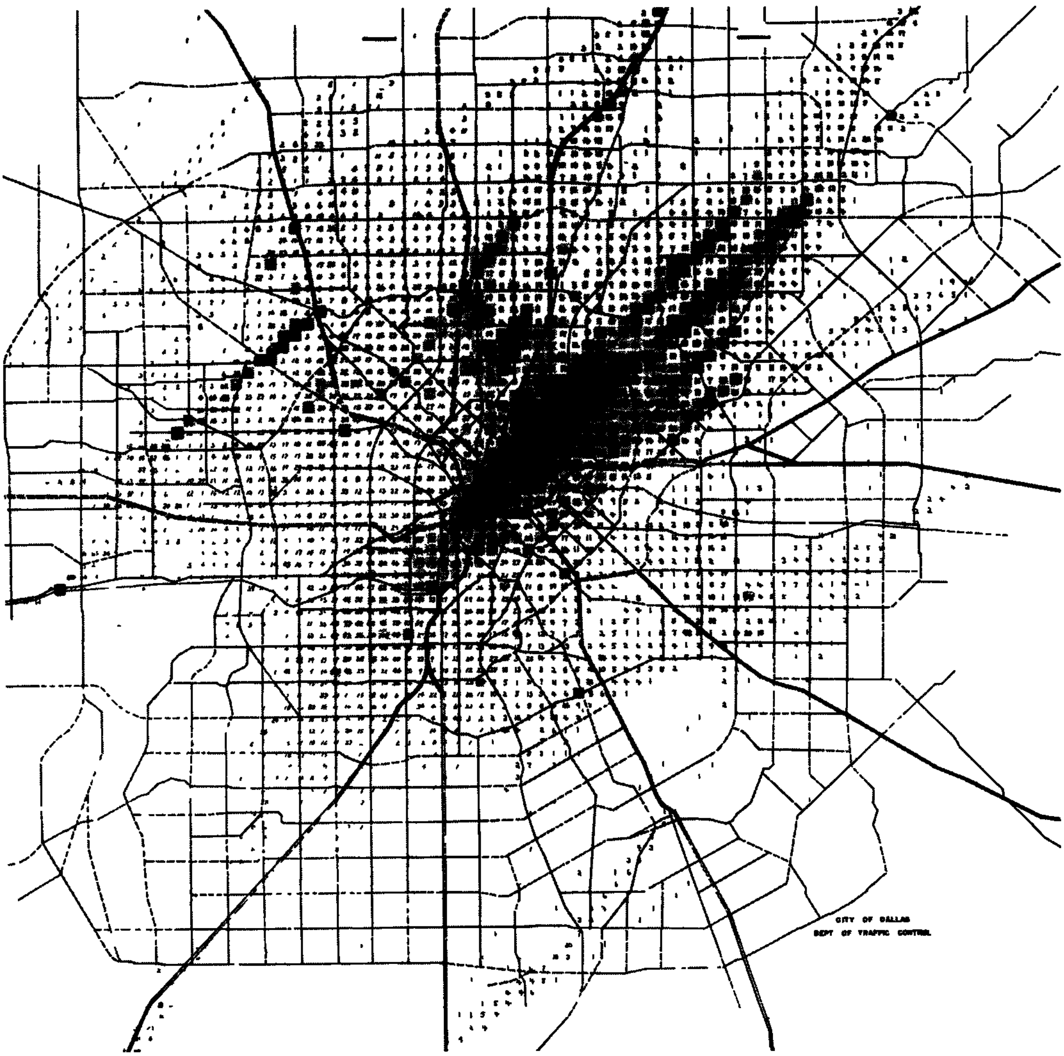


Figure 11. Block type directional contour map showing 1980 traffic desire - northeast-southwest direction.

2. In the machine method used, whole increments of either X or Y along the trip path were arbitrarily selected in solving for the other coordinate value. These derived values had about an even chance of being rounded to either a half or a whole increment. Thus, the cumulative effect of this was generally to give whole values of X and Y the advantage over half values in the final compilation.

As mentioned before, the use of the half increment point value tends to lower slightly the amounts that would have been registered on one of the adjacent whole increment points, thereby flattening some of the peaks and creating a more even and more accurate distribution of the travel paths. As this is being done, a new problem is created: the formation of low spots or valleys of low densities; i. e., the relatively lower valued half-increment spots between two usually higher whole increment points. If these half increment spots are used in the interpolation, the interpolation is made exceptionally difficult because several contour lines would have to be inserted to work down to the low spot from one high, and several more on the other side to work back up to the other higher valued spot. This produces innumerable abrupt and extremely awkward fluctuations. The added difficulty in having to construct these contour lines in half the regular space makes the situation even worse.

If half-increments had not been used, interpolation would have to have been made between adjacent whole increment points, thus passing through the area represented by a potential half-increment value (Figure 9). This fact demonstrates that except for using half-increment values to obtain greater accuracy, these spots could be considered as having a greater value — the value obtained by interpolating between the whole increment points. With this in mind, it can be seen that it is proper to disregard these low half-increment points whenever it is advantageous, either for eliminating abrupt fluctuation or for easier interpolating. The use of the half-increments has fully served its purpose merely in spreading out the travel paths and in adjusting the high peaks of whole increment points to lower, more realistic figures. In other words, during the actual interpolating, the relatively lower half-increment values may be completely disregarded under the above described conditions, and no error will result.

Preparation of Block Type Contour Maps

The preparation of "block" contour maps was an attempt to show more than just the comparative desire densities of various parts of the map. It is impossible to obtain actual desire volumes from a regular contour map due to the necessary introduction of the extra interpolated lines required by the selected contour intervals. The interpolated lines in themselves do not represent actual traffic, but serve only as transition lines between those lines connecting the originally plotted points. Any additional contour lines, such as those constructed by interpolating between points of sharply different volumes, introduce non-existent, erroneous volumes.

The idea of the block map is to avoid the misleading interpolations and make each grid square a separate area for study with its corresponding desire volume complete and independent of adjacent squares, with no overlapping. At the same time, a semblance of contouring is still preserved by appropriate coloring of the squares according to their volumes and a pre-determined scale of contour intervals.

Because the coordinate points were selected so as to represent the area of the grid square immediately above and to the right, the construction of a block map is easily accomplished. The only difficulty arises out of the half-increment points, which if expanded to form squares, would create a map of overlapping squares. This problem was handled by eliminating all half-increment points in advance by splitting the values of each evenly between the two immediately adjacent whole increment points along the main coordinate line on which all three lay.

Use of Directional Contour Maps

The directional contour maps made in Dallas depict 1980 travel desire only. Conventional desire line charts were used in the report that was published in 1951 after completion of an origin and destination survey. It was felt that the conventional charts displayed travel desire adequately to satisfy needs at that time.

In 1951, Dallas had one expressway that was well on the way to completion. Other expressways were contemplated, but very little actual planning based on a factual study of travel habits had been done at that time. Consequently, it was believed that 1980 travel desire should be given prime consideration in selecting future expressway locations.

When the idea of contour maps was first conceived, about all that was expected of them was to furnish a more precise means of selecting new expressway routes. The maps have been completed for some time now, and it is believed that this end has been successfully achieved. Also, the size of the maps, their distinctive coloring, and the very apparent way in which they show major travel desire make them effective as a means for presenting this type of information to those interested in expressway development.

The 1980 desire traffic obtained by expanding 1950 data is being assigned to a proposed major thoroughfare and expressway system. The considerable size of this project was realized at the outset and the possibility of making assignment from the block type directional contour maps was considered. It was hoped that a very substantial amount of time might be saved by so doing.

As explained previously in this paper, actual desire traffic volumes are shown on the block maps. In view of this fact, it looked as though this traffic might be transferred to appropriate street sections thus achieving the objectives of traffic assignment. Closer inspection, though, demonstrated that this could not be done with a satisfactory degree of accuracy. The north-south and east-west directions did not present an insurmountable obstacle due to the abundance of thoroughfares falling into these exact alignments. The other two directions did not present such favorable possibilities. In some cases, it would have been necessary to assign all traffic to the single radial street falling in this alignment. If this were to be done, some way would have to be found to measure the amount of traffic using differently aligned streets to get onto the radial. This problem was appraised from every angle but no procedure meriting confidence was devised. Therefore the idea of assigning traffic from block-type contour maps was abandoned and conventional type of traffic assignment was made on the basis of time saved.

In conclusion, the development of block or area contours does permit some measure of desire volumes. The utility of this type of presentation, however, has not been sufficiently explored to pass judgment on its potential value in actually assigning volumes to proposed thoroughfares, but it does suggest a field for further study.

Comprehensive Arterial Highway Plan for the Cleveland Metropolitan Area

THOMAS J. FRATAR, Associate Partner
Tippetts-Abbett-McCarthy-Stratton, New York

●THE Cleveland Metropolitan Area is co-extensive with Cuyahoga County. It contains 58 municipalities, the largest of which is the City of Cleveland (Figure 1).

The county extends along the shore of Lake Erie for about 30 miles. Its width is about 19 miles at its eastern boundary and about 10 miles at its western boundary. Its population in January 1954 was approximately 1,500,000.

