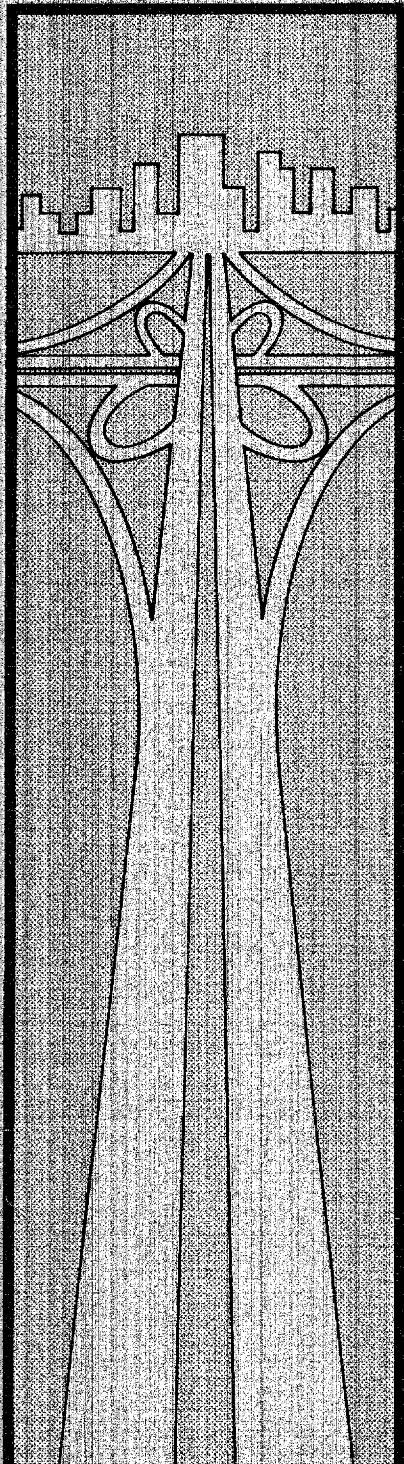
Mueller appendix 46 Volume 20

# HIGHWAY PLANNING TECHNICAL REPORT



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## Developing and Analyzing Functionally Classified Networks Utilizing Traffic Simulation— Phase 1

U.S. DEPARTMENT OF COMMERCE
BUREAU OF PUBLIC ROADS

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# DEVELOPING AND ANALYZING FUNCTIONALLY CLASSIFIED HIGHWAY NETWORKS UTILIZING TRAFFIC SIMULATION--PHASE 1

By

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## PREFACE

This paper reports results of the initial phase of a project aimed at adapting computer-oriented techniques of traffic simulation to the development and analysis of functionally classified highway networks. The first phase, reported here, was basically a procedural development effort which utilized data from a small urban area transportation study. Results of this phase will provide the basis for conducting a proposed second phase which will apply and test the procedure using data from a statewide transportation study.

Part I of the paper provides essential background for what follows by discussing briefly the basic concepts of functional classification and traffic simulation.

Part II describes a classification process which incorporates the analytic capabilities of traffic simulation in the development of a functionally classified highway network.

Part III describes the evaluation of the functional network as developed in Part II, again using computer-oriented techniques of traffic simulation.

Conclusions and acknowledgements are presented in Part IV.

The conduct of the above work was generally confined to capabilities of existing computer programs for traffic simulation. Evaluations were confined to general appraisals of the plausibility of results and of the practicality of the requirements for preparation and processing of data.

# PART I--BACKGROUND

## Conventional concepts of functional classification

The functional classification of highways has been defined (1) [1/] as the grouping of roads and streets into classes, or systems, according to the character of service they will be expected to provide. Character of service in very simple terms is one of traffic mobility, land access, or a combination of the two. The functional systems which provide the above services are usually referred to, respectively, as Arterial, Local, and Collector systems.

In order that each of the above systems may serve its specific function, the classification process is based on functional criteria for each system. Such criteria, as previously defined in "A Guide For Functional Classification" (1) and the "Manual 7A--Standards For Street Facilities And Services" (2), have been used in this project.

The basic concept utilized in these criteria is one of predominant trip length or travel distance served. Conceptually, this implies that, as the length of a trip on a network increases, the level of traffic service should also increase while the level of land access service should decrease. Accordingly, the predominant length of long trips [2/] should be served by a high level system (Arterial), which has the primary function of moving traffic, and the terminal ends of the majority of short, medium, and long trips should be served by a low level system (Local) which has the primary function of providing access to adjacent land uses. There should also be a compromise system (Collector) which serves a dual function of providing a medium level of traffic service for the transition between high and low level systems and of providing access to adjacent land uses. Figure 1 illustrates this functional concept of trip length.

This concept actually defines in a broad sense the manner in which desire lines of travel are converted into the flow of traffic through a highway network. As paraphrased from (1), such a functional concept of the component parts of a highway network serves the following planning purposes:

1. It provides a means for defining travel paths through a road network so as to: (a) provide an optimum blend of directness of routing, high level of service, and economy of highway expenditure; and (b) minimize duplication of service on alternative competing routes.

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1/ The numbers in parentheses identify references in the selected bibliography.

2/ Qualitative terms like "long" trips and "short" trips acquire quantitative values depending primarily upon size of area being studied. For example, a trip that is considered long in the analysis of an urban network might be considered short in the analysis of a statewide network.

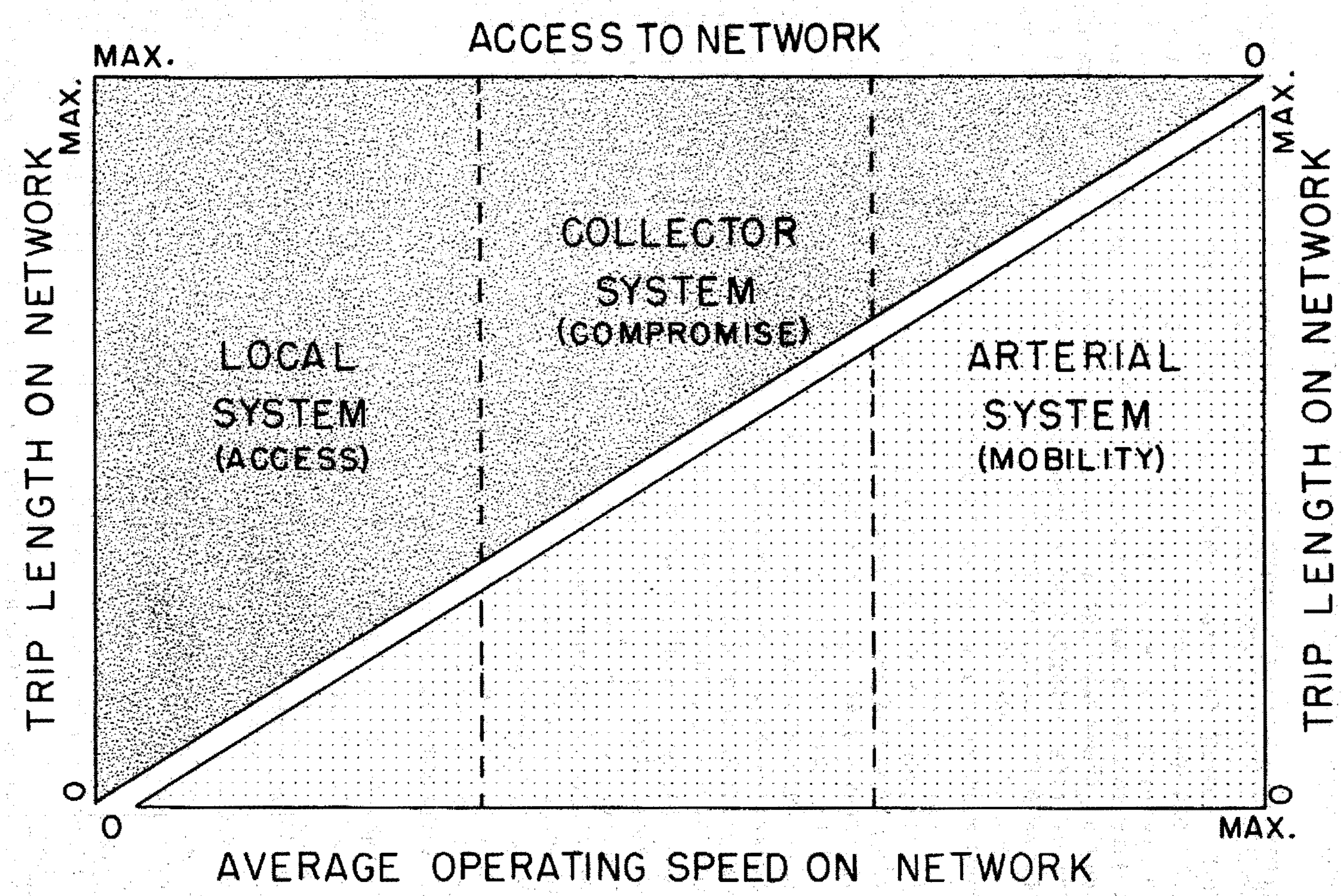


FIG. 1 -FUNCTIONAL CONCEPT OF TRIP LENGTH.

