Interpretation of Desire Line Charts Made on a Cartographatron

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This paper discusses the development of an electronic plotting device and a somewhat different method of summarizing trip desire lines. It evaluates the utility of the desire line. It also evaluates the particular output of this machine, using examples from the Chicago area.

●OF ALL the items recorded in origin-destination (O-D) surveys, the most crucial is, as the name suggests, the address of trip origin and destination. These surveys are designed and carried out principally as a means of insuring that new facilities be located and designed to serve traffic demand. This demand must be fixed geographically in order to achieve this purpose. The origin and destination points provide the two fixed points of demand with service required in between.

Nearly all O-D surveys plot out "desire lines." These are straight lines connecting origin points with destinations. But plotting a line for each journey would be so difficult that different forms of summarization have been developed to present these facts. Basically, this summarization has two aspects—first, summarizing the detailed addresses of origin and destination into area groups and second, grouping the lines themselves.

The first involves establishment of geographic units such as zones, districts, tracts, blocks, etc. The form of this summary imposes problems of detail and also of presentation.

The second form of summary involves grouping desire lines in a particular way. This has generally involved collecting lines into summary bands as volumes increase and lines are closer together. Of course, there are the problems of vehicle vs person trips—separate displays for transit and auto drivers, etc., which increase the problems of more complex detail versus desired simplification.

All of these summarizations have been developed to bring the myriad of detail into some more digestible form—to simplify the picture. But with simplification, one runs the risk of distortion so that extremes are to be avoided. The method found most suitable for the Chicago study involved the use of grid coordinates and the development of desire line density charts.

GRID AND DESIRE LINE DENSITY CHARTS

The grid coordinate method of coding trip origins and destinations and the method for tracing and accumulating all desire lines across the grid was first developed by the California Highway Department (1). This method permitted the use of a large number of small zones (grid squares) and the presentation of desire lines in the form of a density map. The Detroit Metropolitan Area Traffic Study adopted this method and extended it by segregating desire lines by direction and by preparing maps (Fig. 1) on tabulating equipment (2). The machine processing and mapping of trip data was a major step forward.

However, the size of the survey area, the number of trips involved, and the degree of detail required, place limits on the use of this method. Further, the amount of data to be handled is limited by the number of columns in the punched card. The Detroit survey area enclosed some 709 sq mi which were divided into about 2,900 one-quarter square-mile grid units. Over this grid system the trips were traced and accumulated.

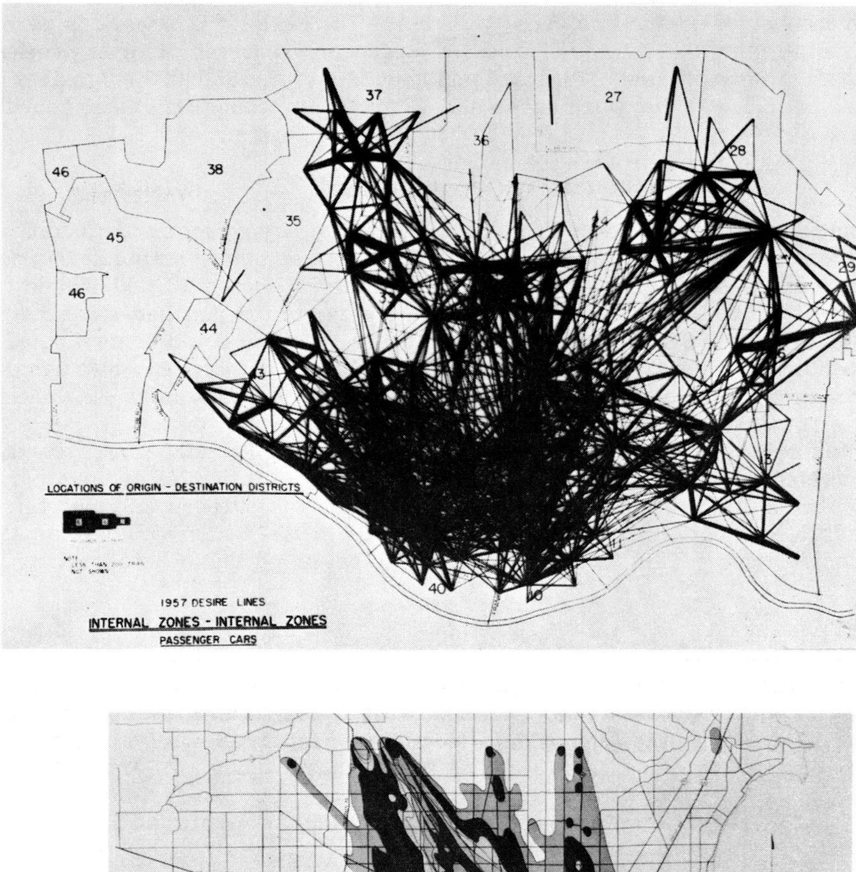

Figure 1. Trip desire line chart and trip desire line density chart (upper—desire line chart from the St. Louis Metropolitan Area Transportation Study, 1959; lower—desire line density chart from the Detroit Metropolitan Area Traffic Study, Vol. I, 1955).

The resultant summary cards, one for each grid square, permitted the selective printing of a large number of desire line density charts. The scale of this work is perhaps best shown by examining the volume of punched-card work required prior to preparation of the coordinate summary card. To trace and accumulate the 250,000 original trip cards required over 1,500,000 work cards and 10 weeks to produce the final coordinate summary cards.

THE CARTOGRAPHATRON

At the outset of the Chicago Area Transportation Study, to overcome the problem of size, several attempts were made to design a computer method for mapping trip desire lines. The size of the study area, 1,236 sq mi, and the estimated 10,000,000 daily trips (or nearly 370,000 individual records) made the use of the punched-card method extremely cumbersome. Similarly, while a computer program could be developed, it appeared to be far too expensive—both in time and dollars. It was clear that use of the computer for summarizing desire lines would have tied up this expensive machine for long periods of time when it could be used for more urgent work.

As a possible solution, personnel of the Armour Research Foundation proposed that trips be traced electronically and displayed on a cathode-ray tube. After considerable exploratory work on this and other proposals, a contract was entered into with the Armour Research Foundation to design and construct a device which would automatically display trip desire lines. This came, eventually, to be called the "Cartographatron" (Fig. 2).

Operation of the Cartographatron

The Cartographatron is an electronic analog device which can display a dot or line of required density and location on the face of a cathode-ray tube. The input is on magnetic tape, prepared on the Burroughs ElectroData "Datatron 205," and the output is a 4- x 5-in. photographic negative (3). The block diagram (Fig. 3), shows the major

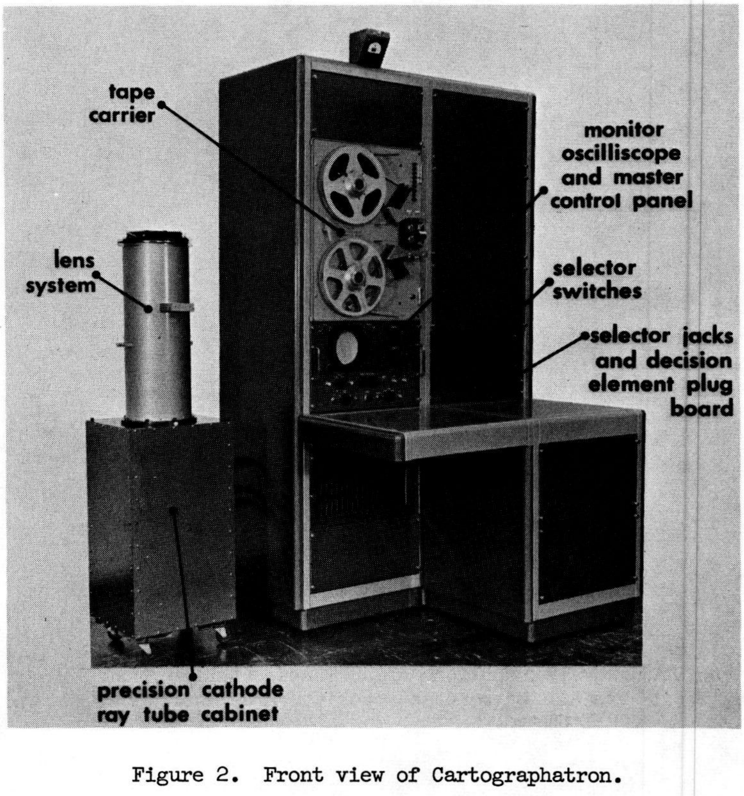

Figure 2. Front view of Cartographatron.

steps in the operation of the Cartographatron. The magnetic input tape contains the coordinate values of the origin of the trip, direction of the trip, the speed and distance of the trace, plus trip characteristic data. Speed in this sense is related to the expansion factor of the trip being displayed. If the trip has a high expansion factor, then the speed will be slow to permit a greater amount of light to be transmitted to the photographic negative. Distance is airline distance between origin and destination. As this information is being read from the tape, a dot of light appears on the face of the cathode-ray tube and moves across the tube to the destination of the trip. The light displayed is recorded on a 4- x 5-in. photographic negative. Because the shutter of the camera is fixed in an open position, all traces are added to the same negative. In this way the photographic plate works as a "memory" or summarizing device. The resulting density at any point on the negative is in proportion to the number and speed (factored trip weight) of traces which passed over that point.

In operation, the Cartographatron reads and displays trip records at approximately the rate of 48 per second. A record constitutes one trace or one unexpanded trip. Allowing time for the changing of tapes, it is possible to display the entire trip file (369, 194 records on 21 reels) for the Chicago area in approximately 3½ hr. Simply sorting this volume of cards on one column could be done at the rate of 600-1, 000 cards per minute. By comparison, the Cartographatron is 3 to 5 times as fast and displays the data besides.

One significant economy lies in the conversion of numeric output to maps. The methods used in all previous studies have required numerous hours of map preparation, posting, drafting and coloring. The Cartographatron accomplished all of this photographically thus eliminating many man hours of work.

Selective Displays of Travel Data

In addition to speed, the ability to select trip characteristics must be considered as a major feature of the Cartographatron. Actually, desire line maps are wanted by analysts in highly selective forms. The ability to select over 4, 000, 000 displays from the Chicago data must be counted as a useful feature. Table 1 gives the trip information identified for the purpose of selection by the Chicago study.