Joint Action for a Comprehensive Survey and Plan

Recognizing the need for a comprehensive arterial highway plan based on the prospective development of the county and comprehensive and up-to-date traffic data, a survey program was agreed upon by the U. S. Bureau of Public Roads, the Ohio State Highway Department, the City of Cleveland, and the County of Cuyahoga. The County Engineer, Albert S. Porter, was selected as Survey Director.

With the financial assistance and technical cooperation of the Bureau of Public Roads, the Ohio State Highway Department undertook a comprehensive origin and destination survey of vehicular trips by means of postcard questionnaires, supplemented by roadside interviews. The county was responsible for traffic volume counts and traffic pattern investigations.

Cleveland participated equally with the county in payment for the services of Tippetts-Abbett-McCarthy-Stratton, who were retained as consultants for the preparation of a comprehensive arterial highway plan and report. Their project engineer in direct charge of the consultant's work was Glenn E. Brokke.

Advisory Committee

An advisory committee was appointed by the Survey Director to keep the various public and semi-public agencies of the county informed as to the conduct of the work and the findings of the consultant during the progress of investigations, and to bring to the consultant's attention the advice and counsel of those agencies. The committee was made up of representatives of the participants in the survey program and also those of several civic, public, and semi-public agencies including the Cuyahoga Mayors' Association, the Cleveland Chamber of Commerce, the Downtown Realty and Building Association, the Metropolitan Park Board, the Regional Planning Commission, the Cleveland Automobile Club, and like organizations.

The procedures which were used in each phase of the consultant's study and the tentative findings developed during the course of the work were reviewed periodically with the advisory committee. These periodic reviews and discussions were valuable in developing a highway plan acceptable to the diverse interests concerned with the program.

Land Use

The existing land use pattern of the area (Figure 2) was influenced by many things, including transportation facilities and zoning regulations. In the inner core of the area there remains little undeveloped land, and little future expansion can be expected there. In the outlying areas desirable sites are available for various uses and the future growth of many of these locations is expected to be rapid.

Many and diverse industries have been attracted to the county. Heavy industries, such as primary metal manufactures, have located in the Cuyahoga River Valley where raw materials can be received from lake vessels and where an ample supply of process water is available. Light industries which are not seriously dependent on heavy transportation facilities are located at numerous sites throughout the county.

On the basis of the availability of sites, zoning regulations, industrial trends, and

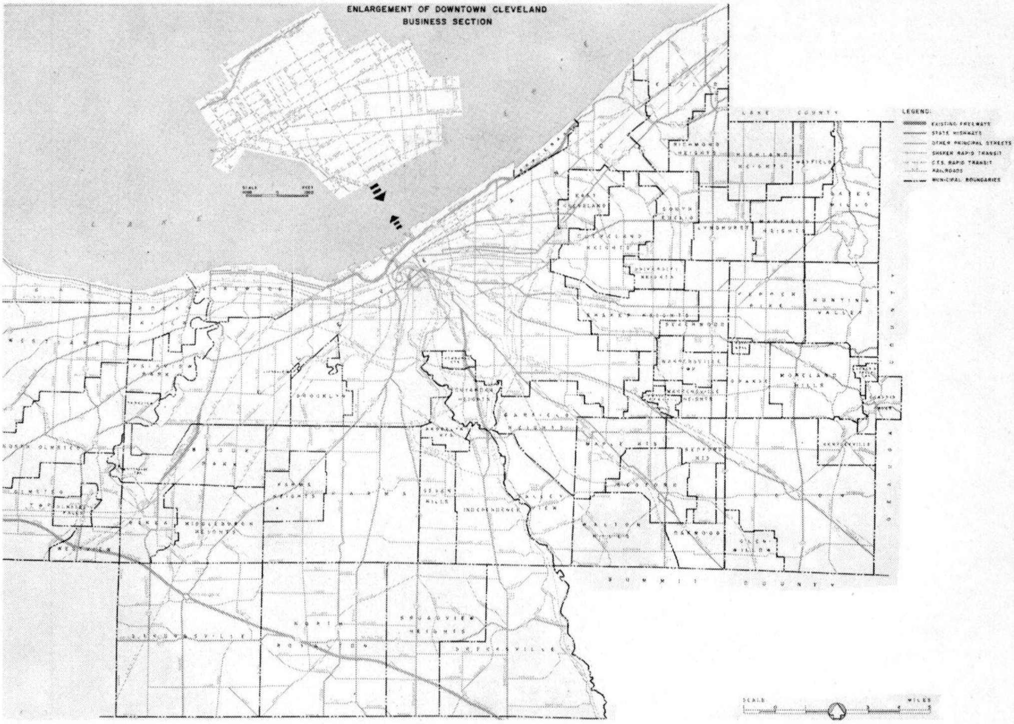


Figure 1. Location map.

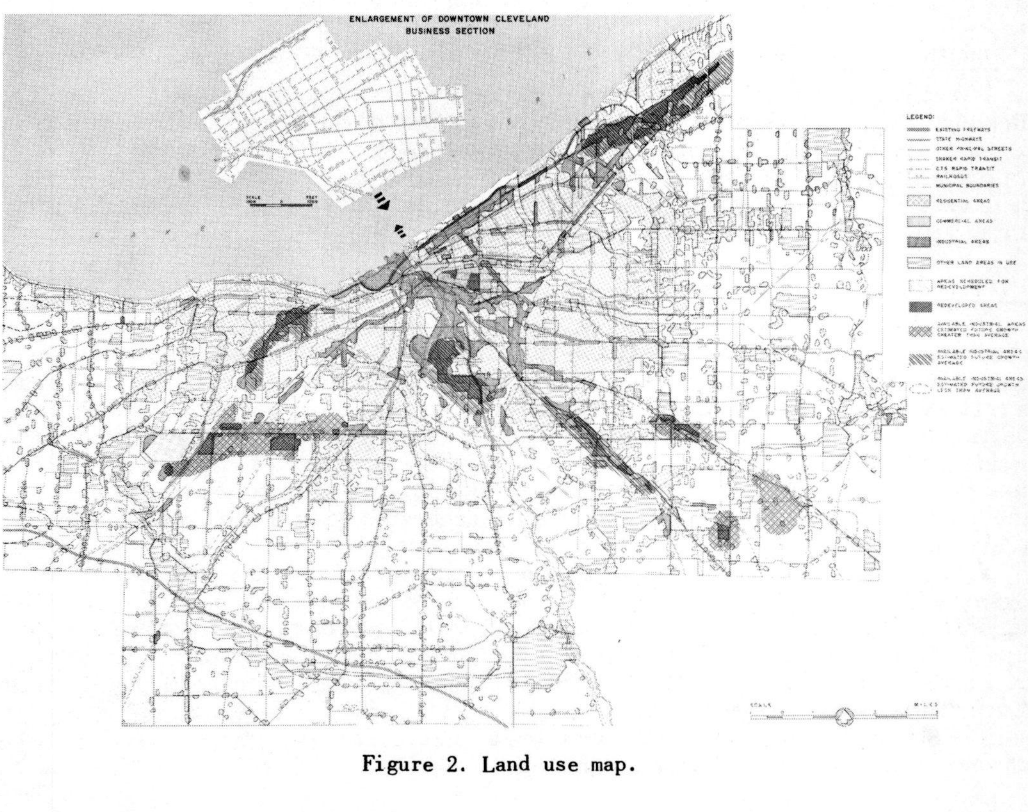


Figure 2. Land use map.

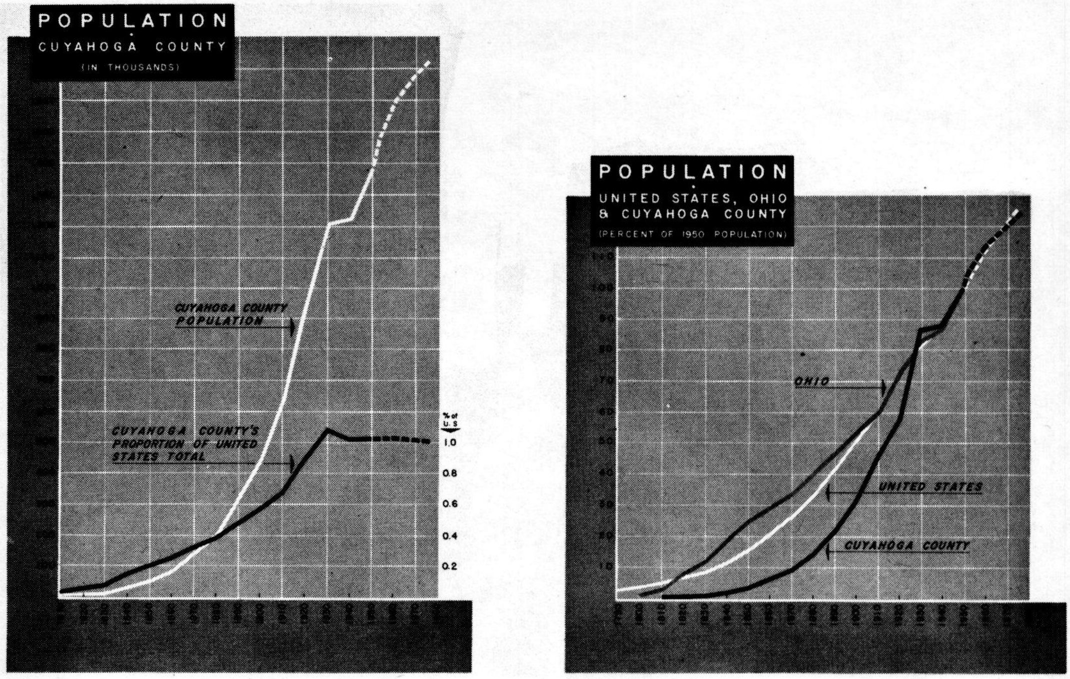


Figure 3. Population trends.

other factors, estimates of the prospective extensions of industrial areas and the probable rates of growth of those extensions were made with the assistance of the Cleveland Planning Commission and the Regional Planning Commission.