2. It provides one of the prerequisites for estimating the amount of traffic a road or street may be expected to carry.

3. It provides a means of determining, in relative terms, the predominant travel distances served by various segments of the total network. This in turn is useful in establishing realistic minimum values for level of service to be provided.

Functional systems may be stratified into subsystems to distinguish between relative levels of service for a basic function. Arterials, for example, may be subclassified into freeways and other arterials to distinguish between free flow and interrupted flow of traffic. Although the primary function of both subsystems is traffic mobility, there might be a substantial difference in the level of service and cost of construction.

An associated concept which is used in functional classification is the one of diminishing returns (1). This concept perceives the selection of functional systems by working down from the top, through the size hierarchy of traffic generators, until a stage is reached at which provision of connections to smaller generators will result in cumulative system mileage beginning to increase at a rate markedly greater than the corresponding rate of increase in service as measured by vehicle-miles of travel or population served. As illustrated in figure 2, this concept is basically an incremental process of determining the cutoff points for the various systems and subsystems.

The application of the functional concepts of trip length and diminishing returns has been limited primarily to the analysis of rural portions of statewide highway networks.

## Computer-oriented techniques of traffic simulation

The computer-oriented techniques of traffic simulation involved in this project were trip distribution and traffic assignment.

Trip distribution is the process of developing a table or matrix of zone-to-zone trips by direction. This table could represent present-day travel as developed from an origin and destination survey or it could represent present-day or future travel as developed from one of the techniques for synthesizing interzonal movements (4).

Traffic assignment is the process of determining the routes of travel of interzonal trips on a highway network and of accumulating the trips on the routes (3).

The Urban Planning Division of the Bureau of Public Roads has tested and documented a package of IBM 7090/7094 computer programs for traffic assignment and trip distribution (3) (4). These techniques are fully

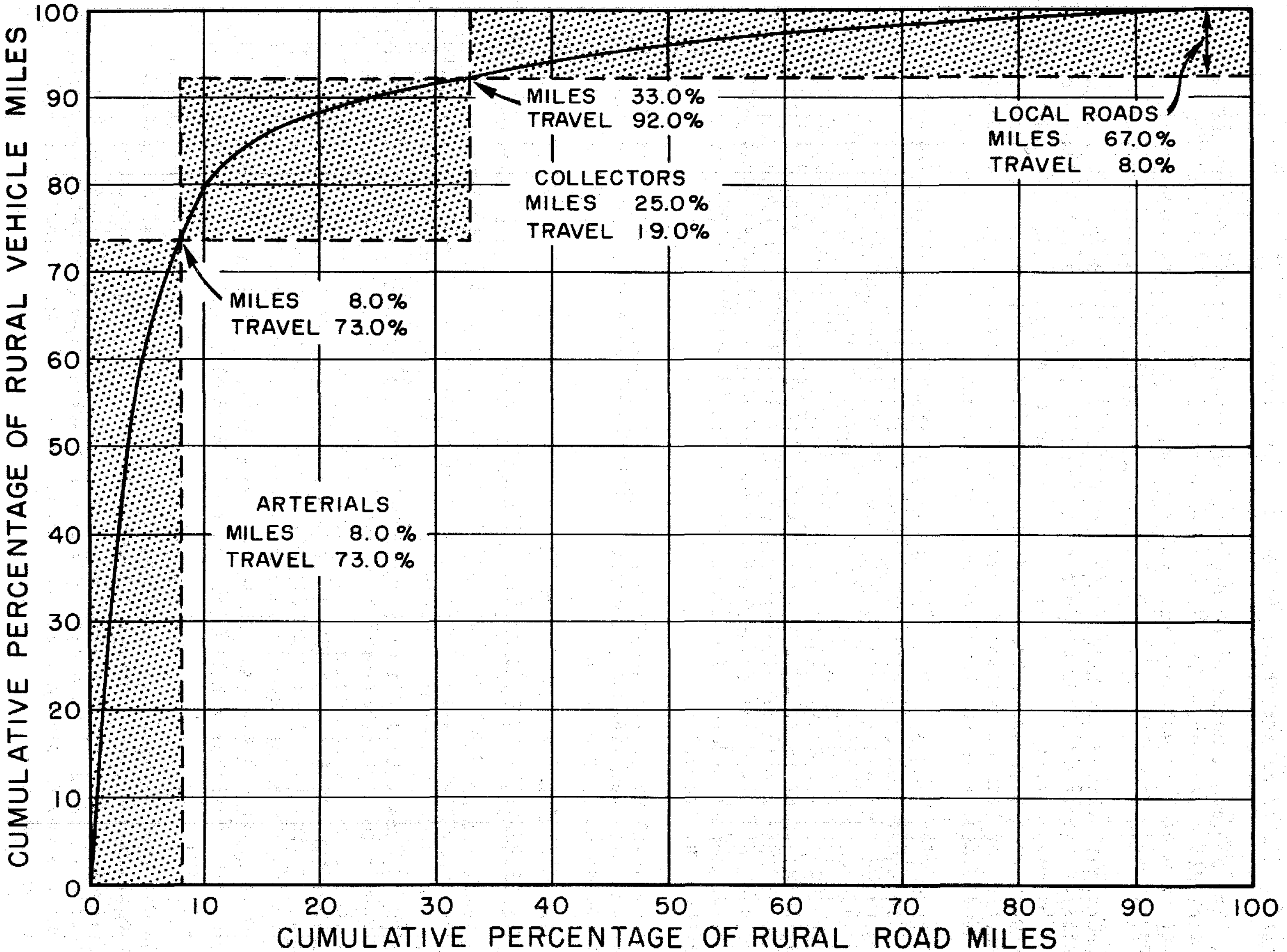


FIGURE 2-- FUNCTIONAL CONCEPT OF DIMINISHING RETURNS

operational and provide the analyst with a systematic procedure that enables him to simulate the probable traffic volume on each link of a highway network. This permits an evaluation of the traffic operational characteristics of any configuration of existing or proposed networks.

Traffic simulation was initially developed for the analysis of urban networks, and until now its application has been essentially in urban areas. At present, however, several States are developing or have developed the application of traffic simulation to statewide highway networks.

### Study premise

The initiation and design of this project were based upon the premise that the integrated application of functional classification and traffic simulation will provide substantial improvement in the planning for efficient and economical development of highway networks. Functional classification will improve traffic simulation by providing a rational basis on which the components of a highway network can be quantitatively described and analyzed. Traffic simulation will improve functional classification by providing the analytical capability by which functional networks can be feasibly and realistically tested and evaluated.

## PART II--DEVELOPING THE FUNCTIONAL NETWORK

### Functional network planning process

This project was conducted within the framework of a functional network planning process that was developed in accordance with the previously discussed premise. This process, as briefly described below, is compatible with the continuing comprehensive transportation planning process as currently practiced in large urban areas and as initially being developed in several statewide transportation studies.

1. Classify the existing network based on present functional usage of roads and streets. This classification would be quickly accomplished by relying upon personal knowledge and judgment without detailed analyses. It would provide the framework for collecting basic data, analyzing existing conditions, and simulating existing travel.

2. Classify the existing network into proposed functional systems based on the most logical usage of roads and streets. This classification would be accomplished through a detailed functional analysis as subsequently described in this paper. The product of step 1 would be utilized in the detailed analysis. The proposed functional network would provide the basis on which a short-range program to improve existing transportation service could be developed.

3. Delineate a future network of proposed functional systems based on logical usage of roads and streets to serve adequately future travel while enhancing orderly growth of the area. This delineation would be accomplished through a detailed functional analysis utilizing the product of step 2. Initially, the existing network of proposed functional systems as determined in step 2 would be evaluated for its capability to serve projected travel. Where applicable, revisions and additions to the existing systems would be delineated to reflect projected growth. This would provide a realistic basis on which a long-range program of improvements could be developed.

4. Analyze the proposed future network on a periodic basis, and if applicable, revise the network and program to reflect changes in growth that were not anticipated in the initial forecasts.

As will be discussed subsequently, this initial phase of the project was confined to work that would be accomplished as part of steps 1 and 2 of the above process.

## Data source

The source of data was the final report of a comprehensive transportation study which was conducted in a small urban area of approximately 22,500 population. Prior to the initiation of this project, the Urban Planning Division had utilized these data in the development of their traffic assignment manual (3). Consequently, a trip table and traffic assignment network for 1961 conditions were available in the proper format for processing with the package of IBM 7090/7094 computer programs.

