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

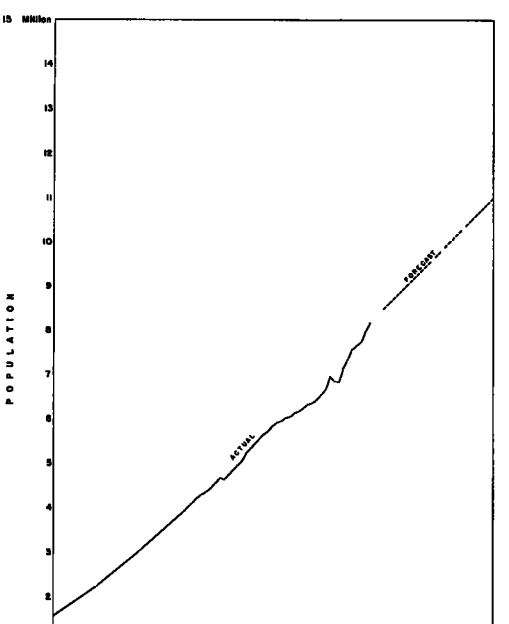


Figure 1. Population forecast for Texas.

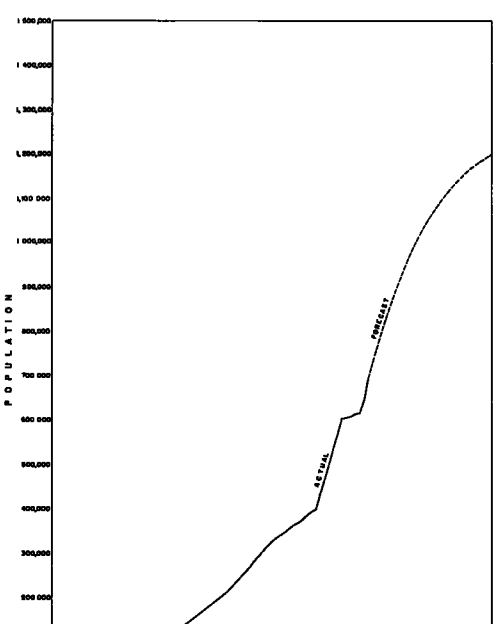


Figure 2. Population forecast for Dallas County.

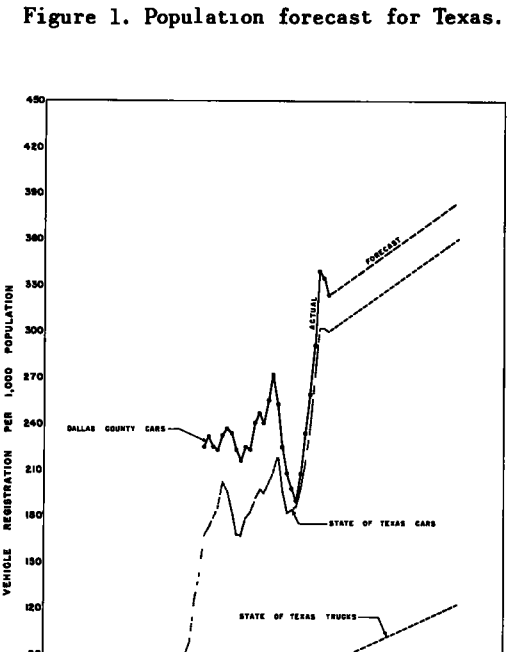


Figure 3. Trend of passenger vehicle and truck registration per 1,000 population.

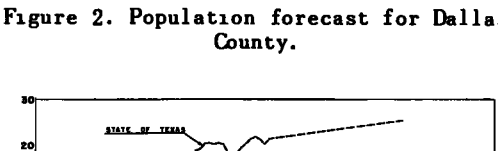


Figure 4. Percentage of trucks per 1,000 population to total vehicles per 1,000 population.

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.