Population Growth and Distribution

Forecasts of the future population of the county were based on studies made for the Regional Planning Commission. It is estimated that by 1975 the population will reach about 1,722,000, an increase of about 16 percent over the 1952 population (Figure 3). At present about 64 percent of the county's population is concentrated in Cleveland, but it is expected that this distribution will change in the future as a result of the anticipated rapid growth of outlying areas (Figure 4).

Present Highway and Mass Transportation Systems

The highway network of the county consists of about 3,100 miles of highways, most of which are of the local street type with the undesirable characteristics which accompany unrestricted roadside developments. Two exceptions are the Memorial Shoreway, a freeway which extends along the lake front, and the Willow Freeway, the completed portion of which extends along the eastern edge of the Cuyahoga Valley south of Broadway. By 1954 the Memorial Shoreway was seriously overloaded. In contrast, the Willow Freeway was rendering only limited service largely because it was constructed from the southern portion of the county toward the congested central area without being supplied with adequate access connections to serve that area.

Mass transportation facilities in the county are operated by the Cleveland Transit System, the Shaker Rapid Transit Line, and several interurban bus lines. The Cleveland Transit System's bus and trackless trolley lines cover all of Cleveland and extend into the surrounding areas. In addition, the Cleveland Transit System is completing a rail rapid transit line with east and west branches. Studies are underway by the county for a subway loop to be constructed in the downtown area of Cleveland.

The Shaker Rapid Transit Line operates an interurban type rail rapid transit between downtown Cleveland and Shaker Heights.

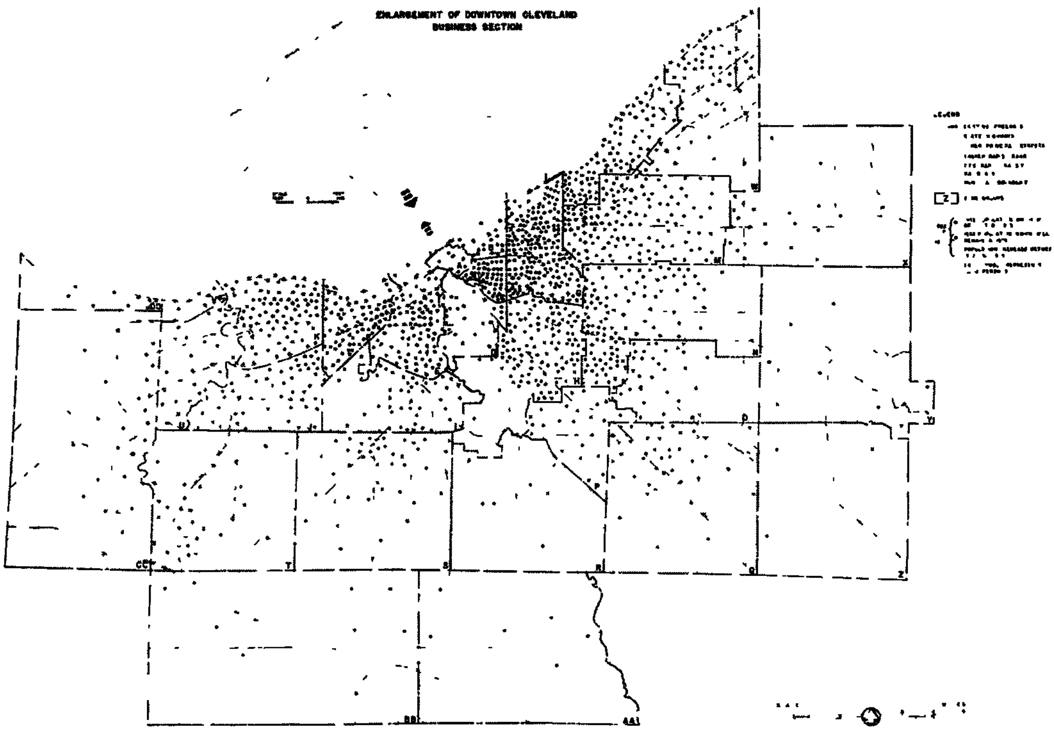


Figure 4. Population distribution, 1952 and 1975.

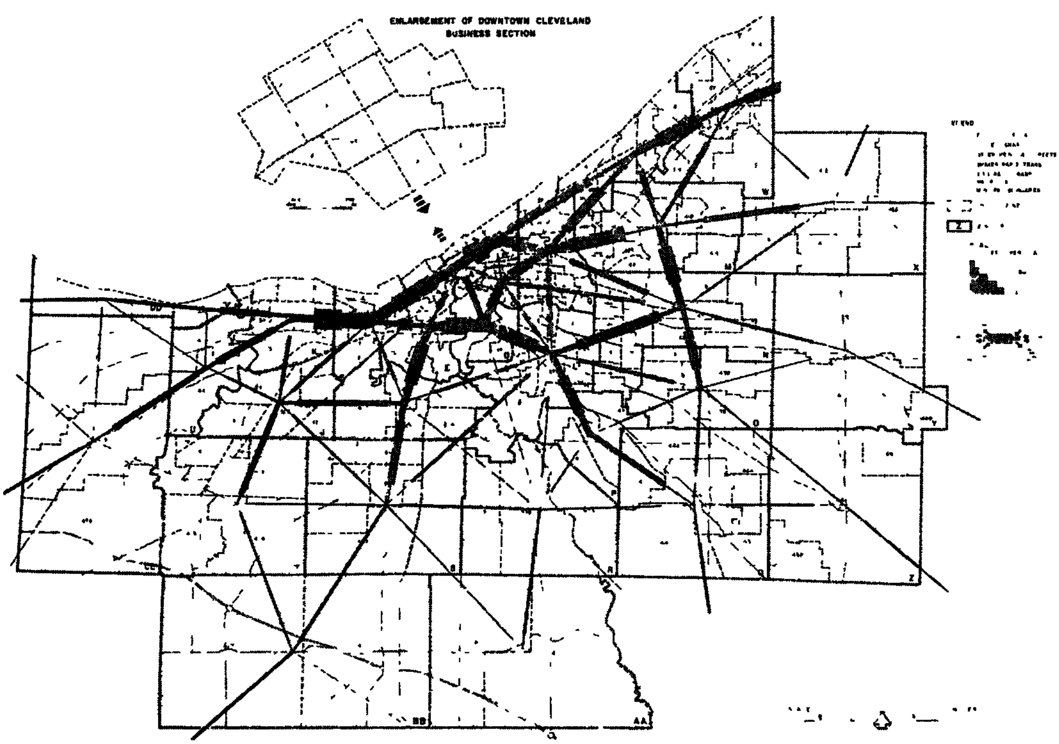


Figure 5. Desire lines, 1952.

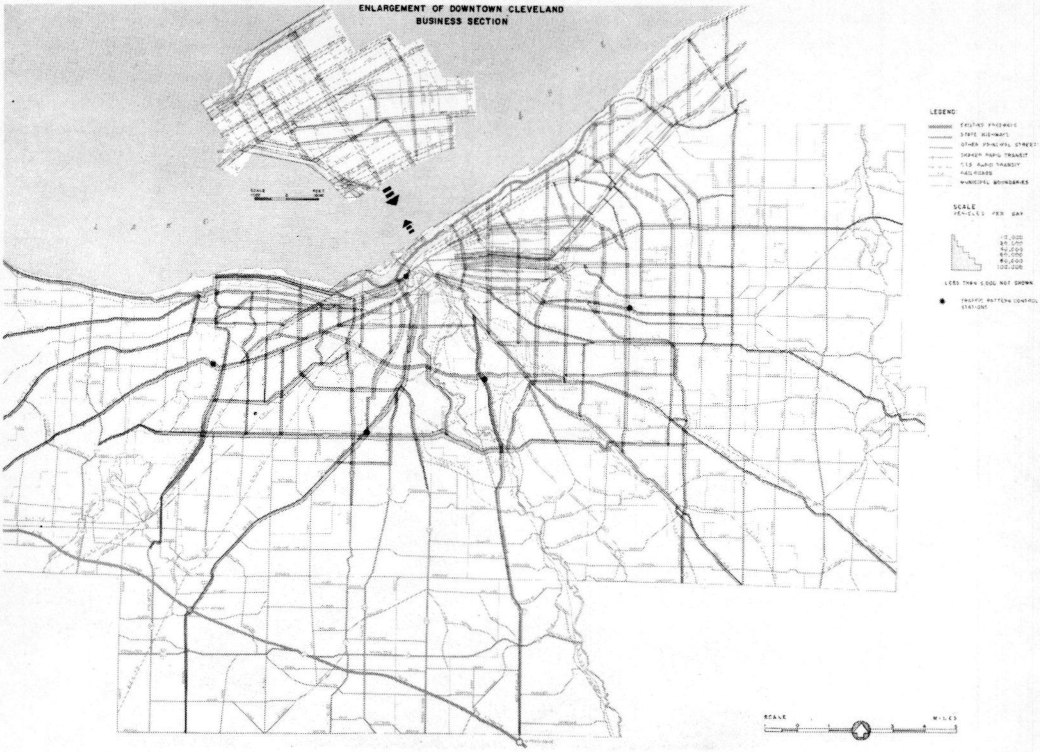


Figure 6. Average daily traffic volumes, 1952.