Although considerable data were available for projected conditions to 1981, this initial phase was limited to the use of data for the survey year of 1961. The primary reason for this limitation was that reliable evaluations of the functional classification procedure could be conducted by comparing traffic characteristics as surveyed on the existing network with traffic characteristics as simulated on an existing network of proposed functional systems. This, in effect, limited the scope of work to steps 1 and 2 of the previously discussed network planning process.

Data which were used in the conduct of this work were as follows:

1. Base maps of the existing network which include street widths, traffic volume counts, traffic controls, major land usage, existing functional classification, and traffic analysis zones.

2. Peak hour traffic capacities.

3. Table of zone-to-zone trips.

4. Base map of the existing traffic assignment network which includes zone centroids, node numbers, link distances, and link speeds.

Some of these basic data are illustrated in figures 3, 4, 5, and table 1. Other data will be illustrated in additional figures and tables as the discussion requires.

The availability of the above data satisfied step 1 of the network planning process. The remaining discussions concern step 2.

## Adaptation of classification concepts

The functional concepts of trip length and diminishing returns, as previously described, were considered in conjunction with the capabilities of the various computer programs within the data processing system for traffic assignment and trip distribution. This resulted in the proposal to utilize vehicle-miles of travel (VMT) from each zone to all other zones as the measure for ranking zones in the diminishing returns concept.

This measure would also incorporate the concept of trip length since if two zones with an equal number of trips were competing for connection to a system, the zone with the larger VMT (i.e., longer trips) would be considered first.

The methodology of developing these adapted concepts involved several unique steps of data processing which were in brief as follows:

1. Development of a table or matrix of interzonal vehicle-miles of travel (VMT). This was accomplished by multiplying the table of interzonal trips by a similar table of interzonal distances. The format of this table was the same as that of a trip table; accordingly, existing programs were used to process the VMT table. This resulted in a printed table of interzonal VMT for each zone, as illustrated in table 2, and a summary table of VMT by zone. The latter was on magnetic tape and punched cards as well as offline print.

2. Development of a table of ranked zones according to VMT as illustrated in table 3. The percent of VMT for each ranked zone as well as the cumulative percentage of VMT for ranked zones was included in this table. The procedure for developing this table was computerized to accept data from step 1.

3. Development of a plot of ranked zones against cumulative percentage of VMT as illustrated in figure 6. The procedure for developing this adapted plot of diminishing returns was computerized to accept data from step 2.

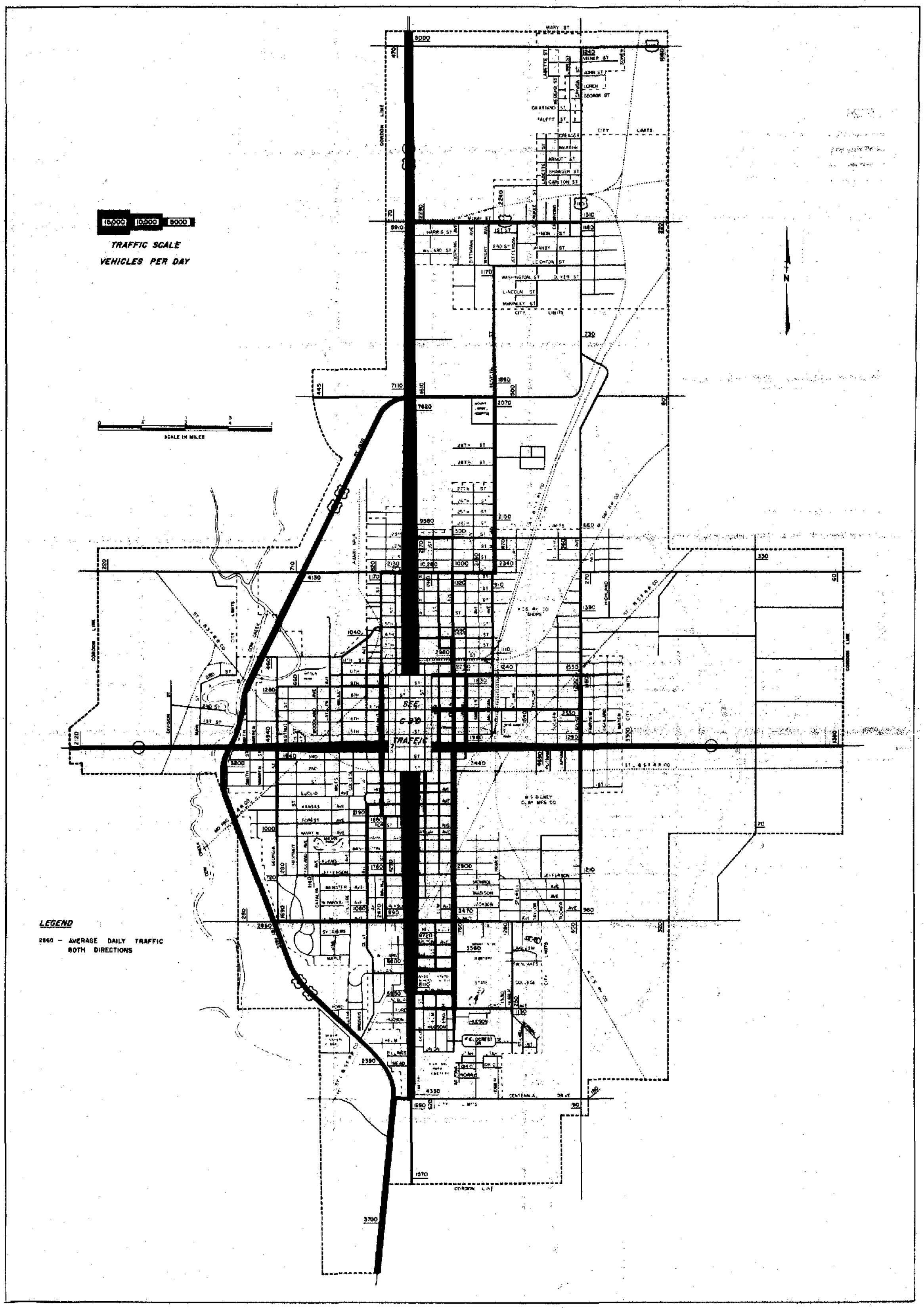


FIGURE 3--EXISTING NETWORK WITH 1961 TRAFFIC FLOW.

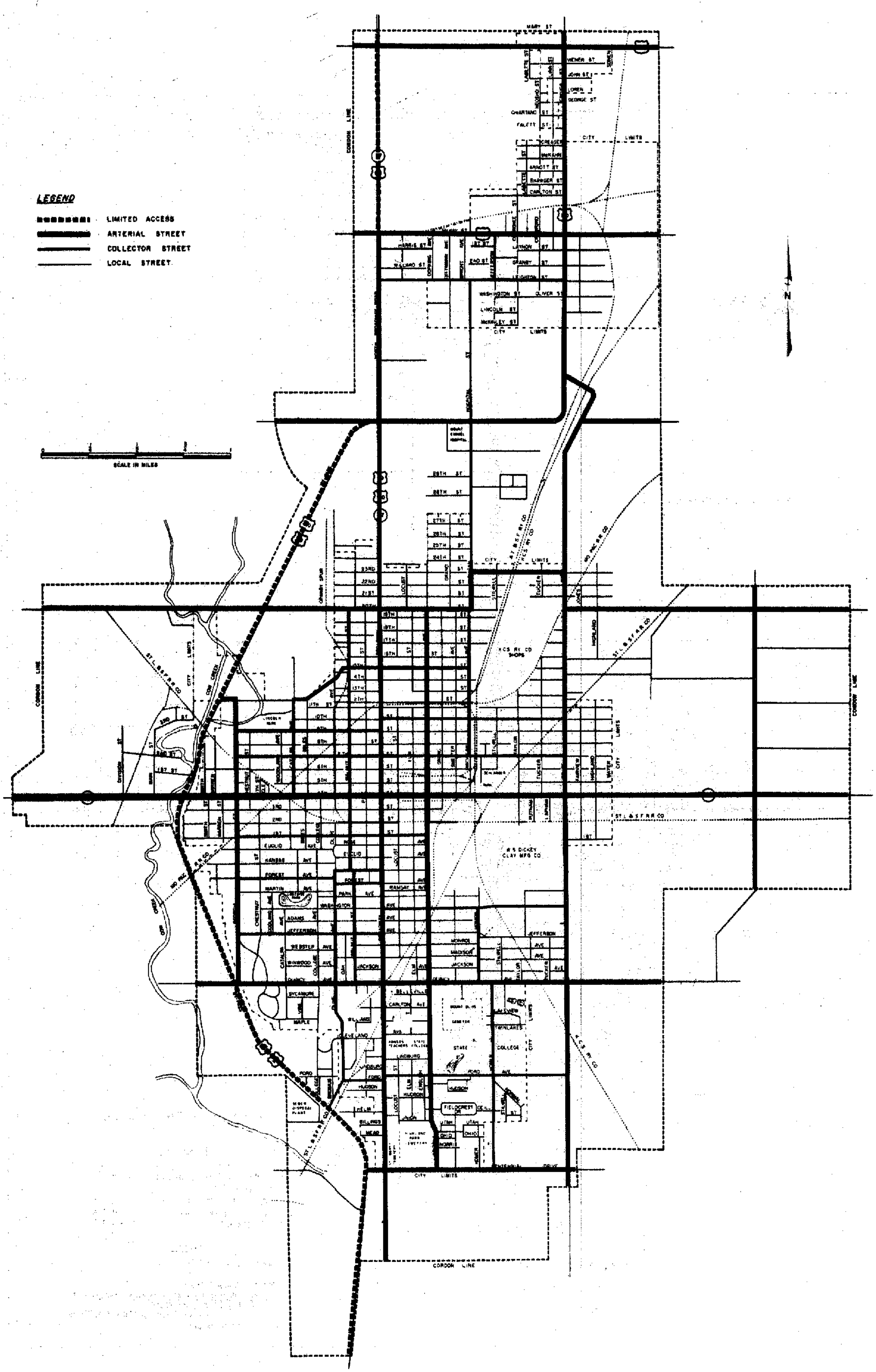


FIGURE 4--EXISTING NETWORK WITH 1961 FUNCTIONAL USAGE.