For this information on trip characteristics, a maximum of 22 digits may be coded onto tape for selection. Also, no more than three digits may be used at any one time in selecting a particular display. An example of how this selection works may be shown by assuming that only the desire lines of all internal person trips shopping at department

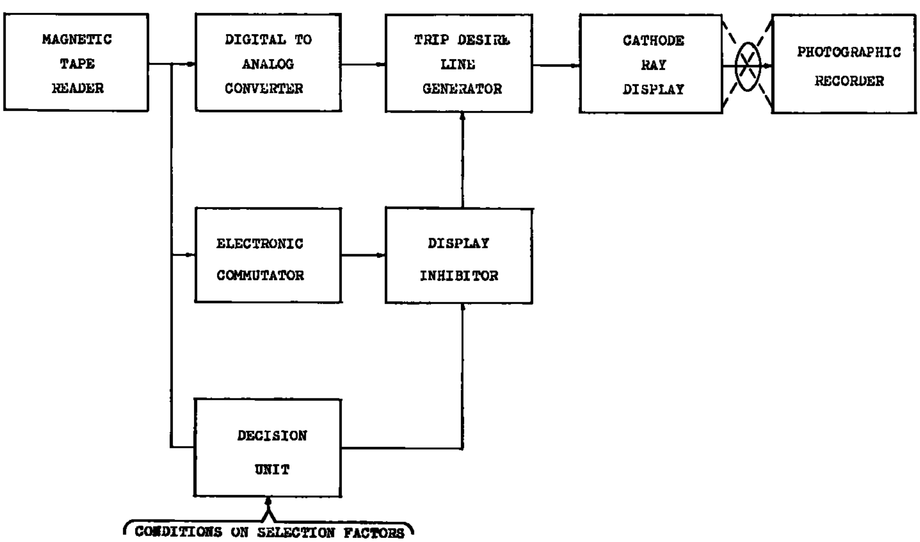

Figure 3. Cartographatron block diagram.

TABLE 1

	Internal (Home Interview) 248,063 Records		External (Roadside Interview) 72,754 Records		Suburban Railroad (External) 5,028 Records		Truck and Taxi 40,751 Truck Records 2,598 Taxi Records
1	Priority mode	1	Station number	1		1	Vehicle type
2	Age	2		2	Departure time O	2	Direction of principal route
3	Occupation	3	Hour period	3		3	Business and industry
4	Industry	4		4	Blocks to station	4	
5	Direction	5	Direction	5		5	Direction
6		6		6		6	
7	Land use O	7	Ring O	7	Total trip time	7	Land use O
8		8	Sector O	8		8	
9	Land use D	9	Ring D	9		9	Land use D
10		10	Sector D	10	Arrival time final D	10	
11	Ring D	11	Airline distance	11		11	Ring D
12	Sector D	12		12	Blocks from station	12	Sector D
13	Mode	13	Vehicle type	13		13	Day of week
14	Parking type	14	Trip purpose (trucks)	14	Miles on railroad	14	Screenline crossing (total)
15	Trip purpose - from	15	Garage code	15		15	Trip purpose - from
16	Trip purpose - to	16	Trip purpose	16	Mode - to station	16	Trip purpose - to
17	Time of arrival	17	D North or south of screenline	17	Trip purpose	17	Time of arrival
18		18	D in or out of study area	18	Auto owner	18	
19	Elapsed time	19	Thru trips	19		19	Elapsed time
20		20	Land use D	20	Airline distance	20	
21	Airline distance	21		21		21	Airline distance
22		22	Station code 1-26 or 30-56			22	

stores are wanted. To select shopping trips only, the main selector number 16 (trip purpose to) is plugged in and button number 3 (code for shopping) is depressed. At the same time selectors number 9 and 10 (land-use destination) are plugged in and buttons 5 and 2 (department stores) are depressed. The display may now be run. The Cartographatron will read all records on the tape, but will display only those meeting the selection requirements. Concurrently with the run, the machine keeps a full count of all records inspected and also a count of those actually displayed.

Other Applications

There is, in addition to the line generation feature, the possibility of point generation or dot maps. As of this time, the only dot mapping done by the Chicago Area Transportation Study has consisted of displaying the origin dot of trip records. The same characteristics as those described for line generation are used. There is, however, the possibility of transferring the land-use survey data, the population data and, perhaps, also street capacity data to magnetic tape and displaying density maps. Another possible application, yet untried, is to prepare scattergrams and correlations on magnetic tape and display them on the Cartographatron. Still a further application which has had limited use by the Chicago study is to use the equipment as a card counting device. While the count is that of unfactored trip records, the speed in which at least a preliminary count could be made of special selections is considerably greater than that of punched card work. The Cartographatron has two counters; one shows the number of records inspected and the other the number displayed.

Application of this equipment to other transportation studies and O-D surveys is limited only in that input requirements be met. The Cartographatron is designed to operate on any geographic area for which data may be coded to a grid system. The grid system used in Chicago covers a 90- by 90-mi area. As shown in Figure 4, this area has been divided into one-quarter square miles by the one-half mile grid system.

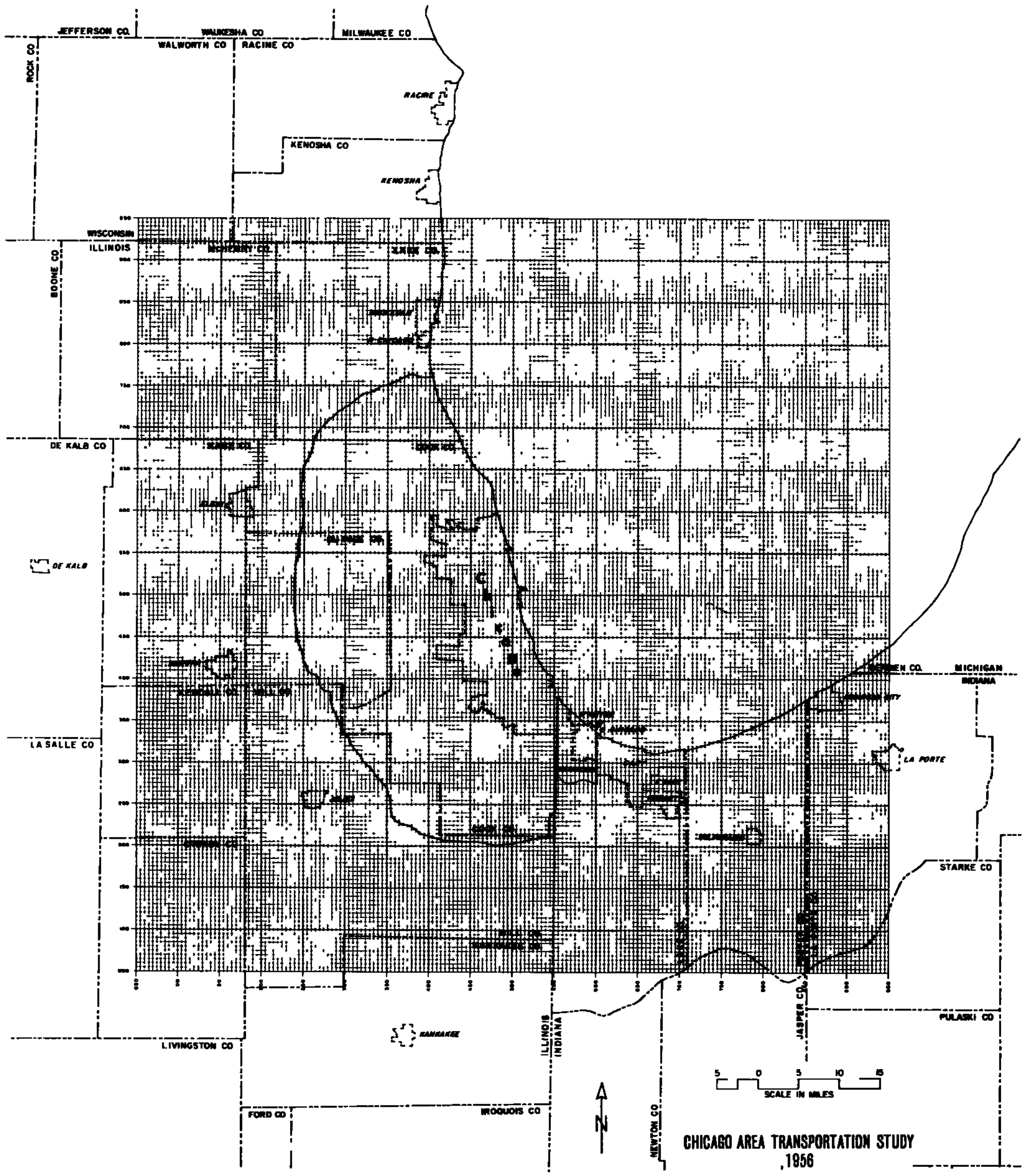

Figure 4. One-half mile grid coordinate system.

The Cartographatron will operate on detail coded to the tenth mile within this system or on a grid of 1,800 by 1,800 units. There are presently arrangements for coding and displaying Pittsburgh Area Transportation Study data on the Cartographatron. The Pittsburgh Grid System is essentially the same as used in Chicago.

Cost of Cartographatron Work

The cost of machine development and construction has been absorbed by the State of Illinois and participating agencies so that the operating cost estimates given here are merely direct out-of-pocket costs.

Cost per lane of tape (20,000 records)	$350.00

This is based on $65 for tape, $200 for machine (computer) running time, and $85 for programming and other preparatory work.

Cost of running and processing one display from one lane of tape	$ 6.00

This cost includes the operator's time, photo-lab labor and supplies, and operating overhead (the unit cost per lane drops as the number of lanes in one display increases).

Although the cost of preparing a single map would be large because of tape preparation costs, the cost of all subsequent displays is only the running cost and represents savings as more displays are required. It should be noted, also, that these costs include photographic work which might otherwise require substantial rough drafting time and be difficult, then, to reproduce.

QUANTITATIVE MEASURES

A question frequently asked by visitors is whether it is possible to measure trip density on these displays. The answer is "Yes." The key to scaling the the Cartographatron display is the addition on each display of a calibration raster. (The Cartographatron displays reproduced in this paper do not reflect the sharpness of detail or pattern discernible in the original photo-print. Limitations of available reproduction facilities have caused this difference between the original and the reproduced copy.) As shown in Figure 5, the raster now used by the Chicago study consists of an eight-by-eight block pattern. The density function of this raster may be plotted as a normal photographic density curve. In Figure 5 the "desire line" miles are known for each of the 64 units of this scale. Each unit represents an area of 6¼ sq mi, or 25 ¼-sq mi grids. The scale is programed so as to employ two variables on both the x and the y axis. These are: (1) the number of times the base display is repeated in each row and column and (2) the expansion factor for each row and column.