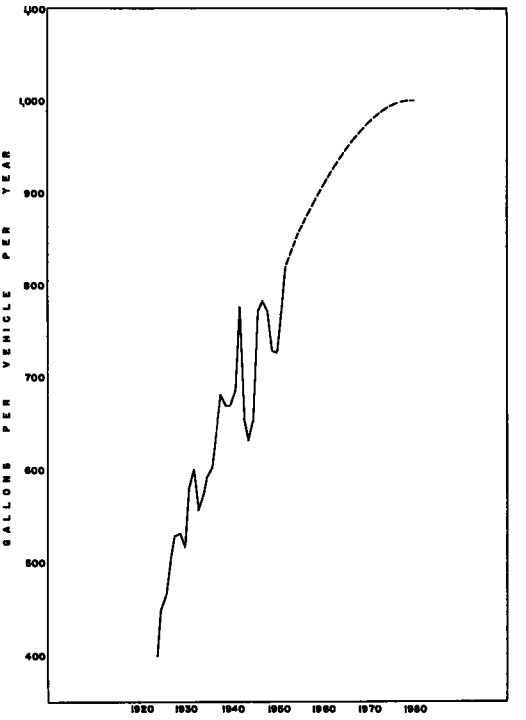


Figure 5. Trend of gasoline consumption - gallons per vehicle per year.