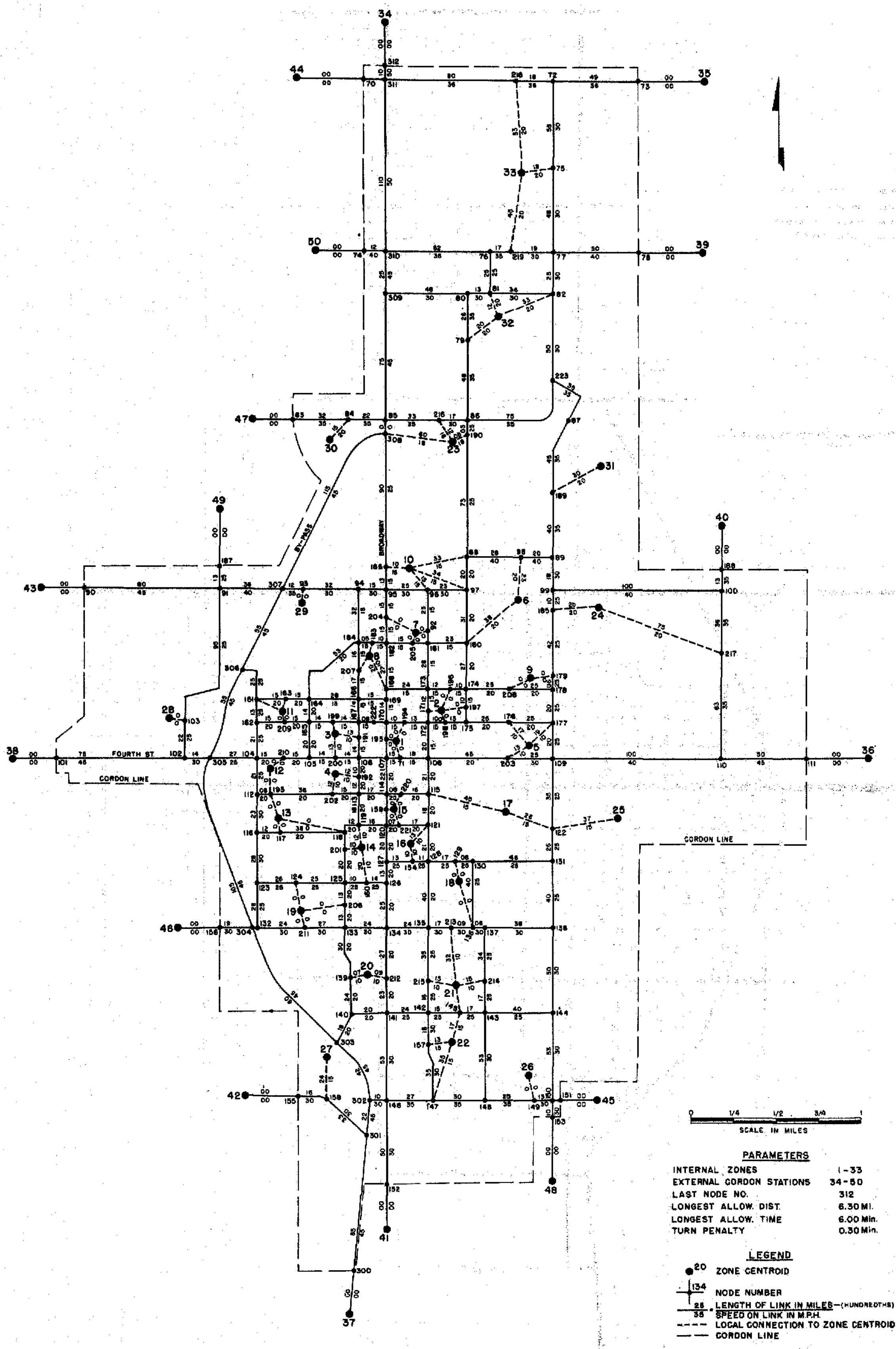


FIGURE 5--EXISTING TRAFFIC ASSIGNMENT NETWORK

# TABLE 1--SUMMARY OF ZONAL TRIP ENDS

| (1) ZONE | (2) INS | (3) OUTS | (4) INTRAS* | (5) TOTAL INS + OUTS (2)+(3) | (6) TOTAL TRIPS (4)+(5) | (7) TOTAL TRIP ENDS (4)+(6) |
|---|---|---|---|---|---|---|
| 1 | 9,415 | 9,411 | 0 | 18,826 | 18,826 | 18,826 |
| 2 | 2,237 | 2,236 | 0 | 4,473 | 4,473 | 4,473 |
| 3 | 1,334 | 1,334 | 0 | 2,668 | 2,668 | 2,668 |
| 4 | 1,068 | 1,068 | 0 | 2,136 | 2,136 | 2,136 |
| 5 | 1,821 | 1,823 | 0 | 3,644 | 3,644 | 3,644 |
| 6 | 530 | 530 | 0 | 1,060 | 1,060 | 1,060 |
| 7 | 1,928 | 1,928 | 0 | 3,856 | 3,856 | 3,856 |
| 8 | 1,483 | 1,485 | 0 | 2,968 | 2,968 | 2,968 |
| 9 | 1,136 | 1,133 | 0 | 2,269 | 2,269 | 2,269 |
| 10 | 2,708 | 2,710 | 0 | 5,418 | 5,418 | 5,418 |
| 11 | 1,634 | 1,639 | 0 | 3,273 | 3,273 | 3,273 |
| 12 | 1,226 | 1,223 | 0 | 2,449 | 2,449 | 2,449 |
| 13 | 1,955 | 1,955 | 0 | 3,910 | 3,910 | 3,910 |
| 14 | 1,728 | 1,729 | 0 | 3,457 | 3,457 | 3,457 |
| 15 | 2,824 | 2,822 | 0 | 5,646 | 5,646 | 5,646 |
| 16 | 1,320 | 1,319 | 0 | 2,639 | 2,639 | 2,639 |
| 17 | 1,419 | 1,421 | 0 | 2,840 | 2,840 | 2,840 |
| 18 | 1,054 | 1,056 | 0 | 2,110 | 2,110 | 2,110 |
| 19 | 1,801 | 1,798 | 0 | 3,599 | 3,599 | 3,599 |
| 20 | 1,278 | 1,278 | 0 | 2,556 | 2,556 | 2,556 |
| 21 | 3,676 | 3,677 | 0 | 7,353 | 7,353 | 7,353 |
| 22 | 1,918 | 1,921 | 0 | 3,839 | 3,839 | 3,839 |
| 23 | 2,213 | 2,211 | 0 | 4,424 | 4,424 | 4,424 |
| 24 | 597 | 602 | 0 | 1,199 | 1,199 | 1,199 |
| 25 | 125 | 125 | 0 | 250 | 250 | 250 |
| 26 | 200 | 198 | 0 | 398 | 398 | 398 |
| 27 | 92 | 92 | 0 | 184 | 184 | 184 |
| 28 | 494 | 495 | 0 | 989 | 989 | 989 |
| 29 | 256 | 256 | 0 | 512 | 512 | 512 |
| 30 | 64 | 61 | 0 | 125 | 125 | 125 |
| 31 | 26 | 31 | 0 | 57 | 57 | 57 |
| 32 | 1,669 | 1,669 | 0 | 3,338 | 3,338 | 3,338 |
| 33 | 1,237 | 1,225 | 0 | 2,462 | 2,462 | 2,462 |
| 34 | 2,401 | 2,402 | 0 | 4,803 | 4,803 | 4,803 |
| 35 | 502 | 503 | 0 | 1,005 | 1,005 | 1,005 |
| 36 | 724 | 725 | 0 | 1,449 | 1,449 | 1,449 |
| 37 | 1,856 | 1,855 | 0 | 3,711 | 3,711 | 3,711 |
| 38 | 1,011 | 1,011 | 0 | 2,022 | 2,022 | 2,022 |
| 39 | 92 | 92 | 0 | 184 | 184 | 184 |
| 40 | 95 | 97 | 0 | 192 | 192 | 192 |
| 41 | 825 | 823 | 0 | 1,648 | 1,648 | 1,648 |
| 42 | 136 | 136 | 0 | 272 | 272 | 272 |
| 43 | 109 | 110 | 0 | 219 | 219 | 219 |
| 44 | 244 | 243 | 0 | 487 | 487 | 487 |
| 45 | 1 | 2 | 0 | 3 | 3 | 3 |
| 46 | 252 | 253 | 0 | 505 | 505 | 505 |
| 47 | 201 | 202 | 0 | 403 | 403 | 403 |
| 48 | 97 | 97 | 0 | 194 | 194 | 194 |
| 49 | 2 | 2 | 0 | 4 | 4 | 4 |
| 50 | 1 | 1 | 0 | 2 | 2 | 2 |
| TOTAL | 61,015 | 61,015 | 0 | 122,030 | 122,030 | 122,030 |