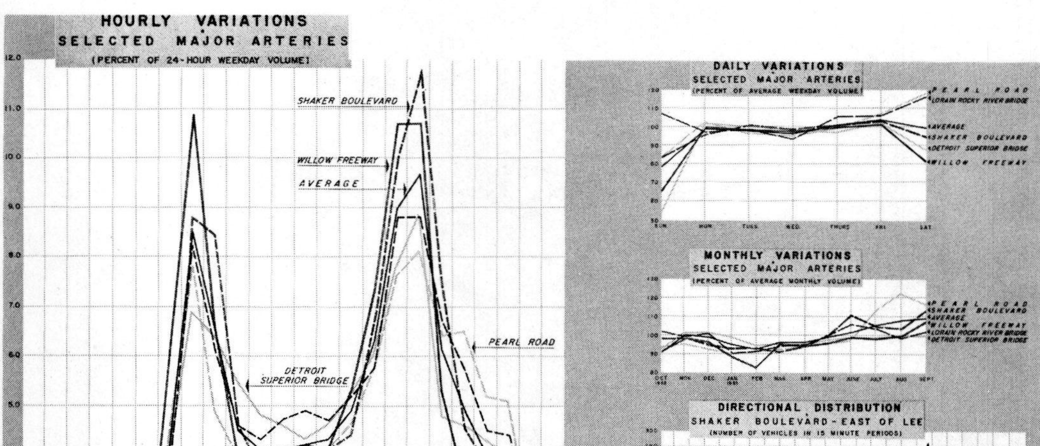


Figure 7. Variations in traffic flow.

Origin and Destination of Traffic

It was found from the comprehensive origin and destination survey conducted by the Planning Survey of the State Highway Department that for the average week day in 1952 about 1,754,000 vehicle trips were made within or through the county. Of these, about 75 percent were passenger vehicle trips, and 25 percent were commercial vehicle trips. About 90.3 percent of the trips had both origins and destinations in the county, 9.3 percent had either an origin or destination but not both within the county, and the balance, 0.4 percent, was through traffic with neither an origin nor a destination in the county. The length of the trips completed within the county varied from a few tenths of a mile to forty miles. The average length was about 5¼ miles.

As a first phase of the investigations, traffic zones were selected by subdividing the county so that traffic movements to and from individual residential communities, shopping and business centers, and industrial districts might be readily determined from survey data. All interested agencies were asked to participate in this work to assure that the origin and destination data so obtained could be used effectively, not only in the present study but in future investigations.

To demonstrate the general desire line pattern of the county without a multiplicity of crossing and overlapping desire lines, the 256 traffic zones used were combined into 45 groups. Each of these groups represents an area of more or less similar characteristics. For clarity, the traffic movements between non-adjoining groups were routed by way of intervening groups (Figure 5). Thus, the traffic which passed through any group without stopping was plotted from the traffic center of that group to the traffic centers of the adjoining groups along the line of travel, and the traffic which originated and terminated in the group was plotted as additional widths.

Daily Traffic Flow and Capacities

The traffic volumes on all of the principal highways in the area were counted by the

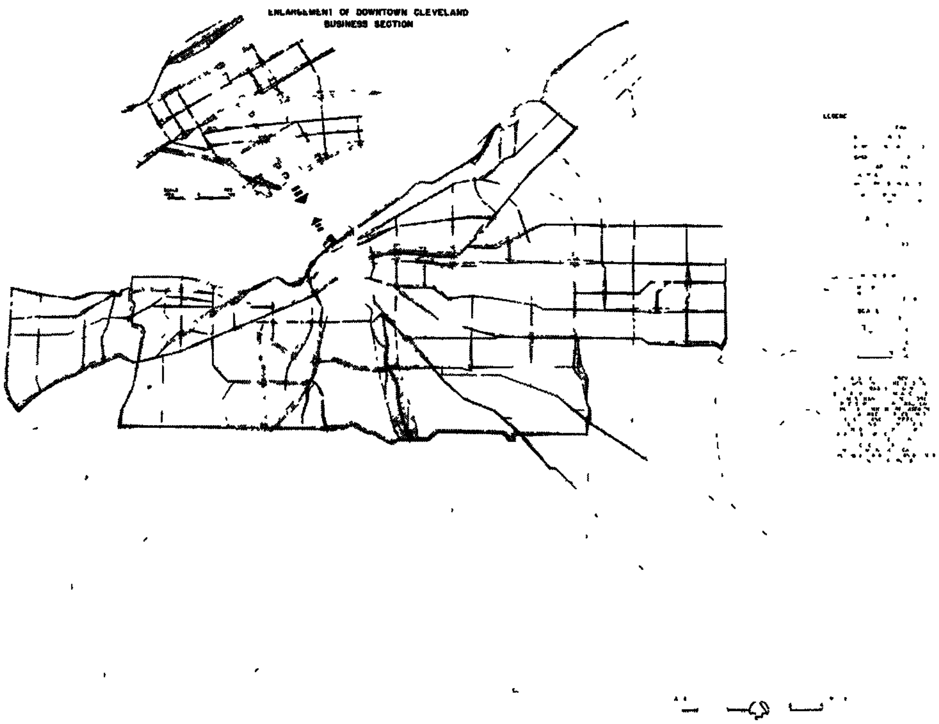


Figure 8. Deficiency and excess of highway capacity, 1952.

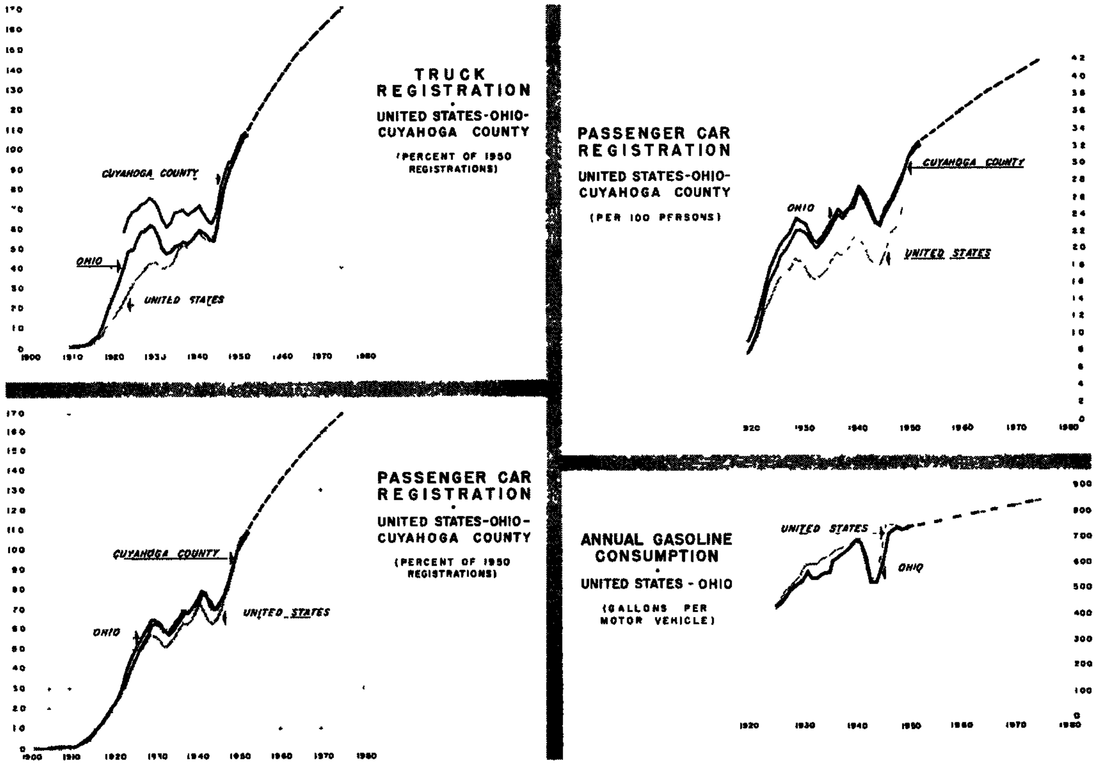


Figure 9. Vehicle registration and gasoline consumption.

county. All of the counts were resolved to a 24-hr week day in October 1952, on the basis of traffic cycle patterns compiled from regular and periodic counts at five traffic pattern observation stations (Figures 6 and 7).

The excess and deficiency of capacity on the existing principal streets in the county for 1952 were computed on the basis of standard procedures. It was found that substantial deficiencies exist throughout the area.