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,

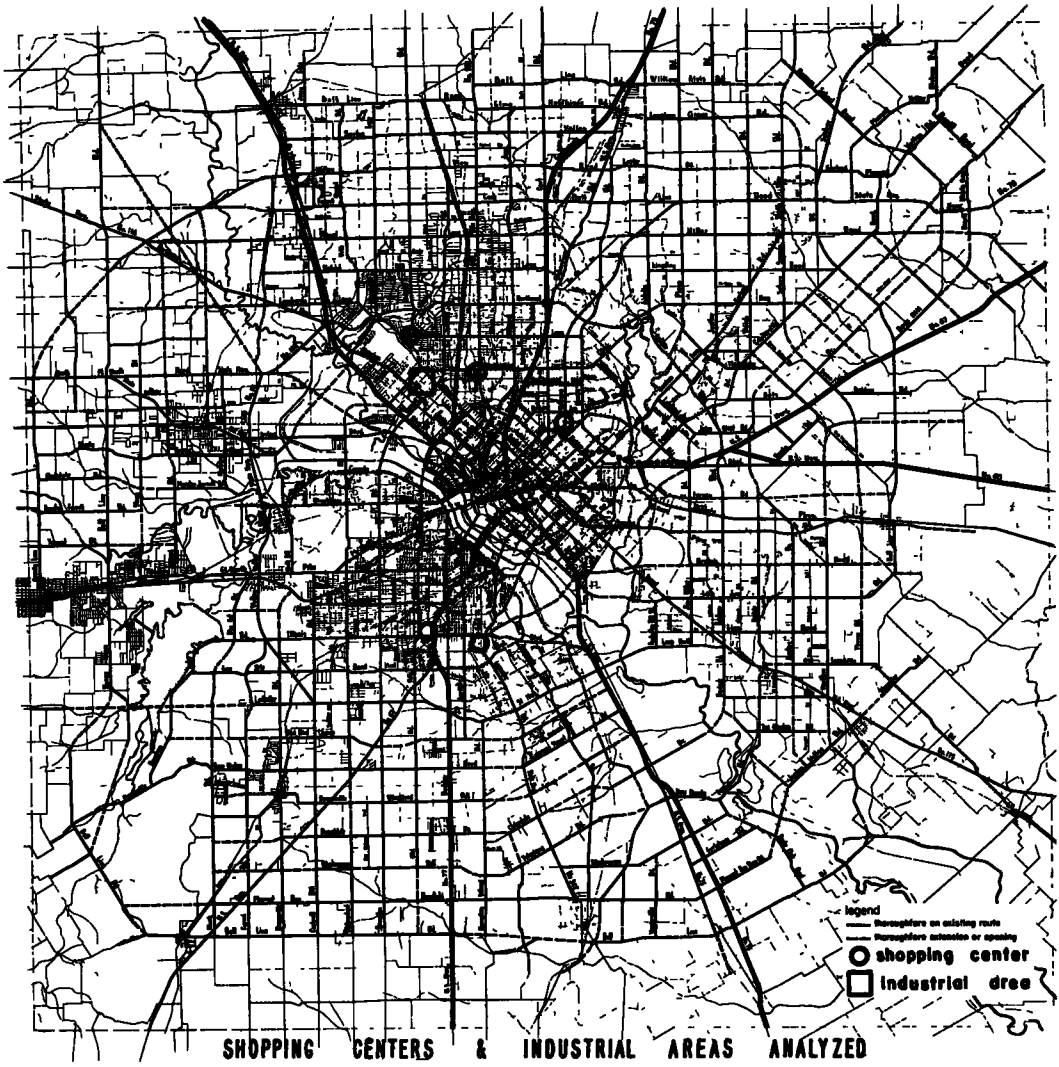


Figure 6. A preliminary major thoroughfare plan.

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 $\frac{1}{3}$-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 $\frac{1}{3}$-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.

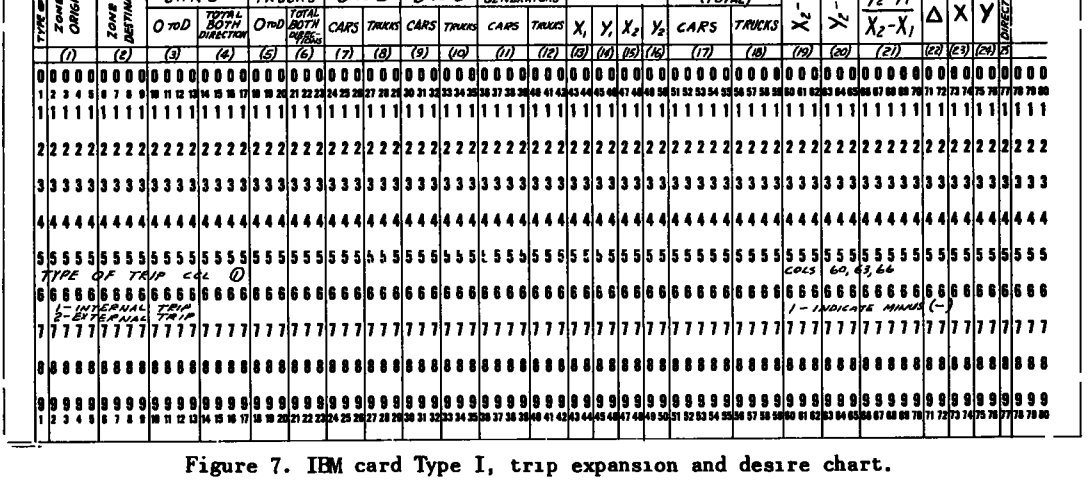
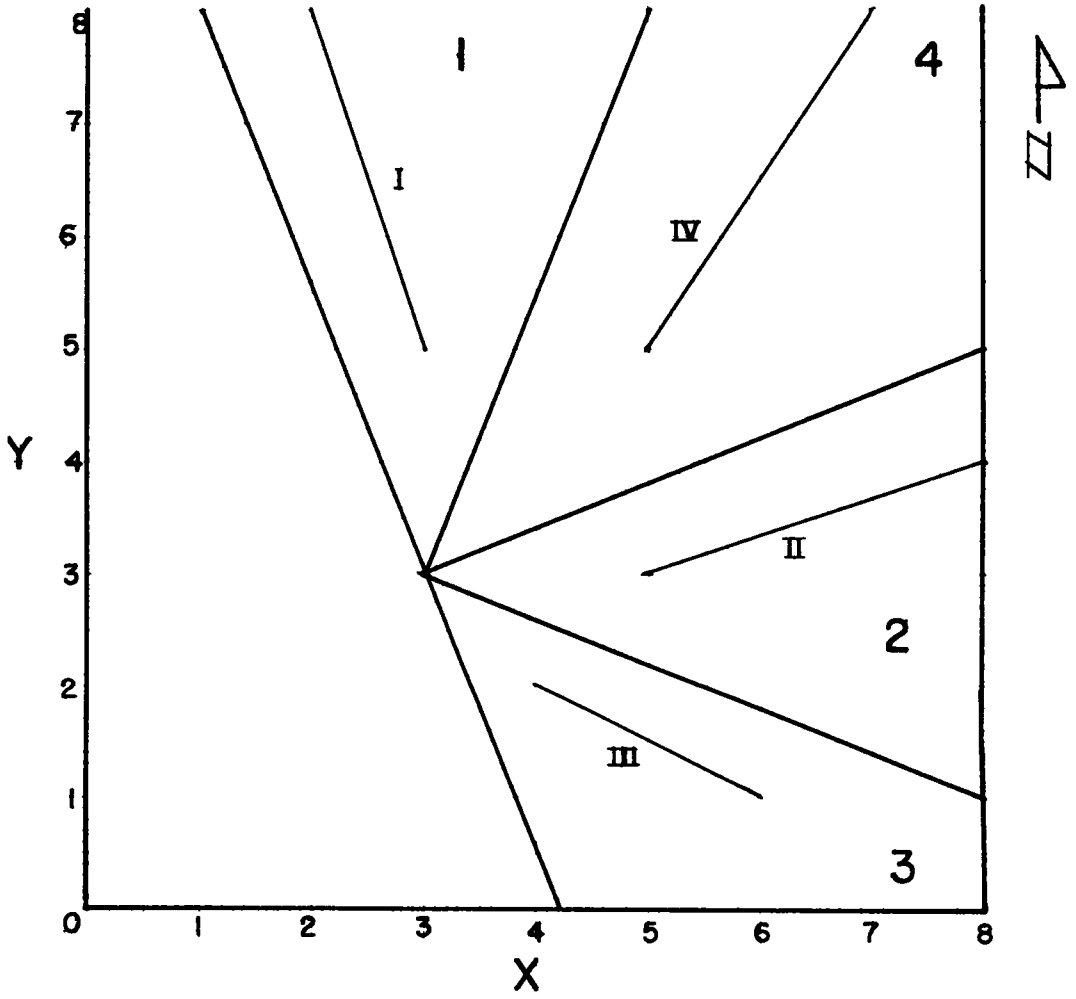