* Intras deleted from trip table

## TABLE 2--INTERZONAL VEHICLE-MILES OF TRAVEL FOR SELECTED ZONES

VMT FROM ZONE 17 TO ALL ZONES

| ZONE | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| 00 | -- | 1980 | 765 | 182 | 209 | 1190 | 264 | 518 | 150 | 880 |
| 10 | 1586 | 480 | 434 | 42 | 636 | 270 | 154 | -- | 492 | 928 |
| 20 | 234 | 864 | 1426 | 1380 | 187 | 21 | -- | 111 | 299 | -- |
| 30 | -- | -- | 1332 | 774 | 3190 | 357 | 1827 | 2240 | 924 | -- |
| 40 | 864 | 850 | 259 | 39 | 183 | -- | 200 | 123 | 42 | -- |

VMT FROM ZONE 18 TO ALL ZONES

| ZONE | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| 00 | -- | 1880 | 1166 | 260 | 216 | 544 | 280 | 416 | 688 | 119 |
| 10 | 532 | 551 | 300 | 306 | 304 | 546 | 216 | 504 | -- | 140 |
| 20 | 72 | 212 | 440 | 1128 | 207 | -- | 52 | 115 | 275 | 132 |
| 30 | -- | -- | -- | 490 | 1152 | -- | 378 | 442 | 420 | 47 |
| 40 | 99 | 280 | 46 | -- | -- | -- | 98 | 48 | 80 | -- |

VMT FROM ZONE 19 TO ALL ZONES

| ZONE | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| 00 | -- | 4609 | 144 | 209 | 477 | 351 | -- | 1596 | 765 | 280 |
| 10 | 1560 | 936 | 126 | 316 | 368 | 1267 | 384 | 870 | 112 | -- |
| 20 | 390 | 1152 | 793 | 888 | 374 | -- | 230 | -- | 165 | 483 |
| 30 | -- | -- | 1034 | 432 | 1458 | 204 | 418 | 792 | 320 | 114 |
| 40 | 44 | 240 | 63 | -- | -- | -- | 204 | 304 | -- | -- |

VMT FROM ZONE 20 TO ALL ZONES

| ZONE | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| 00 | -- | 3038 | 741 | 224 | 195 | 588 | 145 | 735 | 627 | 638 |
| 10 | 1147 | 364 | 450 | 288 | 261 | 1060 | 495 | 234 | 72 | 390 |
| 20 | -- | 1148 | 968 | 484 | 490 | -- | 160 | 48 | 308 | 120 |
| 30 | -- | -- | 702 | 610 | 1342 | 300 | 156 | 589 | 378 | 64 |
| 40 | 45 | 364 | 32 | 41 | 64 | -- | 132 | 90 | 18 | -- |

TABLE 3--RANKED ZONES ACCORDING TO VEHICLE-MILES OF TRAVEL

| RANK | ZONE | VEHICHLE-MILES OF TRAVEL | PER CENT OF TOTAL | ACCUMULATED PERCENTAGE |
|---|---|---|---|---|
| 1 | 1 | 121441. | 10.753 | 10.753 |
| 2 | 34 | 118582. | 10.500 | 21.253 |
| 3 | 37 | 88828. | 7.865 | 29.119 |
| 4 | 21 | 75273. | 6.665 | 35.784 |
| 5 | 23 | 52301. | 4.631 | 40.415 |
| 6 | 10 | 42298. | 3.745 | 44.160 |
| 7 | 32 | 38748. | 3.431 | 47.591 |
| 8 | 22 | 36352. | 3.219 | 50.810 |
| 9 | 33 | 34256. | 3.033 | 53.843 |
| 10 | 15 | 33399. | 2.957 | 56.801 |
| 11 | 17 | 27986. | 2.478 | 59.279 |
| 12 | 7 | 24933. | 2.208 | 61.487 |
| 13 | 2 | 24587. | 2.177 | 63.664 |
| 14 | 19 | 24472. | 2.167 | 65.831 |
| 15 | 5 | 24049. | 2.129 | 67.960 |
| 16 | 41 | 24012. | 2.126 | 70.086 |
| 17 | 38 | 23100. | 2.045 | 72.132 |
| 18 | 11 | 23055. | 2.041 | 74.173 |
| 19 | 13 | 21909. | 1.940 | 76.113 |
| 20 | 36 | 20764. | 1.839 | 77.952 |
| 21 | 20 | 20345. | 1.801 | 79.753 |
| 22 | 8 | 20002. | 1.771 | 81.524 |
| 23 | 35 | 19965. | 1.768 | 83.292 |
| 24 | 14 | 19560. | 1.732 | 85.024 |
| 25 | 9 | 16061. | 1.422 | 86.446 |
| 26 | 18 | 15181. | 1.344 | 87.791 |
| 27 | 16 | 14670. | 1.299 | 89.090 |
| 28 | 12 | 14375. | 1.273 | 90.362 |
| 29 | 4 | 13966. | 1.237 | 91.599 |
| 30 | 3 | 13392. | 1.186 | 92.785 |
| 31 | 24 | 11194. | 0.991 | 93.776 |
| 32 | 28 | 9729. | 0.861 | 94.638 |
| 33 | 6 | 9451. | 0.837 | 95.474 |
| 34 | 44 | 8522. | 0.755 | 96.229 |
| 35 | 29 | 5946. | 0.526 | 96.755 |
| 36 | 26 | 5369. | 0.475 | 97.231 |
| 37 | 47 | 5266. | 0.466 | 97.697 |
| 38 | 27 | 4888. | 0.433 | 98.130 |
| 39 | 46 | 3756. | 0.333 | 98.463 |
| 40 | 42 | 3699. | 0.328 | 98.790 |
| 41 | 43 | 2612. | 0.231 | 99.021 |
| 42 | 40 | 2552. | 0.226 | 99.247 |
| 43 | 48 | 2315. | 0.205 | 99.452 |
| 44 | 25 | 2232. | 0.198 | 99.650 |
| 45 | 39 | 2116. | 0.187 | 99.837 |
| 46 | 30 | 921. | 0.082 | 99.919 |
| 47 | 31 | 822. | 0.073 | 99.992 |
| 48 | 50 | 39. | 0.003 | 99.995 |
| 49 | 49 | 30. | 0.003 | 99.998 |
| 50 | 45 | 25. | 0.002 | 100.000 |