The Densitometer

By comparing the density of areas within the calibration raster with densities of areas within the display, it is possible to scale the display in terms of desire line miles per unit of area. The equipment employed to make these density measurements is a Densitometer. Figure 6 shows the Densitometer used by the Chicago study.

The operation is simple: a light of constant intensity is transmitted through the 4- x 5-in. display negative via a small aperture to a photoelectric cell (the probe unit). The amount of light passing through the negative is translated to voltage and is displayed in numeric terms on the meter. This meter has a maximum reading range of 450 units. The basic densitometer equipment has been modified by the addition of controls for carrying the negative over the light source and a plotting device consisting of a 4X enlargement pantograph. Areas of 0.005 in. in diameter at negative scale (approximately 1/36th of a square mile in Chicago) may be read.

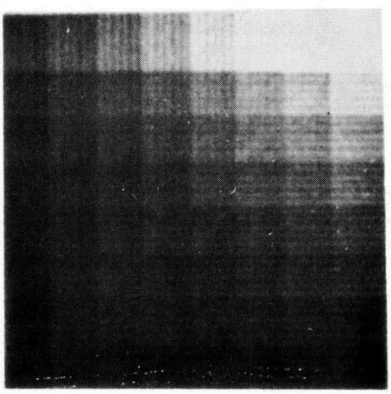

Figure 5. Calibration scale.

Whereas measurements may be made at this scale, they would ordinarily be expressed in terms of the input unit, one-quarter square mile in Chicago. The use of this equipment is limited to the development of profiles and "spot elevations." A complete description of the surface of a

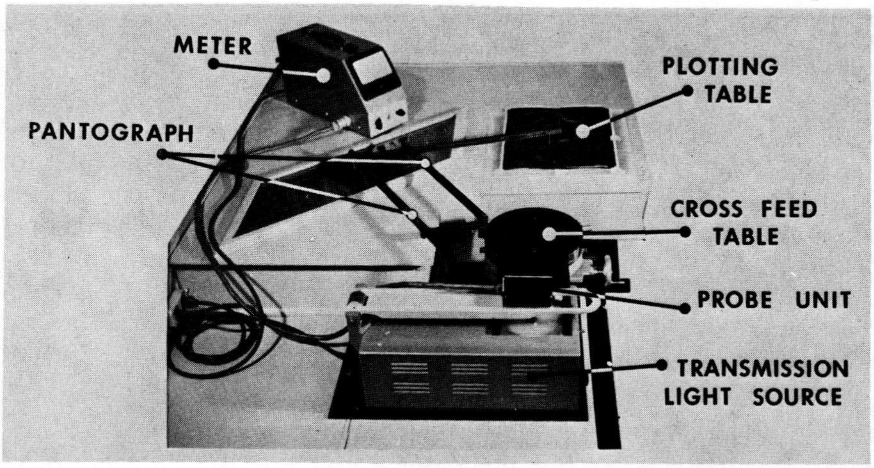

Figure 6. Densitometer unit.

display, because of the number of readings, would require the use of a recording micro-densitometer. It is possible to read the value at any point within 2 to 3 percent of the precise, true value using the equipment shown.

PATTERNS

The California and Detroit mapping of trip desire line densities has employed the use of the "isoline." This line has been compiled and drafted by hand over a printed or posted density map. Each line is compiled so as to enclose areas of similar densities and has been subject to the judgment of the compiler as to exact alignment and shape. Although the resulting maps may be considered to be an accurate picture of the density patterns, they are subject to considerable human judgment. It is doubtful that any two individuals could or would isoline a desire line density map in exactly the same fashion.

In contrast, the original compilation of isolines on the Cartographatron displays is accomplished in the photo-lab. The photographer, by varying the printing exposure, varies the density pattern on the prints (Fig. 7). The scaling of isoline depicted in this fashion is done by preparing profiles of the display on the Densitometer.

The above description of "density splitting" as a basis for isolining is intended only to show that maps similar to those produced in California and in Detroit may be prepared from Cartographatron displays. However, the value of the isoline, as such on Cartographatron displays, has been questioned by the staff of the Chicago study. Because an individual with normal vision is capable of reading up to 20 shades of grey, it has been argued that the basic patterns depicted by isolines may be observed without any cartographic aids on the display. Certainly, the principal patterns are readily apparent. Depending on the data displayed and the use intended, the addition of quantitative measures may be desirable. Such measures can be accomplished on any Cartographatron display.

USEFULNESS OF DESIRE LINE DISPLAYS

The preceding portions have described the design and workings of the Cartographatron. It is a unique machine. It summarizes great quantities of information in visual form. It is fast. It is electronic. It proceeds from coded data to virtual final presentation without clerks or draftsmen. All of this is of interest but there are many who will say, "Of what real use are desire lines? What is the advantage of this stepped-up data processing device in actual application?"

Justification clearly depends on use and usefulness of O-D survey data in supplying both increased knowledge and the increased ability to make the right decision in planning

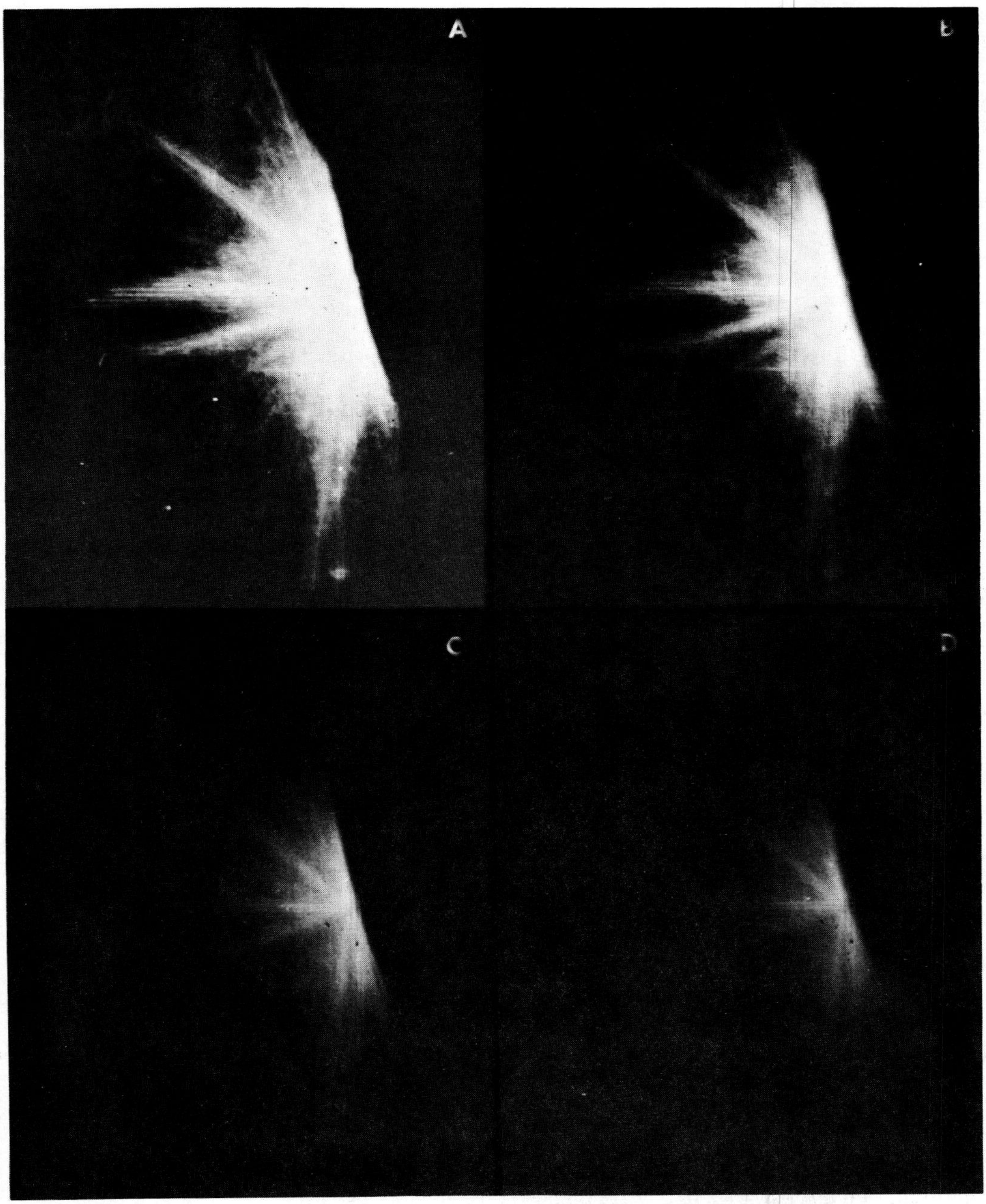

Figure 7. Density splits.

and building new transportation facilities. This matter has been puzzled over at some length in trying to measure the costs and risks of developing the equipment as against the utility of the ultimate output. It is felt that desire line summaries were critically necessary in understanding the large mass of O-D data collected.

Although one cannot exactly measure the benefits of such a machine against its development cost, two great values are apparent at this time. The first is that these desire line prints create careful and unbiased images of traffic patterns in the minds of the team of analysts and technical personnel who will have to interpret proposals. The second and less tangible benefit lies in the "sales value" of these presentations.

The first benefit of common images is by far the more significant one. Members of the study staff, as well as personnel from related agencies and decision-making officials, all have difficulty understanding large masses of data and seeing a great metropolitan region as a whole rather than a series of locations or political jurisdictions. These summary pictures create accurate, regional images of the travel data. These images being common background help to relate one person's work to another's. Both have common information. Common technical denominators produce much more effective team work and collaboration.

Obviously, these pictures, being new and carefully developed, were excellent means of communication to citizens, local groups and interested agencies. It is not simply that they were made "electronically" (which, being a "good" word, insures the respect of the layman) but rather that the impression gained of travel behavior, as the viewer has experienced it, is suddenly confirmed. He knows this is right. The data are reliable. What he has seen agrees with his observations. Once this respect for accuracy is established, communication is easier and more profitable.

To capsulize this argument, one picture is worth a thousand words. But the proof is in the result. Therefore, the remainder of the paper consists of examples.

Interpretative Examples

Figures 8-11 show four maps of the Chicago region. The first three provide data which can be obtained from secondary sources but which are easily portrayed because they are stationary. These figures also have much bearing on trip desire line patterns.

Figure 8, showing political boundaries, is simply taken from a highway road map of the region. Outlined is the cordon line marking the boundaries of the internal survey area.