Figure 7. IBM card Type I, trip expansion and desire chart.



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

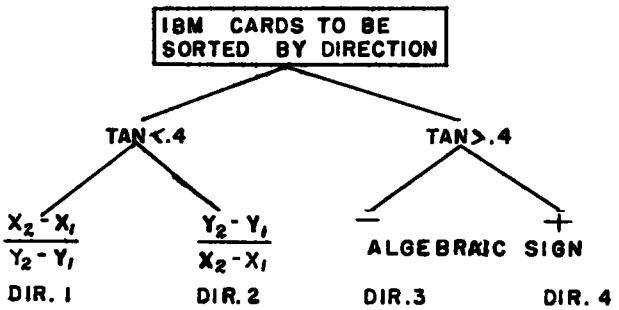


Figure 8. Directional movements.

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

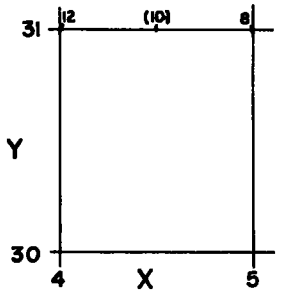
X	Y	Vehicles
4.0	31.0	10
4.0	31.0	2
5.0	31.0	2
5.0	31.0	6

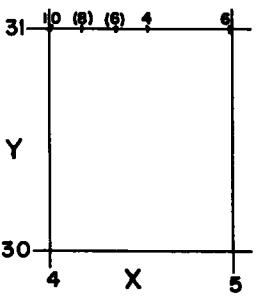
B

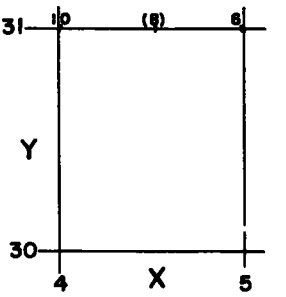
Solutions rounded to the nearest half-increment value of X

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.