The Willow Freeway leads in availability of capacity. Some other existing facilities, such as the Memorial Shoreway East in the vicinity of East 9th Street and the Bratenahl Freeway east of Eddy Road, had excess capacities due primarily to lack of sufficient terminal capacity (Figure 8).

Traffic Volume Trends

In 1952 there were 32 passenger vehicles for each 100 residents in both Cuyahoga County and the State of Ohio (Figure 9). At the same time, in many regions of the nation where reasonably adequate facilities were available, the ratio was much higher. In California, for example, it was about 40.

The total vehicle registration for the county reached 505,000 in 1952, and it is estimated that by 1975 it will reach approximately 790,000, of which about 725,000 will represent passenger vehicles.

A general indication of the amount which each vehicle is driven annually is given by the records of motor vehicle fuel consumption. The annual gasoline consumption per vehicle increased from 680 gallons in 1940 to about 740 gallons in 1950. It is estimated that the annual consumption per vehicle will reach 850 gallons by 1975, with a commensurate increase in travel.

Future Traffic by Areas

The trips made into and out of any area are related to the type and intensity of land

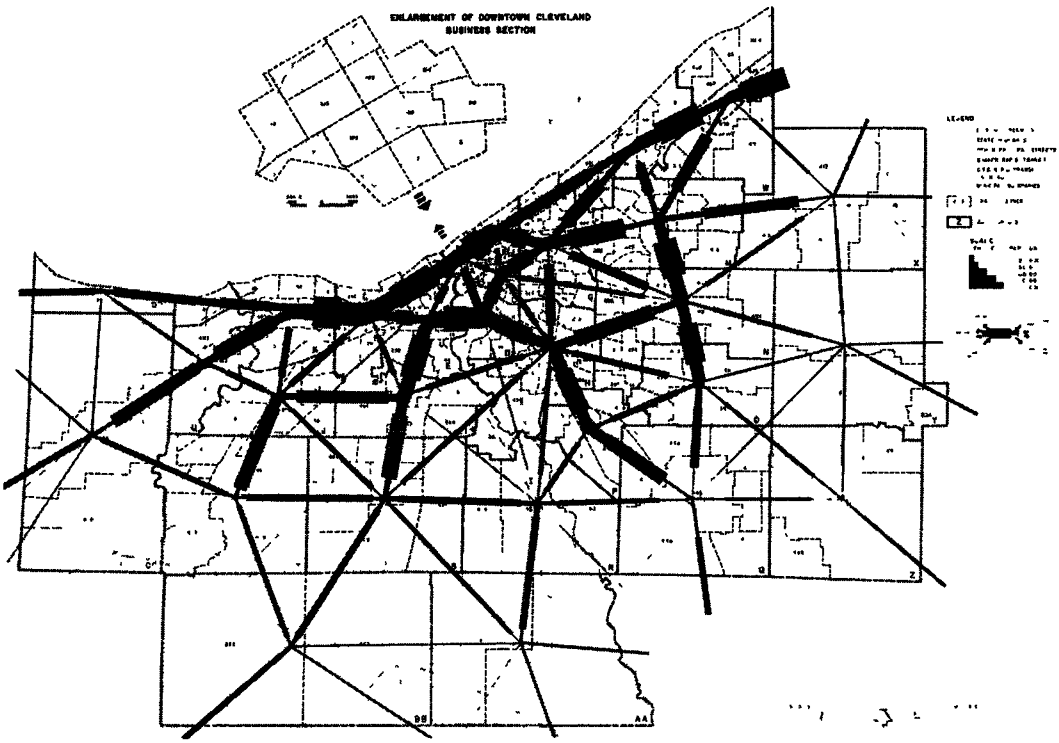


Figure 10. Desire lines, 1975.

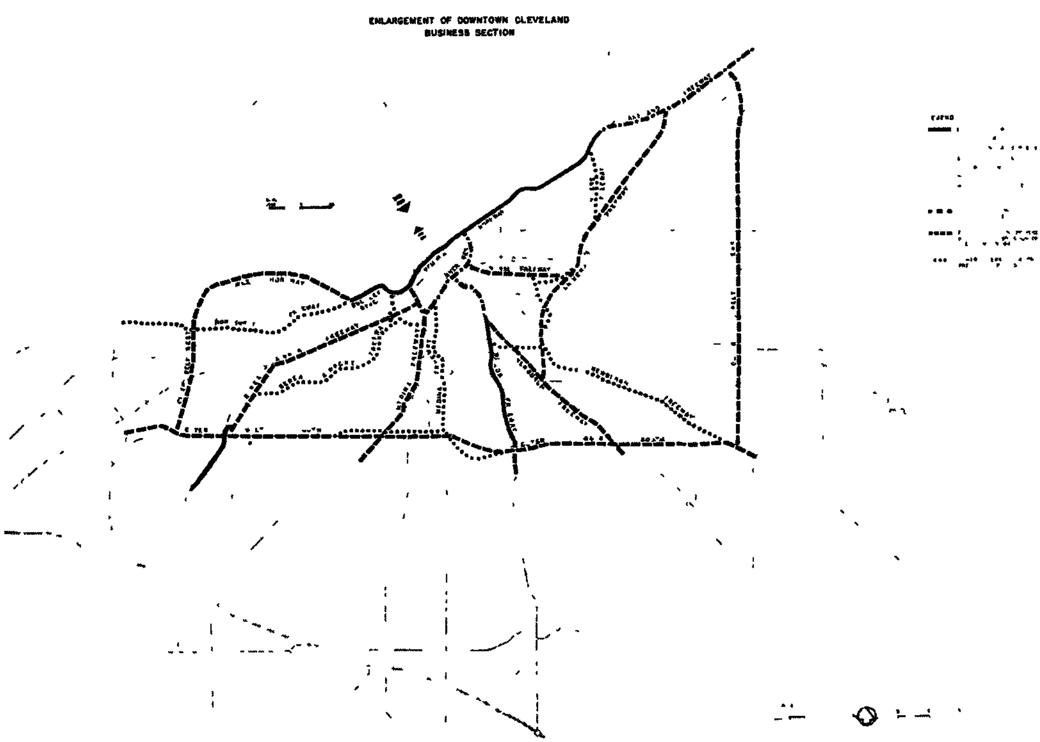


Figure 11. Existing freeways and previously proposed locations.

use of the area. Thus, for a zone which is exclusively residential in character, the total trips into and out of it have a direct relationship to its population. If a zone is entirely industrial in character, the total trips into and out of it are related to the employment in the zone. In the same manner, the total trips which enter and leave a traffic zone of other characteristics can be related to those characteristics.

To determine the future growth of trip generation, the future population of each zone was estimated, industrial and business trends were examined, and the zones were rated according to their probable future development. Careful consideration was given to anticipated changes in the character of each portion of the county. Civic agencies and others concerned with the problem cooperated actively in this work. The total anticipated annual average daily trips in 1975 are estimated at 3,136,000, an increase of 79 percent over the 1952 total.

Estimating Zone-to-Zone Distribution of Future Trips

If the various parts of an area change in a uniform way, the future traffic pattern will be a uniformly expanded copy of the existing pattern. Of course, uniform changes cannot be expected. Portions of the area will remain more or less stable, while other portions will expand or diminish. To estimate for the county studies the logical distribution which is compatible with the anticipated future conditions of development, a new theory of distribution was conceived and a method of successive approximations was developed to perform the distribution. That method was described at the 33rd Annual Meeting of the Highway Research Board. The following is a brief description of the method.

1. For each zone the estimated future traffic volume is distributed to the movements to and from it and within it, in proportion to the relative attractiveness of those movements.

Reasonable indicators of relative attractiveness are existing traffic movements and estimated zonal traffic growth factors.

As a practical matter, the intrazonal movement of the zone may be treated in the same way as an interzonal movement, with due regard to the difference between a trip and a trip end. That was done in the Cuyahoga study.

2. At the end of the first distribution each movement, except intrazonal movements, has two volumes resulting from the zonal distributions at each end of the movement. The pairs of volumes are averaged to obtain a first approximation of zone-to-zone movements and intrazonal movements.

3. The averages for the interzonal pairs of trips radiating from each zone and the first approximation of intrazonal volume are summarized to determine adjustment factors for the zones to be used in the second approximation.

4. For each zone the originally estimated trips are again distributed to interzonal movements and to movements within the zone in proportion to the volumes and adjustment factors obtained by the first approximation. The pairs of tentative volumes obtained for interzonal movements by this distribution are averaged as before, and the process repeated until the desired conformity is obtained.

In the Cuyahoga study experiments were made with variations of the method. It was found that for the procedure outlined above, the convergence was very rapid and otherwise satisfactory. With punched cards and IBM equipment the mechanics of the procedure is relatively simple.

The successive approximations method, with some refinements, was used for the traffic study recently completed for Detroit[1] under Dr. J. D. Carroll's direction.

It is to be hoped that with continued application of the successive approximation technique in other studies the reasonableness of the theory involved will be tested and practicable refinements developed. These refinements should, however, be consistent with the accuracy of the raw materials used, that is, the measured O-D data, and the estimates of future growth.

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[1] Row, Arthur T., "An Approach to O-D Data Analysis," Traffic Quarterly, January, 1955.