Figure 9 shows the population by place of residence using isolines to identify areas of common density. This is made in the same way as a dot map but groups regions carrying similar dot densities into isolines.

Figure 10 shows the amount of floor area at each ¼-sq mi grid of the region. Floor area measurements were not made in much of the suburban area because of costs of secondary source data. However, more than 85 percent of total floor area is represented on this model. Floor area is a critical index of trip generation as can be seen by comparison with Figure 11 which shows the number of person trips beginning at each grid square on an average week day. This model will look very much like that for floor area excepting only the suburban areas where no floor area measured are shown.

All of these reflect the structure of the Chicago region and provide all the needed evidence to form a mental image of what the major desire line patterns would be. Reference to succeeding illustrations will demonstrate that the pictures are persuasive as to accuracy and that for the first time there is clarity to an otherwise vague image. The basic argument for the value of desire line displays is based on the justness of this claim.

The aggregate display of desire lines of all person trips is shown in Figure 12. This is what your mental image should have been. This is the sum of 10, 500, 000 person trips made by over 3, 000, 000 travelers on an average week day. All modes of travel are included.

In Figure 13 only the desire lines of travelers on suburban railroads or elevated and subway trains are shown. This is a unique pattern. These are travelers with very special requirements. As we would expect, they focus on the CBD. They are generally long trips. The sunburst shown here still has a sharp pattern which marks the "fingers" of land development that extend outward along commuting railroads. The desire lines are drawn only between "home" and "office" and do not necessarily have a relation to the rail line over which they traveled.

Figure 14 shows the patterns of bus riders. These are shorter journeys and are heavily concentrated in the densely built-up part of the region, primarily within the City of Chicago. There is little or no visible bus use in the outer suburban parts of

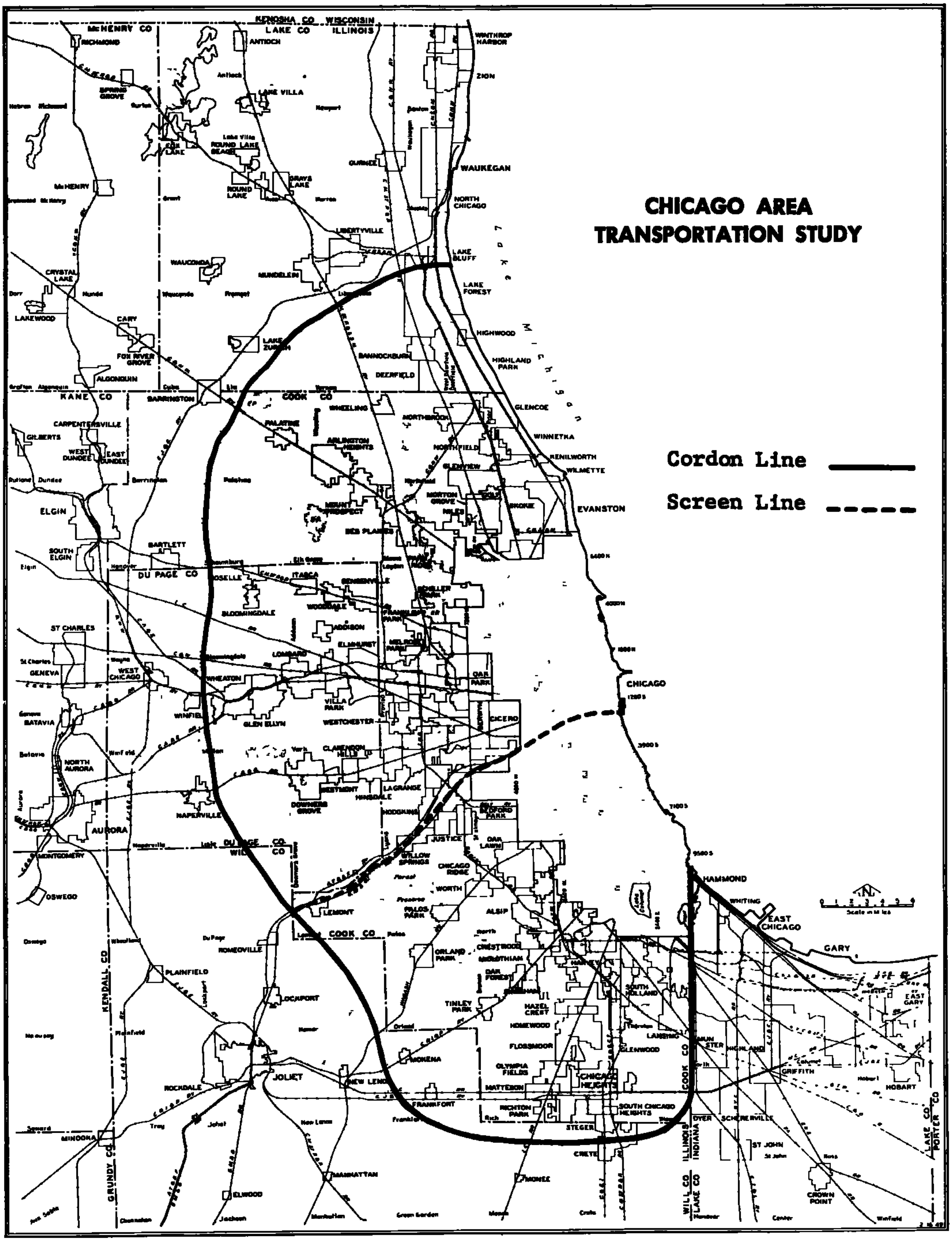

Figure 8. Study area and political boundaries.

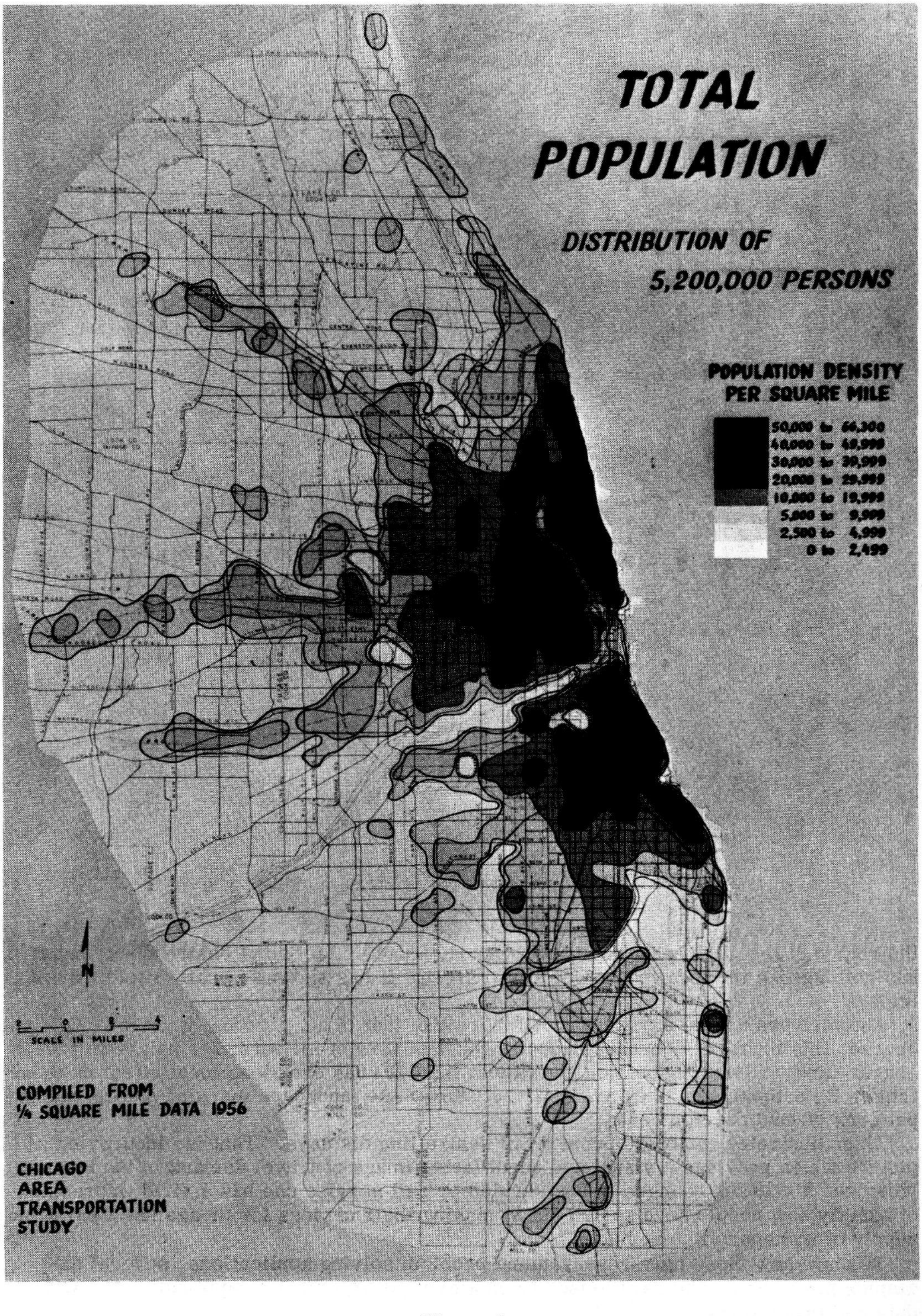
TOTAL POPULATION
DISTRIBUTION OF
5,200,000 PERSONS
POPULATION DENSITY PER SQUARE MILE
50,000 to 66,300
40,000 to 49,999
30,000 to 39,999
20,000 to 29,999
10,000 to 19,999
5,000 to 9,999
2,500 to 4,999
0 to 2,499
N
SCALE IN MILES
COMPILED FROM
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Figure 9.