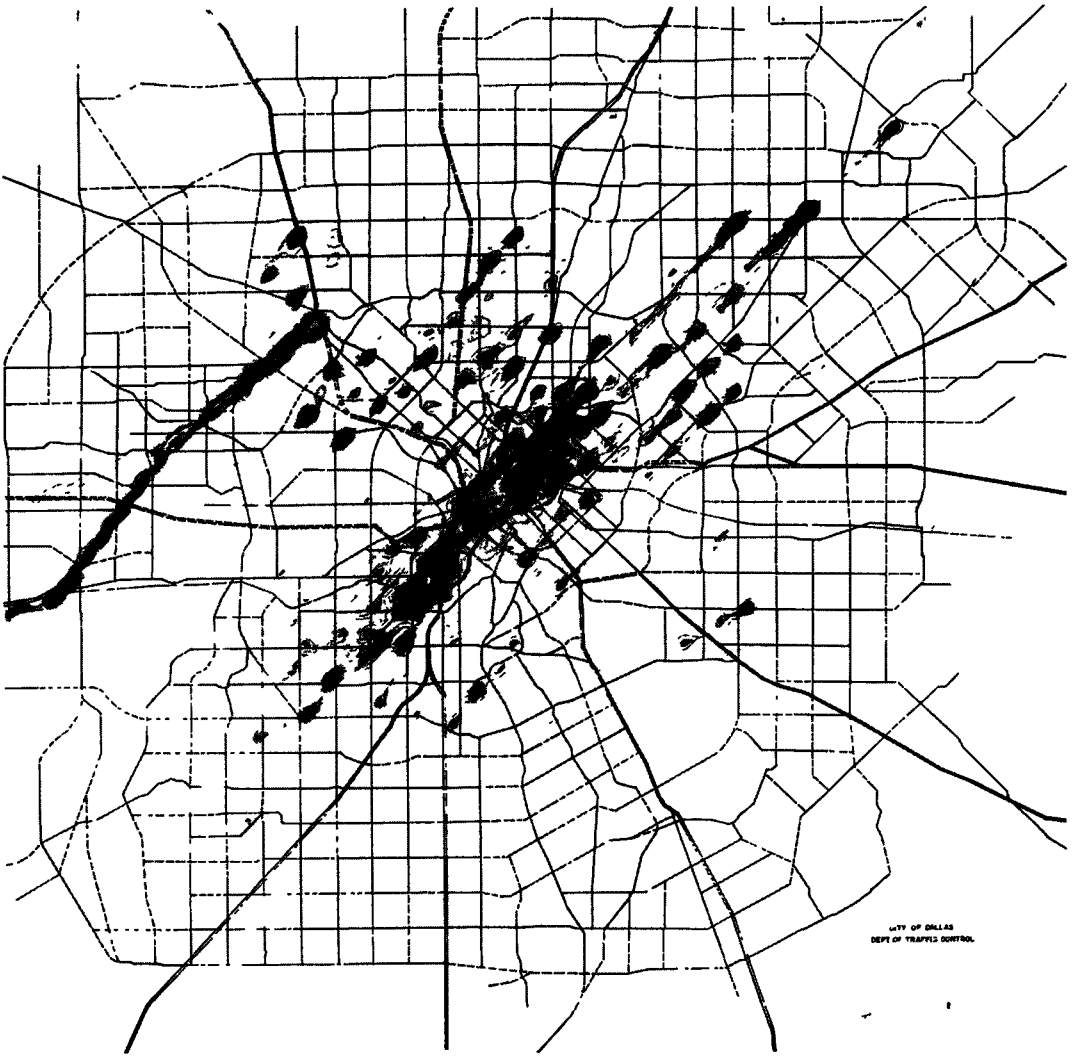


Figure 10. Directional contour map showing 1980 traffic desire - northeast-southwest direction.