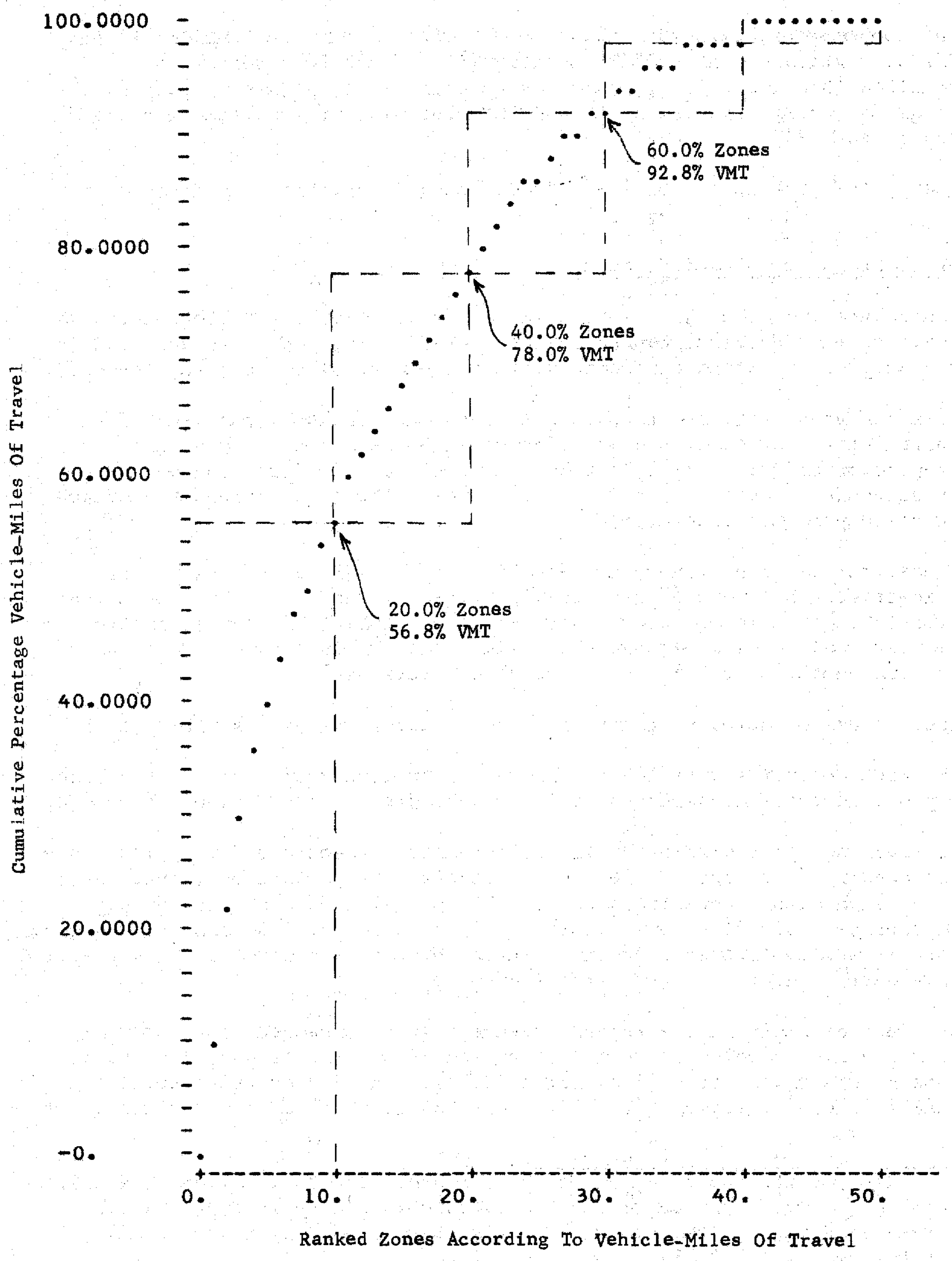


FIGURE 6--ADAPTATION OF DIMINISHING RETURNS CONCEPT.

The computer programs for steps 2 and 3 were written in FORTRAN II with FAP subroutines from the BELL Monitor (3). These two steps were combined into a single program package which will operate as part of the program library tape in the BELL-BELMN control monitor system for traffic assignment. 3/

The system flow chart for steps 1, 2, and 3 is exhibited in figure 7.

## Utilization of adapted concepts

Basic data in table 3, as well as the curve formed by the plot of ranked zones against cumulative percentage of VMT in figure 6, were analyzed for the purpose of estimating appropriate increments of diminishing returns.

This analysis resulted in the stratification of ranked zones into five increments of an equal number of zones which produced a diminishing proportion of VMT. As illustrated in figure 6, the first increment produced 56.8 percent of total VMT; whereas, the last increment produced only 1.0 percent of total VMT.

These increments provided the means by which a schematic network, as illustrated in figure 8, was developed in accordance with the concept of diminishing returns as previously described in Part I. The schematic network would presumably provide maximum service in terms of VMT with a minimum number of miles of interzonal connections.

The process of developing the schematic network was as described below.

1. Zone centroids were identified by distinctive code symbols on a base map of the traffic assignment network according to respective increments.

2. Each centroid within the first increment was connected to immediately surrounding centroids of the same increment. This was done on the basis of straight line connections unless the logical connection was through another centroid of a lower increment. The straight line connections were not allowed to intersect at any point other than a centroid. This resulted in a neatly interconnected first increment.

3. Centroids within the second increment were connected to immediately surrounding centroids of the first or second increments according to the same procedure as above. Centroids 13, 17, and 19 required special analysis because it was not readily obvious from visual observation where

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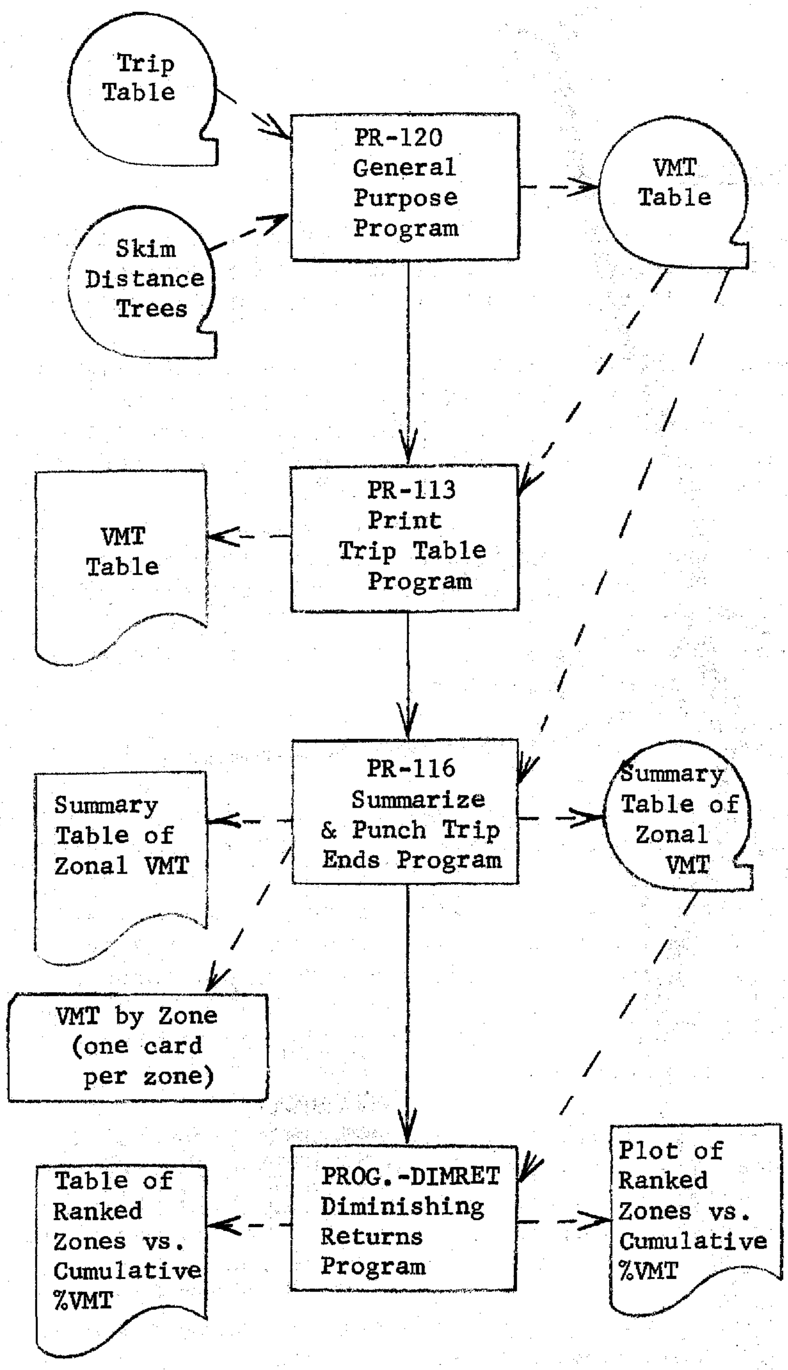
3/ A written description of the computer program for steps 2 and 3, as well as a copy of the object deck, may be obtained by writing the U.S. Bureau of Public Roads, Advance Planning Division, 1717 H Street, NW., Washington, D. C. 20235.

Flow




Comments

Option 7 of PR-120 specifies the multiplication of two similar matrices. Skim distance trees are via the minimum time path.

The original purpose of this program was to print trip tables. However, it will print VMT tables as well as skim time and distance trees.

Punched cards are optional. The original purpose of this program was to summarize trip ends. However, it will also summarize zonal VMT.

Punched cards may be used as input instead of tape.

FIGURE 7--SYSTEM FLOW CHART.