Future Distribution of Cuyahoga County Trips

The analysis of the future distribution of Cuyahoga trips indicated that the rapid development of suburban areas will have a major influence on future traffic movements (Figure 10). By 1975 there will be a large demand in the eastern sections of the county for capacity on north-south and northwest-southeast highways, as well as for travel between the northeastern sections and the central portion of Cleveland. In the western section of the county the anticipated growth of Parma and other suburbs will result in large increases in traffic flows to and from those areas. These increases in demand in many cases would seriously overtax the existing highways and will require substantial increases in the capacity of the county's highway network.

Basic Concepts in Highway Planning

For the over-all problem of the county it was necessary to examine the basic concepts of how people can best be transported in going about their ordinary community activities, and how other vital services such as heavy trucking and inter-community transportation can be provided without seriously interferring with the functions of neighborhood streets. It is clear that in addition to any other modes of transportation which exist or may be developed, transportation services must be available on highways designed to accommodate both public and private vehicles.

To be satisfactory, a comprehensive highway plan must be fully integrated with the land use pattern. New highway locations to serve the people of the community should be selected on the basis of the needs for handling traffic, minimum interference with existing structures and natural neighborhoods, and principles of good engineering and economy. The new highways must be located so as to divert through traffic around critical areas of congestion on the older streets and allow those streets to fulfill their essential functions of local service. Highways improperly located will not solve the problems and can create additional conditions of traffic congestion.

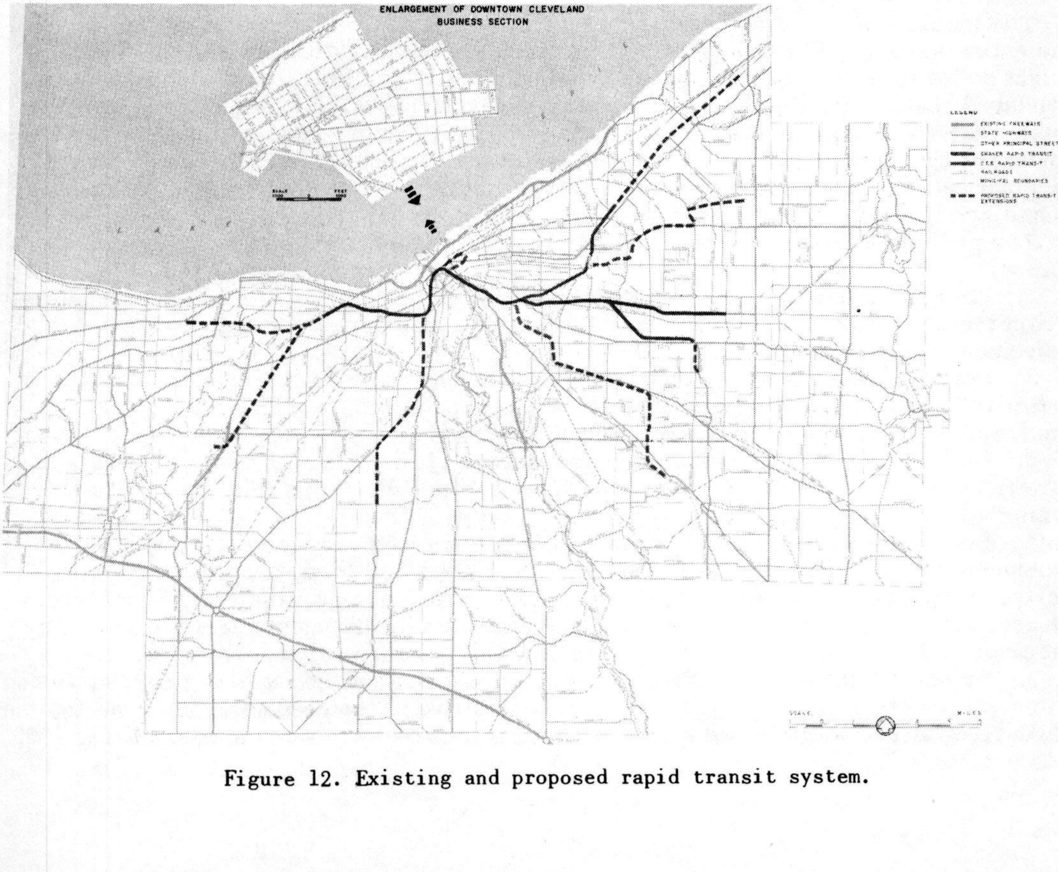

Figure 12. Existing and proposed rapid transit system.

Previously Proposed Freeway Layouts

In 1944 the Regional Association of Cleveland brought together various proposals for freeway layouts and adopted a freeway system to be used as a guide for future planning. In the ensuing years, various other civic agencies prepared layouts which included modifications of that system (Figure 11). Although outstanding talents were brought to bear in the development of the original layouts and modifications, only sketchy traffic data were available and only a few alignments were studied in detail in regard to such matters as services rendered, engineering feasibility, construction costs, and like matters. By 1952 only two freeway sections were constructed.

Existing and Proposed Rail Rapid Transit Lines

For use in this study an analysis of possible extensions of the rail rapid transit system was made jointly by the Regional Planning Commission and the Cleveland Transit System (Figure 12).

The diversion from the highways to the existing and proposed rapid transit lines will be a function of the attractiveness, comfort, speed, and convenience of rapid transit travel in competition with travel by highway buses and private passenger vehicles. The rapid transit system will be most effective in carrying passenger traffic between the downtown area of Cleveland and the intensely developed suburbs.

For this study, a detailed analysis was made of data on origins and destinations of riders of the Shaker Rapid Transit. From this analysis the probable extent of the zones of influence of prospective rapid transit lines was determined and factors were computed for estimating the diversions which would be made from highways to new rapid transit lines. These factors were compared with estimates furnished by the Cleveland Transit System and, as general agreement was found, the Cleveland Transit System estimates were used in this study.

Freeway Study Layouts

The traffic which will use any part of a freeway system is influenced by the extent of the entire system. For this reason, it is necessary to visualize the systems which might be appropriate and to test each by computing the traffic service which would be rendered, estimating the costs and benefits, and evaluating location problems and related matters. Refinements of the layouts include the determination of suitable means for carrying the traffic found to be in excess of the capacity of various sections of the original schemes, and for carrying the traffic initially assigned to freeway sections subsequently found to be unjustified.

The procedure used in the assignment of traffic to alternative freeway layouts was as follows:

1. Travel-time measurements were made on all principal routes within the county. From these, the most favorable time of travel was determined for each zone-to-zone movement via existing streets.
2. Operating speeds were selected for the various sections of each freeway system, and travel time ratios were computed for each zone-to-zone movement for travel via the freeway systems versus travel on city streets.
3. On the basis of data compiled by the Bureau of Public Roads and approved by the American Association of State Highway Officials, the time ratios were related to the trips that would use the freeway systems.
4. For each freeway system, punched cards were prepared for each zone-to-zone movement to show the numbers of passenger car trips and truck trips that would be diverted to the system in 1952. For each zone-to-zone movement the ramp which would be used in entering the freeway system, the freeway interchanges traversed in making the trip, and the ramp used in leaving the freeway were indicated.
5. By sorting the punched cards for each possible movement at each interchange and summarizing the traffic volumes on the cards relative to the respective movements, the basic freeway use which would be experienced if the freeways were in operation in 1952 was established.

6. A traffic expansion factor was determined for each traffic zone for 1975 and, by the method of successive approximations, the interzonal and intrazonal trips to be made in 1975 were estimated. Interchange routing cards, representing the 1975 trips, were prepared and summarized (in the same manner as the cards representing the 1952 trips) to determine the traffic volumes which would use each element of each proposed freeway system in 1975.

7. On the basis of past experience, estimates were made of the generation of new traffic which would result from the construction of each of the proposed freeway systems and the anticipated new traffic volumes were added to the 1952 and 1975 freeway traffic volumes diverted from existing streets.

All previous proposals were studied and modifications were developed where found to be appropriate. All of the system layouts investigated included the 17 miles of freeways now constructed and certain alignments proposed but unbuilt which the Advisory Committee considered to be fixed unless subsequently found to be unsuitable for the needs of the anticipated traffic.

Freeway System A

The system selected for initial study included a layout which is similar to that prepared in 1944 by the Regional Association of Cleveland as a general guide for freeway planning. That system was designated system "A-1" (Figure 12).

If system A-1 had been in operation in 1952, it would have carried approximately 40 percent of the traffic which was actually carried by the existing highway system. The diversion to the freeway system would have amounted to about 4,100,000 vehicle miles per day. By 1975 the anticipated traffic increases would tend to impose on system A-1 traffic loads which would greatly exceed maximum freeway capacities at several locations.