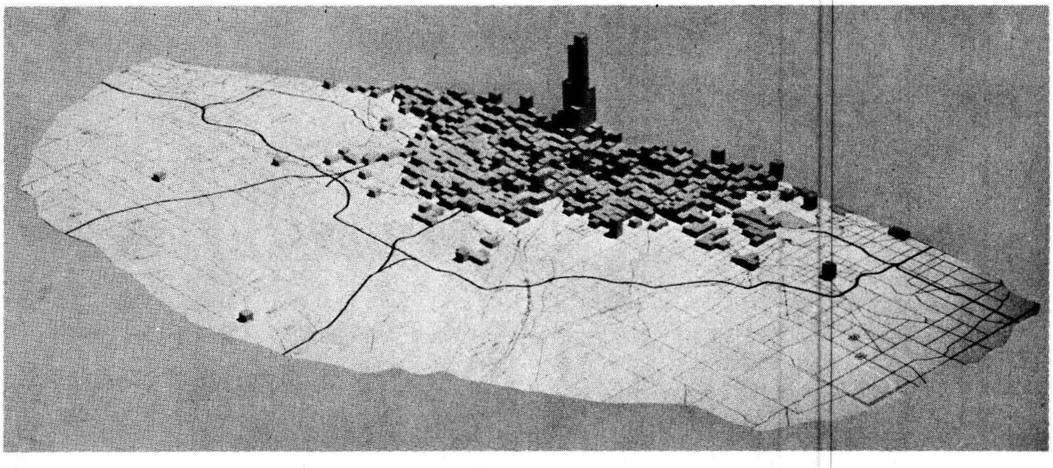

Figure 10. Model of total floor area.

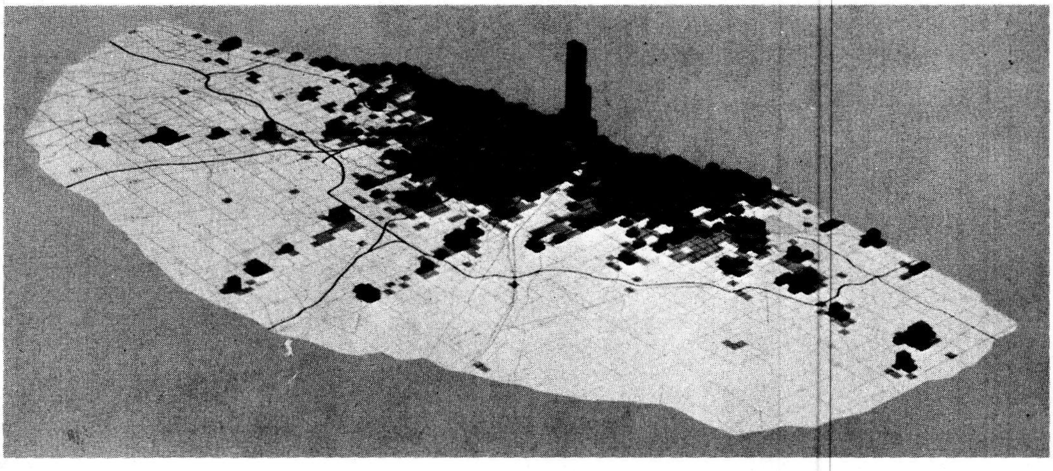

Figure 11. Model of total person trip destinations.

the region. The CBD is the focus of the most dense collection of desire lines, but it has nothing like the focal power for bus trips that it has shown for rail, rapid transit trips.

Auto drivers create a pattern much more like that of all persons (Fig. 15). Of course, this must be so because about three-quarters of all person trips are in passenger cars. Closer inspection shows that the CBD has even less focal effect on these trips. By comparison, they are distributed over the landscape marking out the major patterns of land development.

This illustrates the basic property of desire line displays. That is, identifying a picture which provides a visual and quantitative image of travel demand in the region. When one discusses changes in bus service or rail service one has a vivid impression of exactly how people have sorted out in making their choices for or against a particular supply of transportation services.

To show how these have research and problem solving applications, several examples are given. The first arises from a critical argument on applications of O-D data and predictions.

It has been argued with reason, that facilities must be planned for peak-hour requirements rather than for average daily needs. It is further argued that peak-hour travel should be forecast and that this can be accomplished by forecasting journeys to work. On the opposite side of this argument (and this side was taken) are the people who argue that peak-hour demands can be better inferred as a function of total daily travel. The Cartographatron provides a ready means to examine which is the more plausible contention.

To do this, the desire lines were displayed—first, for all auto driver trips originating in the two peak hours between 7 and 8:59 a.m. (Fig. 16). Next, for comparison, and at similar scale, are the auto driver journeys going from home to work (Fig. 17). In addition, for comparison, the auto driver journeys starting other than during the 4-hr

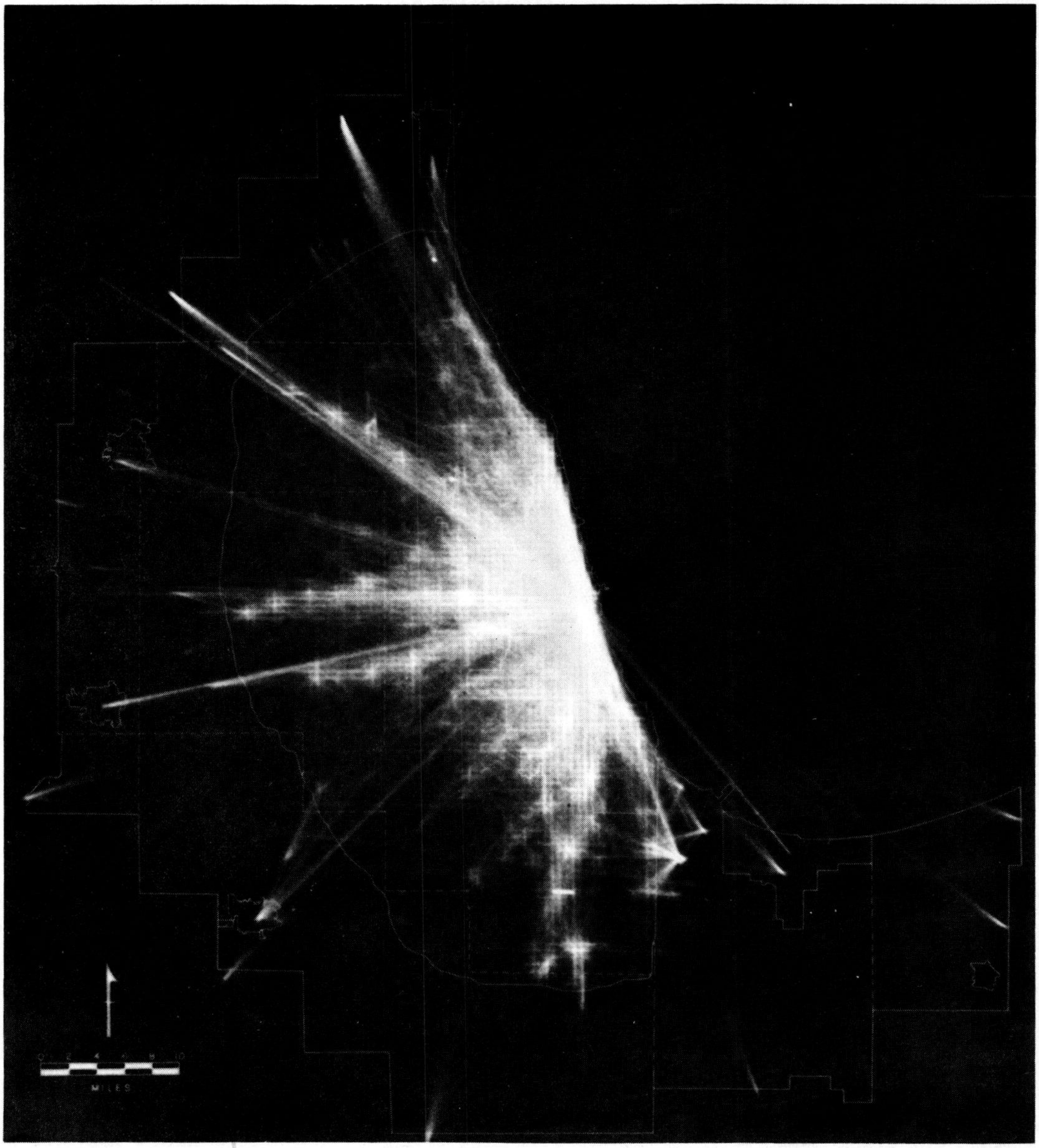

Figure 12. All person trips.

periods 7 a.m. or 8 a.m. and 5 p.m. or 6 p.m. are displayed (Fig. 18). Now the reader may judge for himself whether these are significant differences in the several patterns. Do the work trips look more like peak-hour travel than the all auto driver trips? Is the peak pattern different from the off-peak pattern? How do all of these compare with total daily travel (Fig. 19)?

For over-all patterns, the work trips are as much different from peak-hour patterns as peak-hour travel is different from total daily travel. Off-peak travel, however, seems to have quite marked differences. This answer was less pleasing than had been hoped by the author but it is possible to judge for oneself because of the properties of this machine.