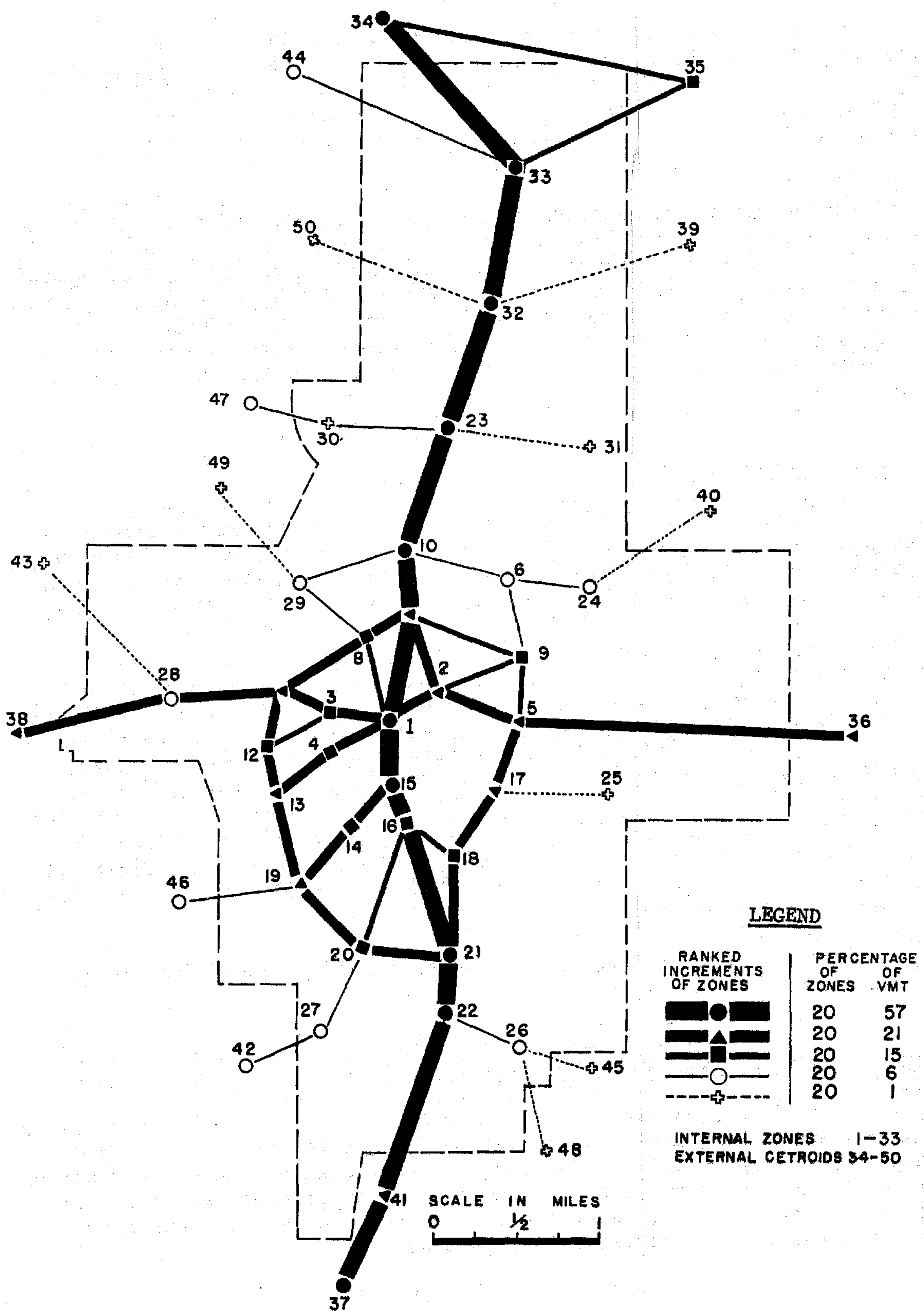



FIGURE 8--SCHEMATIC NETWORK.

the point of connection should be made. Data on interzonal VMT, as previously discussed and illustrated in table 2, were analyzed for this purpose. As shown by the circled values in table 2, centroid 17 is primarily oriented to zones to the north but it also has a secondary orientation to the south. Connections were provided, therefore, to the north and south.

4. Since the first two increments produced 78 percent of total VMT which was considered as the principal point of diminishing returns in figure 6, the remaining centroids beginning with the third increment were connected to the framework formed by the interconnection of the first two increments. The connecting points for the majority of these centroids were fairly obvious from visual inspection. In questionable cases, however, connections were made in accordance with the procedure previously described for centroid 17.

## Analysis of schematic network

Several inferences were drawn as a result of visually comparing the schematic network with the existing traffic flow in figure 3, the existing functional usage in figure 4, and the predominant configuration resulting from a loaded spider-web network (3) in figure 9.

1. The basic framework formed by the interconnection of zone centroids in the first two increments of the schematic network presumably described the optimum channelization of travel between the most important traffic producing zones. The pattern of channelization was primarily oriented to the north and south with a secondary orientation to the east and west. This would serve as the basis for defining a proposed Arterial system.

2. The geographic location and relative rank of centroids in the last three increments, as well as their points of connection to the framework formed by the first two increments, would provide the basis for defining a proposed Collector system.

These inferences were utilized in the selection of proposed functional systems as will be discussed next.

## Delineation of proposed functional systems

The delineation of proposed functional systems was expedited by a decision to accept tentatively the Local system that is represented by centroid connections in figure 5. This system was designated by the Urban Planning Division during the development of the traffic assignment network. Its designation was based on, but did not completely agree with, existing functional usage as illustrated in figure 4.

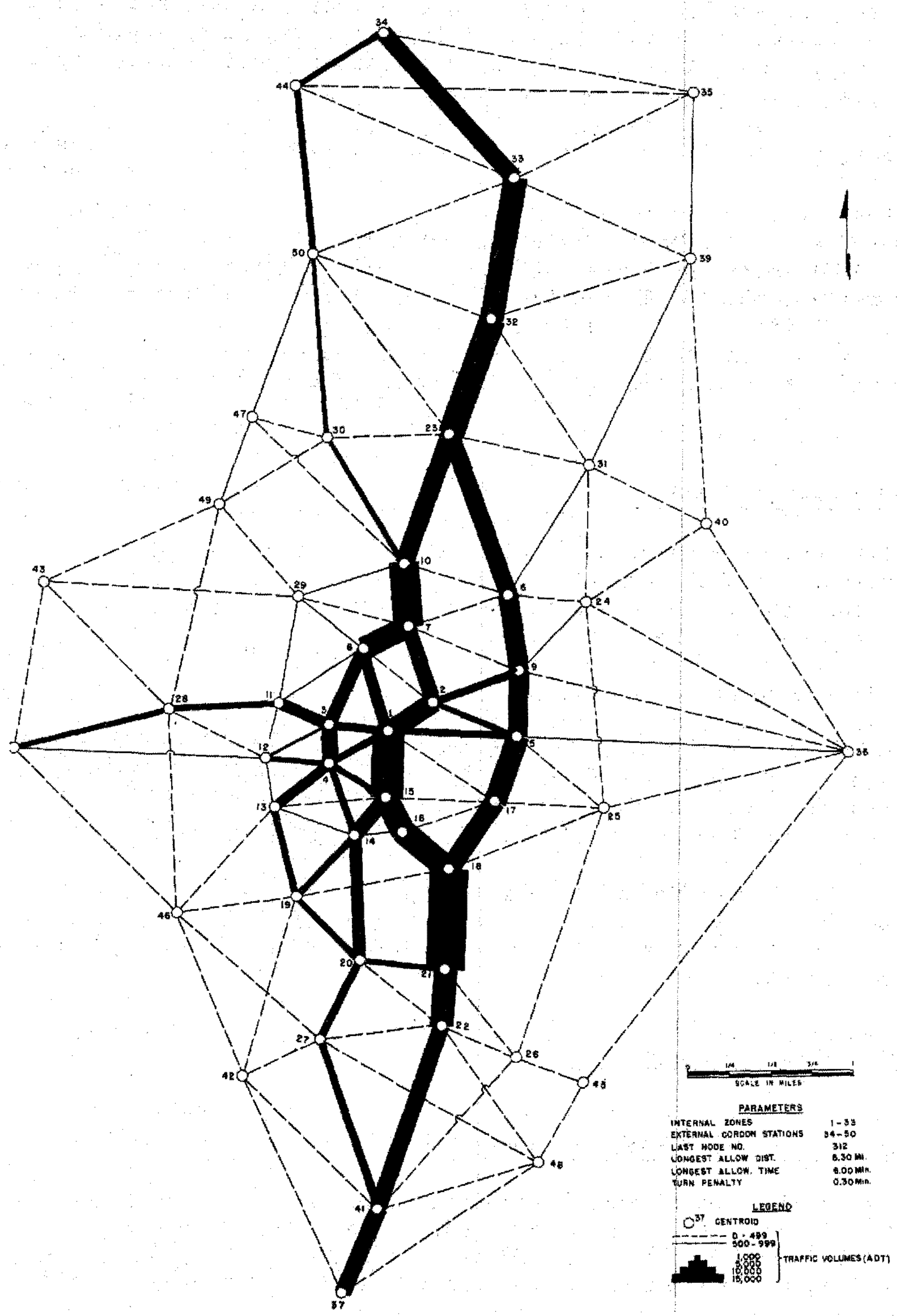



FIGURE 9--LOADED SPIDER NETWORK.