If system A-1 could carry the traffic that would desire to use it in 1975, regardless

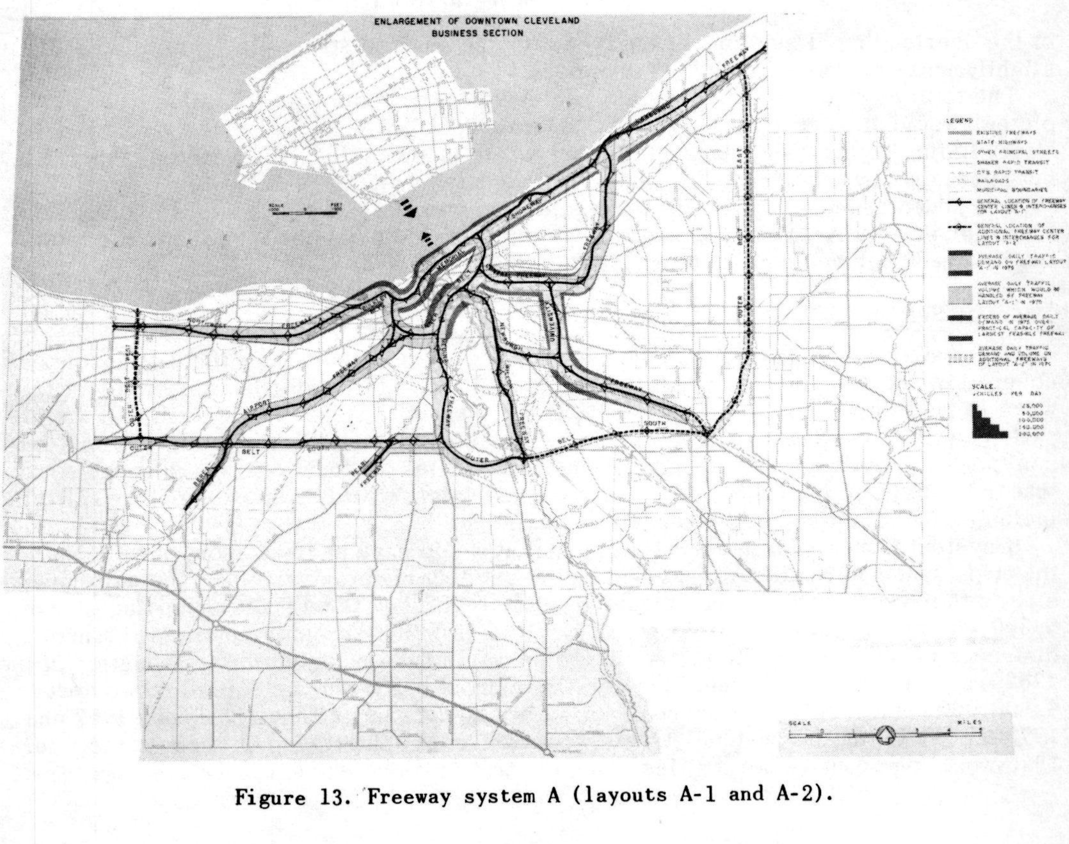

Figure 13. Freeway system A (layouts A-1 and A-2).

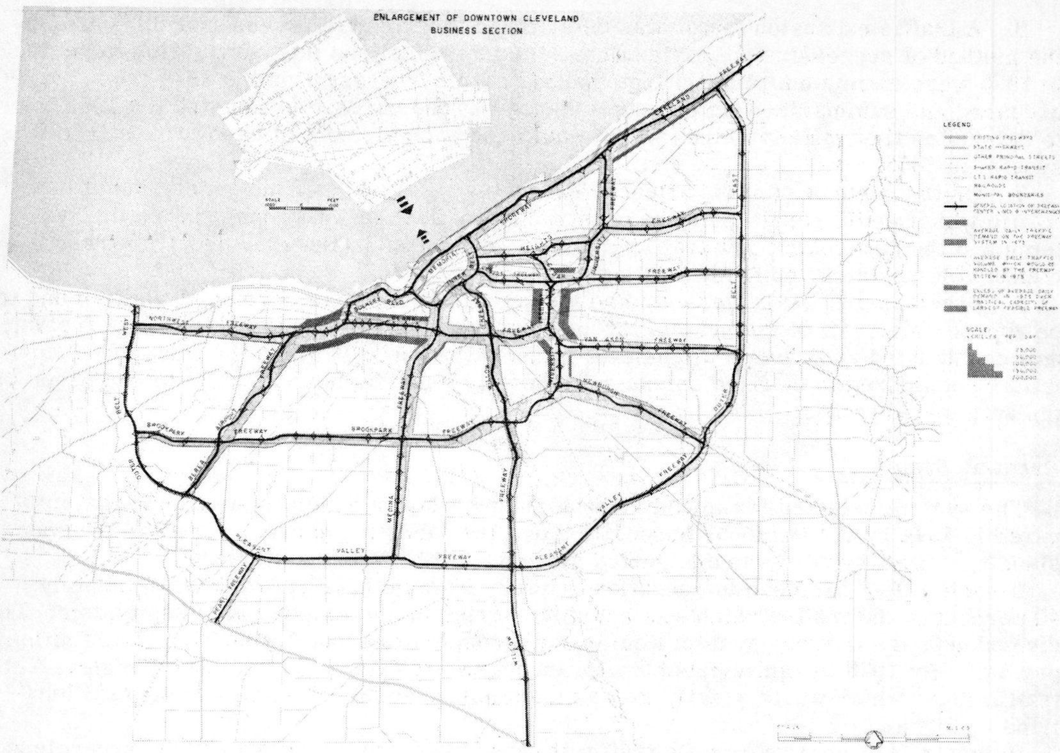

Figure 14. Freeway system B.

of the overloading of sections of the freeway, the surface streets in 1975 would still be slightly more congested than they are today.

The total cost for the system A-1, exclusive of the cost of the 17 miles now completed, would amount to approximately \$390,000,000.

A similar layout was prepared to incorporate modifications suggested in general layouts prepared by other agencies and was designated system "A-2."

The added mileage of system A-2 would have no material effect on the overloading found for system A-1. Consequently, system A-2 would also be inadequate for future traffic needs but would cost approximately \$444,000,000.

Freeway System "B"

Freeway system "B" was selected with a view toward correcting the deficiencies uncovered by the analyses of systems A-1 and A-2 and determining the suitability of freeways in areas not covered by those layouts (Figure 14). It was recognized that the locations where freeways would not be necessary should be determined, and for that reason freeway alignments were included in system B for all locations where it appeared that they might be justified. The length of the system would be approximately 161 miles, including the 17 miles of freeways now completed.

If system B had been in operation in 1952 it would have carried about 46 percent of the trips which were actually carried by the existing highway system. The daily diversion to the system would have amounted to about 805,000 trips, corresponding to about 5,300,000 vehicle miles. Although many vehicles would encounter increased travel distances by using the system, the diversion would have resulted in the reduction of the 1952 traffic on existing county highways from about 9,200,000 vehicle miles to about 4,800,000 vehicle miles, a decrease of about 47 percent. Although between 1952 and 1975 the traffic on the surface streets would increase, the traffic on those streets in 1975 would be about 14 percent less than the traffic which existed in 1952.

Although the traffic demands on some sections of system B in 1975 would seriously overload those sections, the overloading would be much less severe than for systems A-1 or A-2.

The total construction cost for system B, exclusive of the cost of the 17 miles now completed, would amount to approximately $618,000,000.

Recommended Freeway System

The studies of systems A and B and variations of those systems revealed the areas where freeways are most urgently needed and also the areas where surface arterial highways could accommodate the anticipated demands. Extensive field reconnaissance was made for the selection of tentative alignments which could handle the anticipated traffic volumes safely and efficiently and be appropriate for the existing and anticipated land use and in conformity with the topographic conditions. Consideration was given to the desirability of making maximum practicable use of low value property and avoiding physical barriers, expensive existing structures, cemeteries, schools, churches, parks, playgrounds, and similar areas.

Consideration was also given to the surface arterial highways which are now adequate or which could be made adequate with reasonable improvements. The capacities of these surface arterial highways were reviewed and determinations were made of the extent to which they could carry anticipated future traffic loads and thereby diminish the need for freeway type improvements. In addition, recognition was given to the various localized improvements of surface arterial streets which are programed or proposed.

The recommended layout (Figure 15), incorporates several alignments found to be satisfactory in the previous studies and others which were made satisfactory by readjustments of other segments of the freeway network.

The recommended system, together with principal arterial surface streets, would

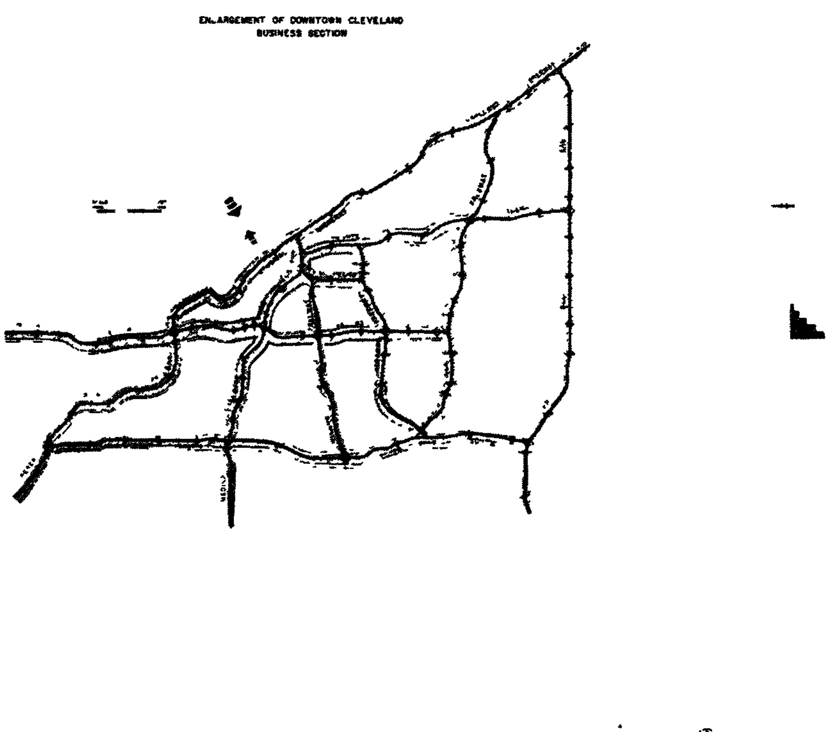

Figure 15. Freeway system C.