Another local problem arises from the continual concern over truck needs. Some

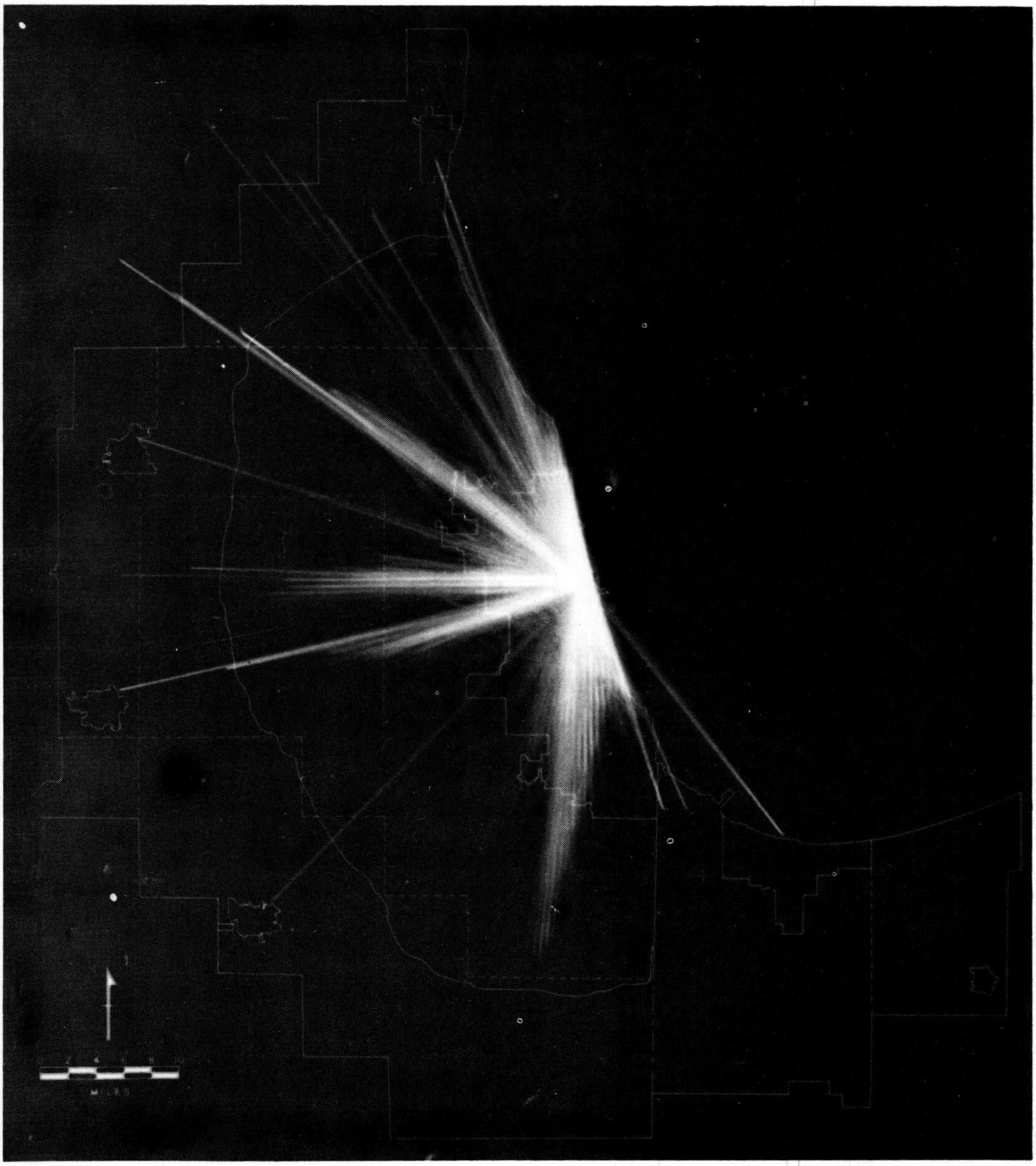

Figure 13. Rapid transit trips.

Figure 14. Bus trips.

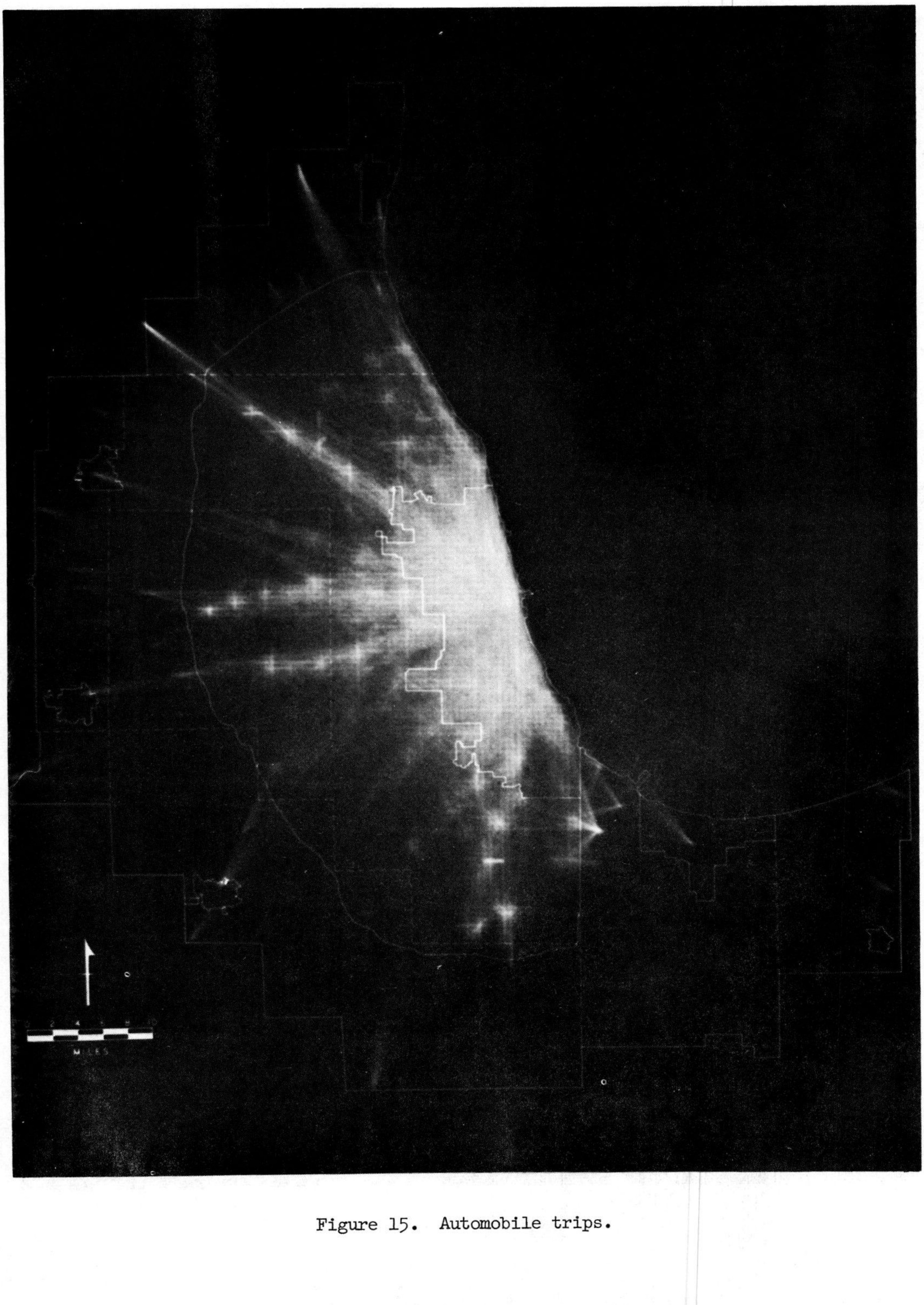

Figure 15. Automobile trips.

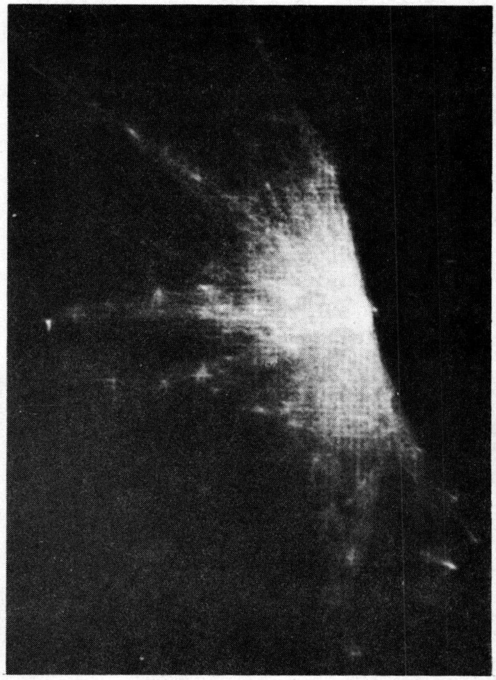

Figure 16. Peak hour automobile trips.

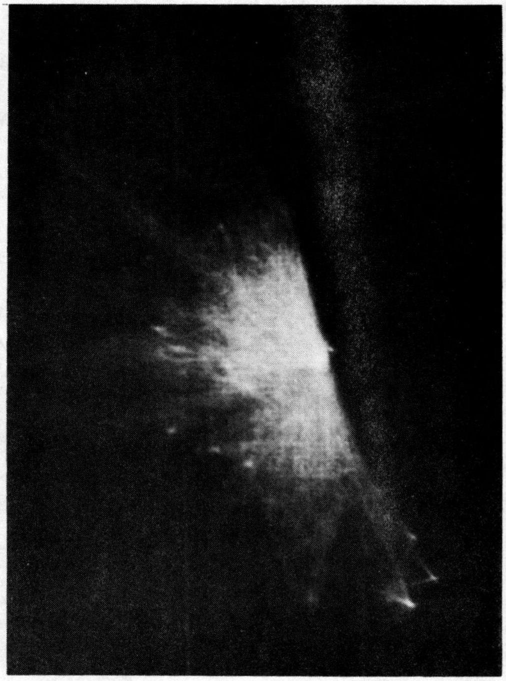

Figure 17. Automobile work trips (vehicle-miles equal to Figure 16).

Figure 18. Off-peak automobile trips (vehicle-miles equal to Figure 16).

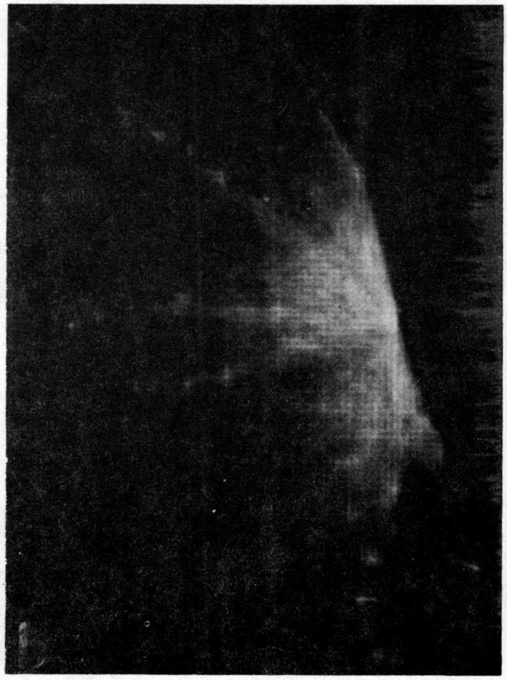

Figure 19. Automobile trips (vehicle-miles equal to Figure 16).

advise special facilities to get trucks off certain streets whereas truckers, sensitive to taxes and urban delays, are extremely concerned that planning be geared to their requirements. In Figure 20 all truck trips are displayed. Here again the picture is generally similar to that of auto drivers. This is of substantial significance because it suggests that additional studies to determine whether special facilities are needed for trucks might not be rewarding because trucks go where autos go and can therefore use the same facilities. (More than this, they do not clash during peak-hour traffic.)