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.

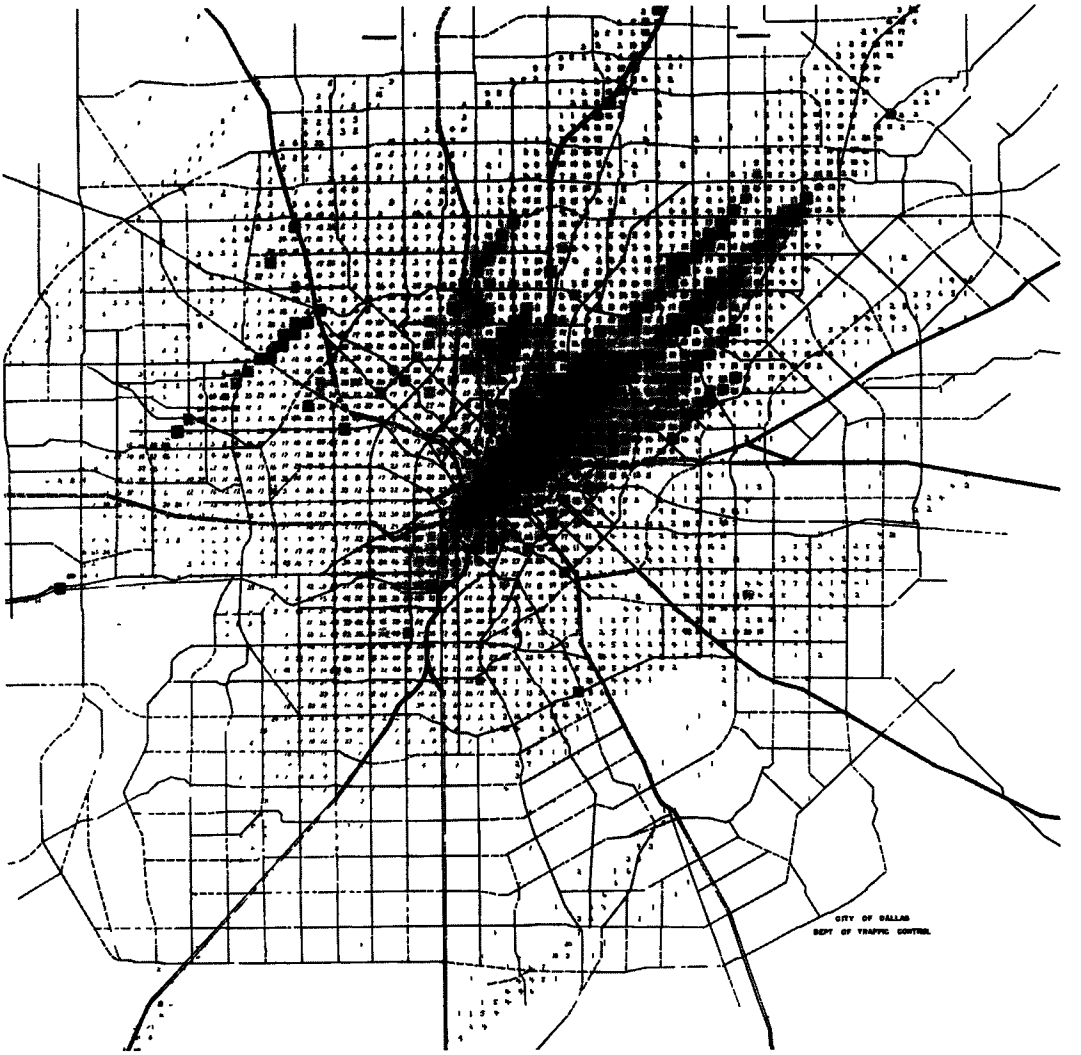


Figure 11. Block type directional contour map showing 1980 traffic desire - northeast-southwest direction.

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.