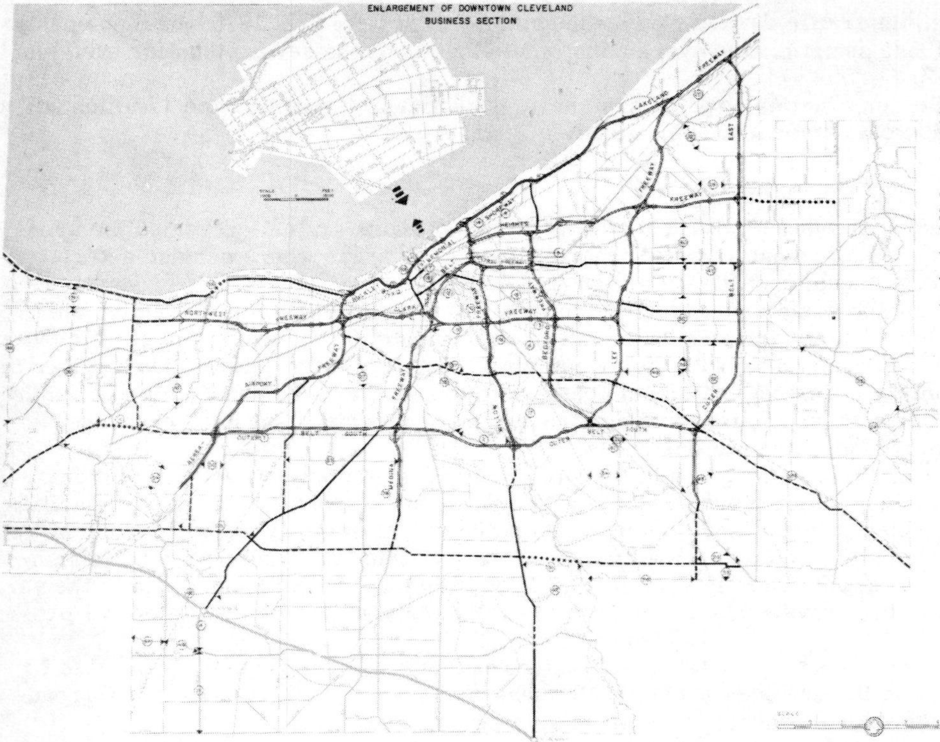

Figure 16. Comprehensive highway plan (with schematic layout of recommended freeway system).

provide a good geographical distribution of arterial highways. The length of the freeway system would be about 119 miles.

The freeway system and the principal arterial streets would adequately accommodate the traffic in 1952 and, with an appropriate allowance for anticipated diversions to the proposed rail rapid transit system, the highways would also be able to accommodate satisfactorily the anticipated 1975 traffic volumes.

On an average weekday in 1952, 1,754,000 vehicle trips were made in the county. It is estimated that if the freeway system "C," together with the proposed rail rapid transit system, were completed and in operation in 1952, 730,000 of those trips would have been made via the freeway system, 980,000 would have been made entirely on surface streets, and the passengers who were transported in the remaining 44,000 vehicle trips would have traveled by rapid transit rather than by automobile. It is anticipated that by 1975 the automobile trip potential will increase to about 3,140,000 trips per day. With the freeway system and the rapid transit system in operation, in that year the distribution of that potential would be 1,185,000 trips on the freeway system, 1,880,000 trips on surface streets, and 75,000 trips converted to rides on the rapid transit.

With both the freeway system and the proposed rapid transit system in operation in 1952, almost 6,000,000 vehicle miles would have been traveled daily on the freeway system. The diversions to the freeway system and to the rapid transit system would have reduced the travel on the surface streets by approximately 45 percent.

By 1975 there would be about 9,000,000 vehicle miles traveled daily on the freeway system. Although at that time the mileage traveled on the surface streets would be slightly greater than the mileage traveled on those streets in 1952, the increased travel would be made in outlying areas where additional surface street capacity would be available. The surface streets in the north central area of the county would be required to carry approximately 15 percent less traffic than they carried in 1952.

The total cost for freeway system C, exclusive of the cost of the 17 miles now completed, would amount to approximately $508,000,000, or about $5,000,000 per mile.

If the freeway system were complete, for the entire period 1952-1975, the average cost of the system per vehicle mile of travel on it would be about 0.8 cents.

The Selection of Priorities

The selection of priorities for the construction of the various portions of the recommended freeway system must be such that the interim stages will provide reasonable solutions for the traffic problems during those stages. As far as possible, each segment completed should be a usable entity. The termini of successive improvements should be so located as to avoid the creation of new conditions of congestion. The order of priorities was based on the following:

1. The relief which it would provide for existing conditions of traffic congestion.
2. The service which it would render, as measured by the construction cost per mile of travel.
3. The sequence required for integration of the entire program.

In most instances these criteria lead to clear cut decisions. In a few instances, however, the relative merits of two or more components are about equal and rearrangements of their respective priorities would also be feasible.

Principal Surface Arterial Highways

The construction of highways to freeway standards can be justified only in locations where the traffic volumes are very large. A network of principal arterial streets at grade is needed to supplement the freeways. This network would provide major feeder routes to the freeway system and would accommodate the through traffic in locations where the volume of that traffic does not justify freeway construction. The network of principal surface arterial highways should be adequate to take care of the important through traffic volumes not accommodated by the freeway network, but should not include the streets where the traffic service requirements are essentially of a local character (Figure 16).

Annual Cost of Freeway System

The average annual cost for the entire recommended freeway system, estimated on the basis of right-of-way purchase costs amortized over a period of 20 years, and an interest rate of 3 percent, would be about $28,000,000. Maintenance costs were omitted as corresponding costs would be incurred in repairing the damages to surface streets which would be caused by the excessive traffic loads if the freeways are not built.

Over-All Justification

The average annual cost of vehicle ownership and operation in the county, excluding state and federal gasoline taxes and registration fees, is estimated at about $560,000,000 over the next 20 years. In addition, an average of $47,000,000 will be collected annually in the county for state and federal gasoline taxes and registration fees. The estimated average annual benefits of the program over the next 20 years would amount to $41,000,000 in savings of out-of-pocket expenses and $73,000,000 in the value of time and convenience.

Thus, the annual cost for the construction of the entire freeway system is only 68 percent of the annual savings in out-of-pocket expenses of road users; 60 percent of the annual state and federal gasoline taxes and registration fees; and only 5 percent of the gross annual costs, exclusive of taxes, for vehicle ownership and operation in Cuyahoga County.

The freeway program most certainly appears to be a good investment.

THE NATIONAL ACADEMY OF SCIENCES—NATIONAL RESEARCH COUNCIL is a private, nonprofit organization of scientists, dedicated to the furtherance of science and to its use for the general welfare. The ACADEMY itself was established in 1863 under a congressional charter signed by President Lincoln. Empowered to provide for all activities appropriate to academies of science, it was also required by its charter to act as an adviser to the federal government in scientific matters. This provision accounts for the close ties that have always existed between the ACADEMY and the government, although the ACADEMY is not a governmental agency.

The NATIONAL RESEARCH COUNCIL was established by the ACADEMY in 1916, at the request of President Wilson, to enable scientists generally to associate their efforts with those of the limited membership of the ACADEMY in service to the nation, to society, and to science at home and abroad. Members of the NATIONAL RESEARCH COUNCIL receive their appointments from the president of the ACADEMY. They include representatives nominated by the major scientific and technical societies, representatives of the federal government, and a number of members at large. In addition, several thousand scientists and engineers take part in the activities of the research council through membership on its various boards and committees.

Receiving funds from both public and private sources, by contribution, grant, or contract, the ACADEMY and its RESEARCH COUNCIL thus work to stimulate research and its applications, to survey the broad possibilities of science, to promote effective utilization of the scientific and technical resources of the country, to serve the government, and to further the general interests of science.

The HIGHWAY RESEARCH BOARD was organized November 11, 1920, as an agency of the Division of Engineering and Industrial Research, one of the eight functional divisions of the NATIONAL RESEARCH COUNCIL. The BOARD is a cooperative organization of the highway technologists of America operating under the auspices of the ACADEMY–COUNCIL and with the support of the several highway departments, the Bureau of Public Roads, and many other organizations interested in the development of highway transportation. The purposes of the BOARD are to encourage research and to provide a national clearinghouse and correlation service for research activities and information on highway administration and technology.