One of the applications of any O-D survey is that of fixing locations for new expressways. If it is reasoned that short trips are of little significance as potential expressway users, then the vehicle trips of greater than say 10 mi of desire line length may be selected out (Fig. 21). This is one of the more difficult charts to read. Obviously, there is no great single concentration of these lines. It would be very difficult to band

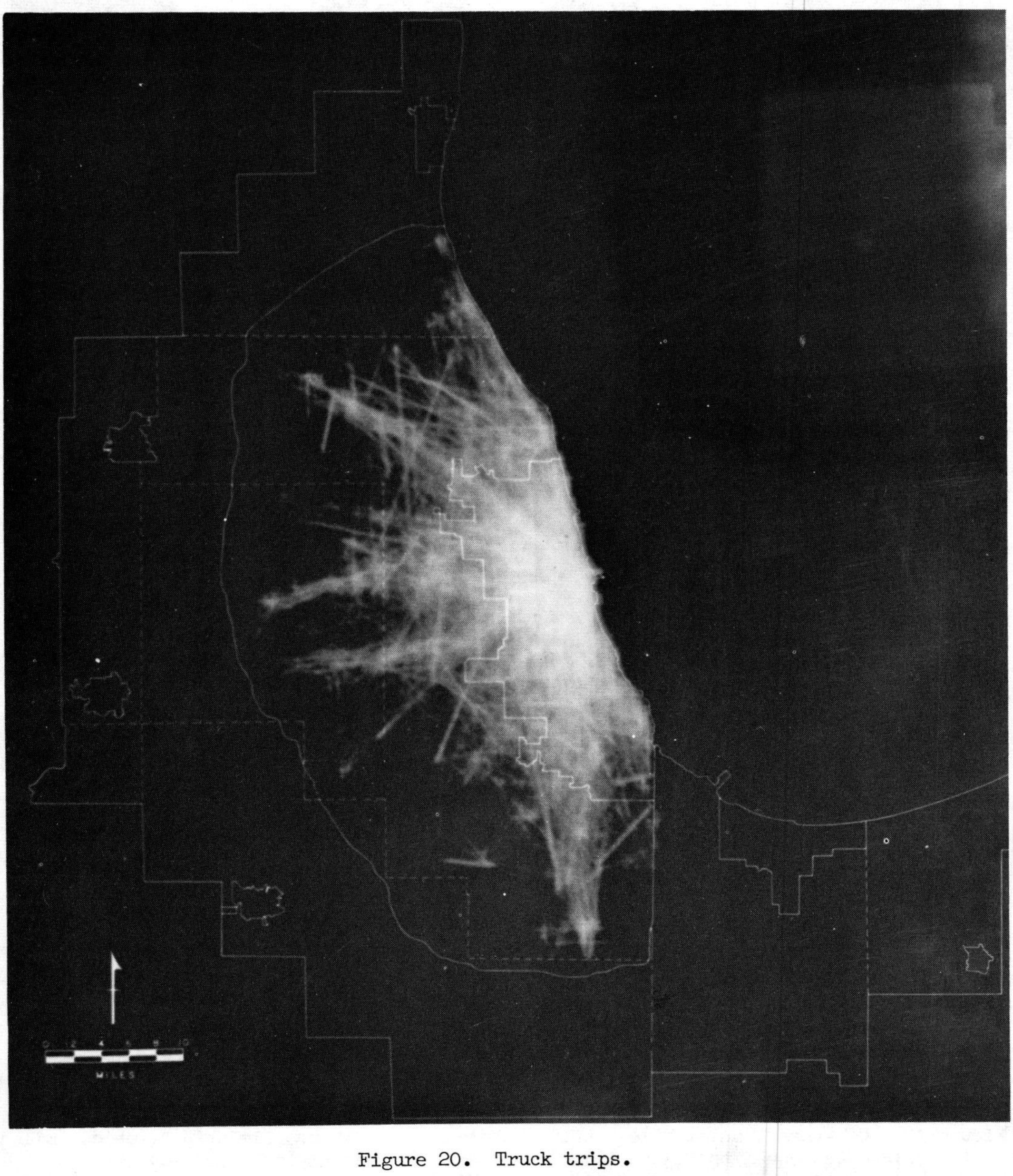

Figure 20. Truck trips.

them together into major sectoral groupings to suggest particular expressway locations.

Quite surprisingly, however, much information as to location of expressways was gleaned by plotting only the shortest trips. In Figure 22 only vehicle trip desire lines of less than 3 mi are displayed. Suddenly, little constellations of travel are isolated from one another. These journeys mark out the small community areas where travel is short. The local, internal travel of communities should move freely on collector and arterial streets. The piercing of these patterns by express highways designed to serve longer journeys may not be suitable. Thus, there is strong visual evidence of community definition as an aid in determining most suitable locations for fully controlled access routes.

One final use may round out the examples of applications which are constantly enlarging. This involves furnishing data to other public agencies—in this instance, the

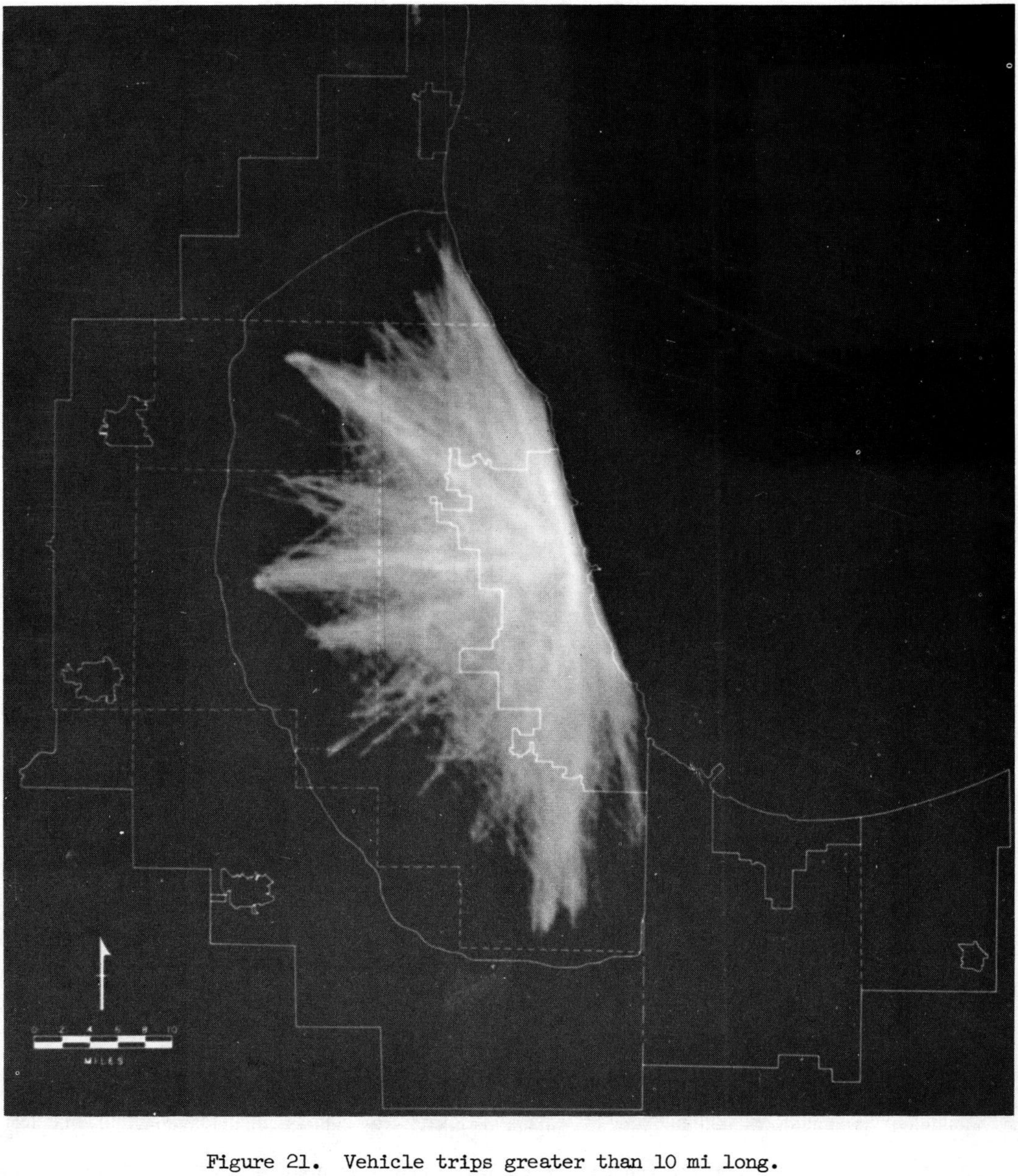

Figure 21. Vehicle trips greater than 10 mi long.

Chicago Department of City Planning. They have been working for some time on proposals for modernizing older shopping centers in the city. They have been interested in possible schemes for revising traffic facilities to improve access to these older commercial centers. To study this more closely, they requested tabulations of trips to selected locations in the city. It was easy to supply this information in a visual output.

Figure 23 shows the origin pattern of all travelers going to shop in the vicinity of 63rd and Halsted Streets. Here is an example of dot maps and also a quick and usable output.

Figure 24 shows the accumulated desire lines of these shoppers. Needless to say, this was much more immediately usable data to the planners and they have reported that the materials were of great interest to the local merchants in the area. Additional requests are now on hand. Service of this kind increases the acceptance of general

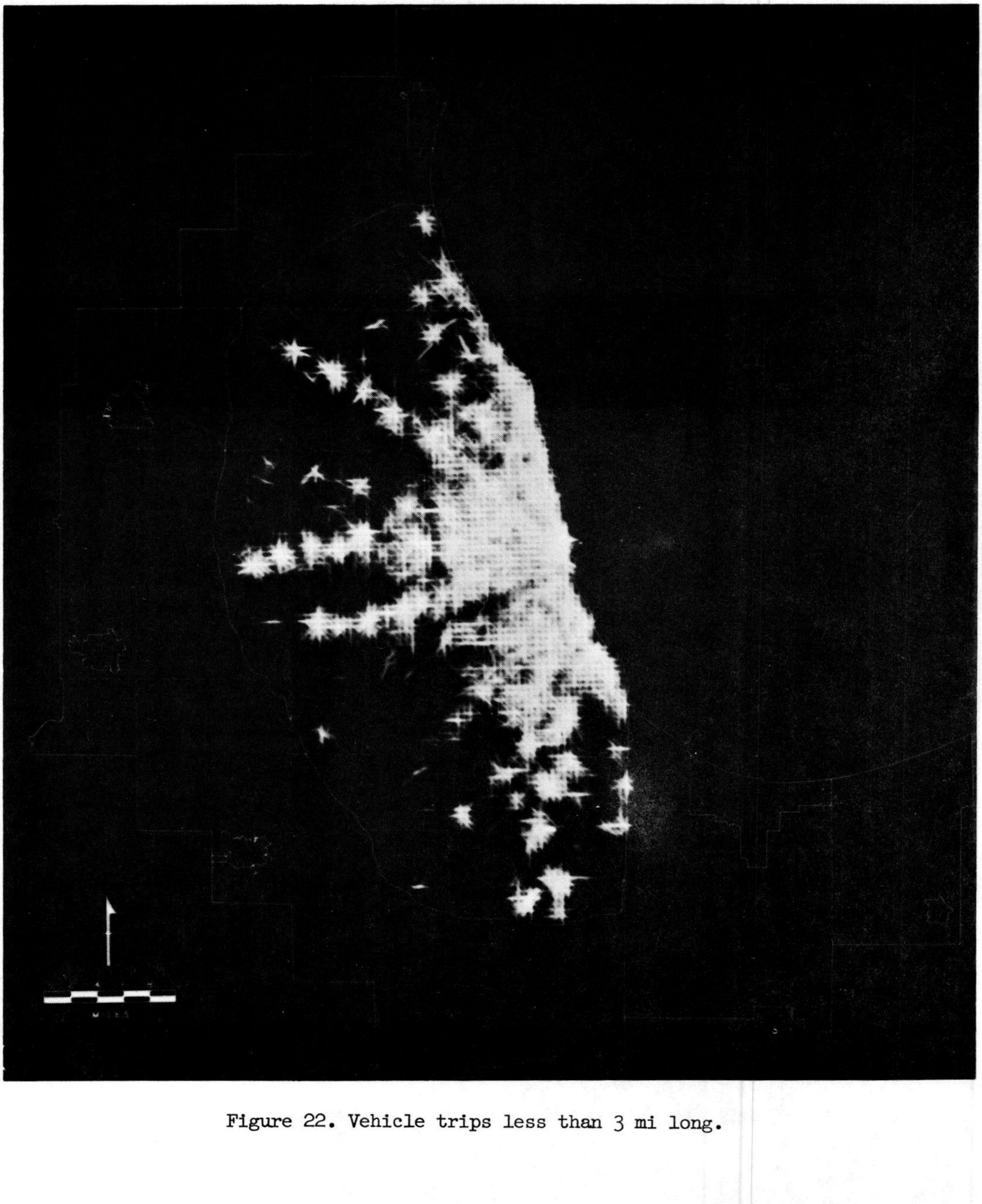

Figure 22. Vehicle trips less than 3 mi long.

survey data and will be very useful in detailed study of specific local problems.

New and varied uses of this machine are continually being found. The exact measure of utility cannot be established, nor is it possible to measure exact worth. The Pittsburgh Area Transportation Study is using it to display their data. The visual image of travel demand and pattern obtained from these displays is an essential piece of knowledge for an accurate understanding of the regional travel demand of any large urban area. It is recognized that, once known, the value of the knowledge is discounted—particularly if it conforms to preconceived notions. However, exact information, carefully presented will continue to have significant meaning in properly evaluating any problem. To work out the program of transportation facilities best suited to an urban region is of such compelling importance that carefully assembled factual data of many types must be on hand to insure that decisions are made in the public interest. Seen from this viewpoint, the machine and its output are well worth the development cost.

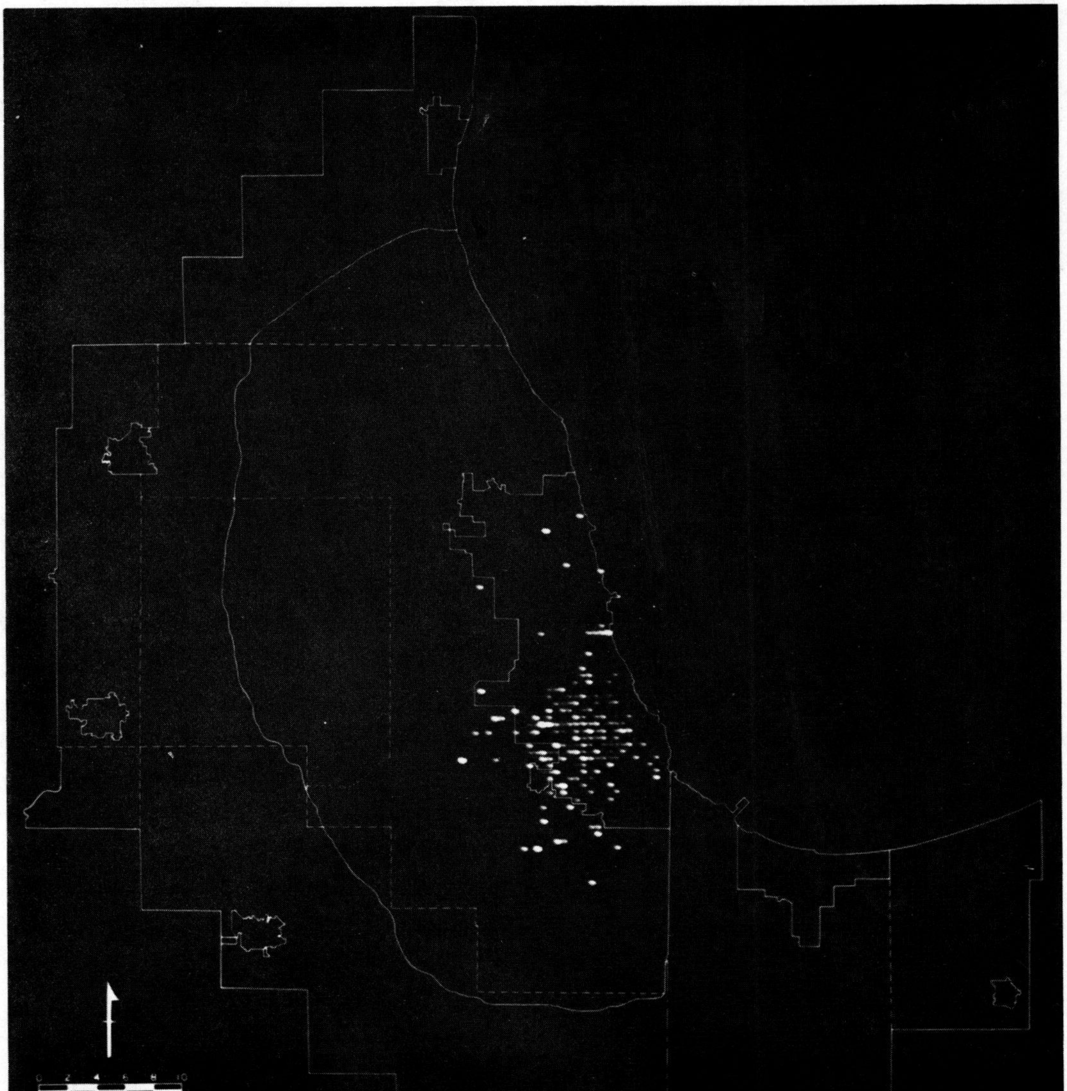

Figure 23. Origin of shopping trips to one district.

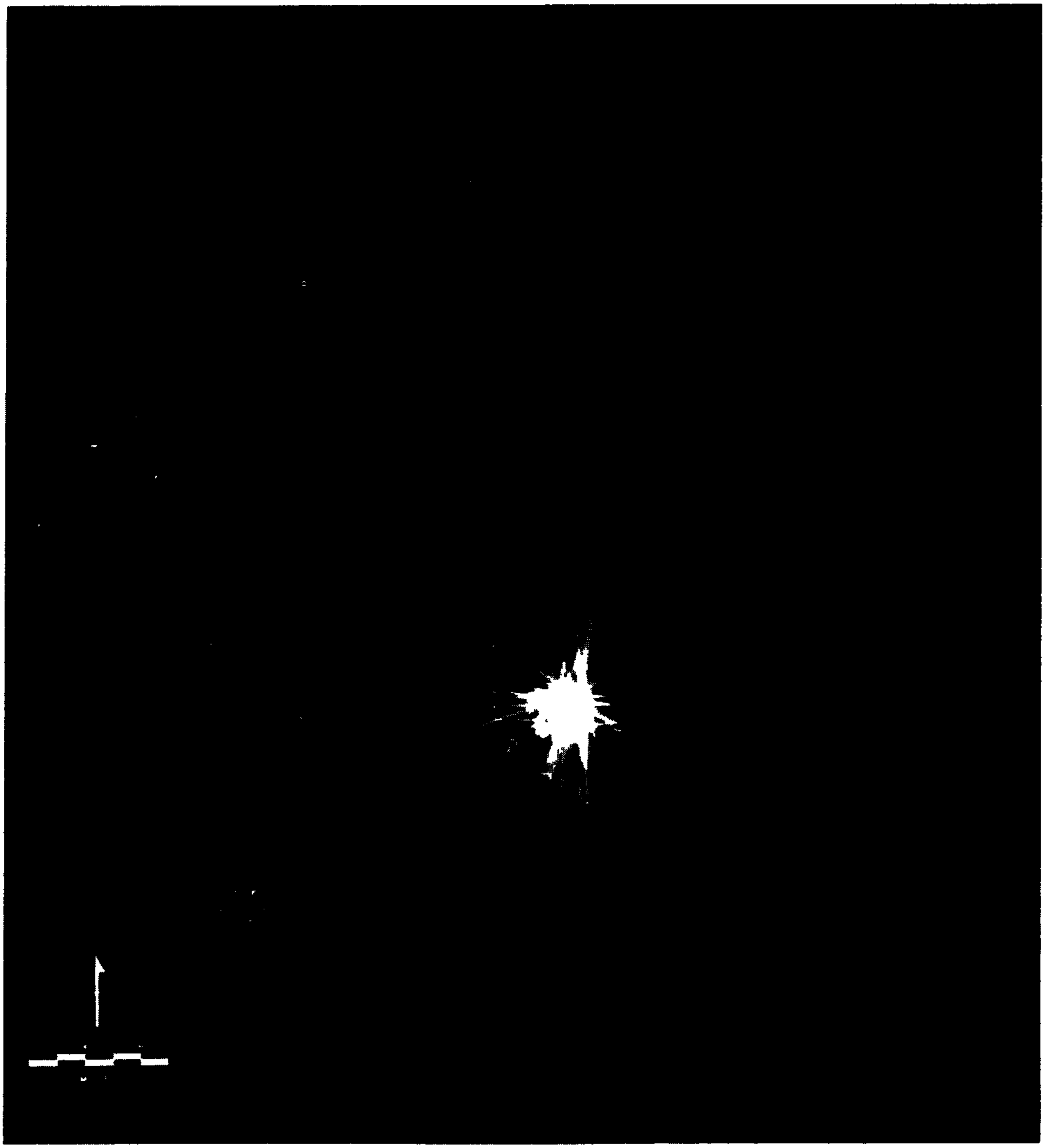

Figure 24. Desire lines of shopping trips to one district.

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