The above decision was based on the assumptions that the designated Local system would not require substantial revisions as a result of logical functional analysis and that any necessary revisions would come to light during the evaluation of the proposed systems.

This decision resulted in considerable savings of time as it was necessary only to make a logical distinction between Arterial and Collector functions for the remaining roads not included in the Local system. This distinction was made by visually examining physical characteristics of the existing network in light of (a) inferences drawn from the development of the schematic network, and (b) functional criteria on service, spacing, and continuity of systems.

The resulting classification of Arterial and Collector systems is shown in figure 10. A comparison of the functional systems based on existing use (figure 4) and proposed functional systems developed in this project (figure 10) will reveal considerable resemblance between the two. Some basic differences do exist, however, in that the proposed network has less mileage in the Arterial system, more mileage in the Collector system, and approximately equal mileage in the Local system.

## PART III--EVALUATION OF THE NETWORK OF PROPOSED FUNCTIONAL SYSTEMS

Prior to the advent of traffic simulation utilizing electronic computers, the potential of functional classification could not be fully realized because there was not the technical capability to test, evaluate, and adjust proposed functional systems on the basis of traffic operational characteristics of the total network. The evaluation phase of this project, therefore, was very important because it involved, perhaps for the first time, a dynamic test and evaluation of the functional concepts of trip length and diminishing returns as well as the operational aspects of the functional components of the total highway network.

### Assignment of level of service

An essential first step in the evaluation process was the assignment of a level of service to each component of the functional network. The concept of level of service is a basic element of functional classification. That is, some roads must give preference to movement of traffic, others to land access, and some must serve both functions. These specialized characteristics can be established through the manner of layout of the network, the geometric design features of individual facilities, and the use of traffic control features.

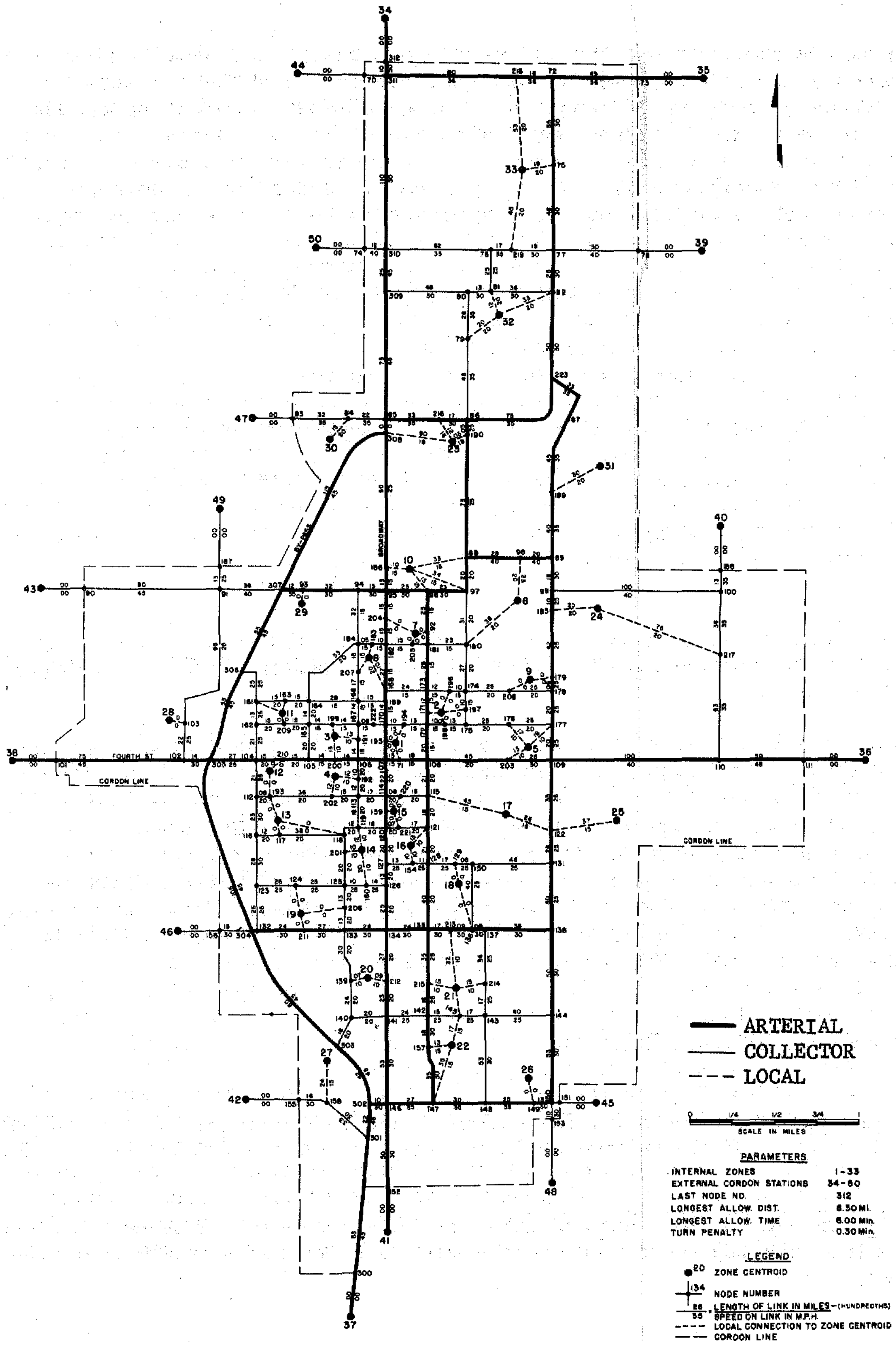



FIGURE 10--FUNCTIONAL NETWORK.

Each of the proposed functional systems was assigned a level of service in accordance with recommendations included in (2). These levels of service were in terms of ranges of minimum desirable operating speeds which reflect, to a varying but distinctly different degree, the function of the system. The range of speeds, as illustrated in table 4, permitted a realistic assignment of level of service depending upon geographical location such as central business district or outlying suburban area.

TABLE 4

LEVEL OF SERVICE
Minimum Desirable Operating Speeds

| Functional System | Average Speed 4/ |
|---|---|
| Arterial | 25-35 |
| Collector | 20-25 |
| Local | 10-20 |

These levels of service were part of the basic data that described the functional highway network for the process of traffic simulation as discussed below.

## Preparing the functional network for processing

The second step in the evaluation of the functional network was the preparation of the network for processing with the package of IBM 7090/7094 computer programs. A description of the functional network was coded, key punched, and transferred to magnetic tape. This was done in accordance with standard procedures (3) with the exception of functional identification. The computer programs, as currently written, do not have provisions for identifying Collectors as a separate system according to node numbers. This problem was easily resolved by using the column provided for jurisdictional code in the existing coding format to distinguish between functional Arterials and Collectors.

With the exception of functional identification and level of service, the computer descriptions of the existing highway network (figure 5) and the

4/ The functional network does not have Arterials of freeway design. Otherwise, the top of the range of speeds for Arterials would have been higher.

proposed functional network (figure 10) were basically identical. This expedited the conduct of the above step and can be attributed to the previous decision to use the preselected Local system.

The next step was to subject the functional network and existing trip table to the traffic assignment process. This process resulted in an abundance of printed data of which the most important were as follows:

1. Trace of minimum time-routes between zones. The trace of the minimum time-routes between any one zone and all other zones is defined as a "tree."

2. Traffic volumes on each link of the network, by direction, complete with turning movements.

3. Vehicle-miles of travel (VMT) and vehicle-hours of travel (VHT) for each functional system.

4. Average trip length for each link of the network.

These data, in conjunction with previously discussed data on characteristics of the existing network and existing travel, provided the basis on which evaluations were conducted. The techniques and results of the evaluations are summarized in the following discussions.

Evaluation of traffic flow

The initial evaluation was concerned with the reasonableness of traffic flow that resulted from the simulated functional network. The evaluation was limited to an analysis of two basic elements of traffic flow as follows:

1. An analysis of the routes of travel between zones in relation to the functional components of the routes.

2. An analysis of traffic volumes on links in relation both to the function and the geographical location of the links.

The routes of travel between zones were analyzed by plotting the minimum time routes or "trees" for selected zones. The minimum time tree for zone 1, as illustrated in figure 11, is a typical example of the logical and efficient routing that resulted from the functional network. The channelization or drainage of short sections of the Local and Collector systems into longer continuous sections of the Arterial system illustrates very distinctly the reasonableness of the routes.

One illogical route was detected, but it was of minor importance. This route was for zones 43, 49, and 29. It is very obvious from figure 11 that the route utilized a section of the Collector system that is located between two sections of the Arterial system. This resulted from an incorrectly coded link distance. Such errors can be easily corrected prior to assigning traffic to the network.

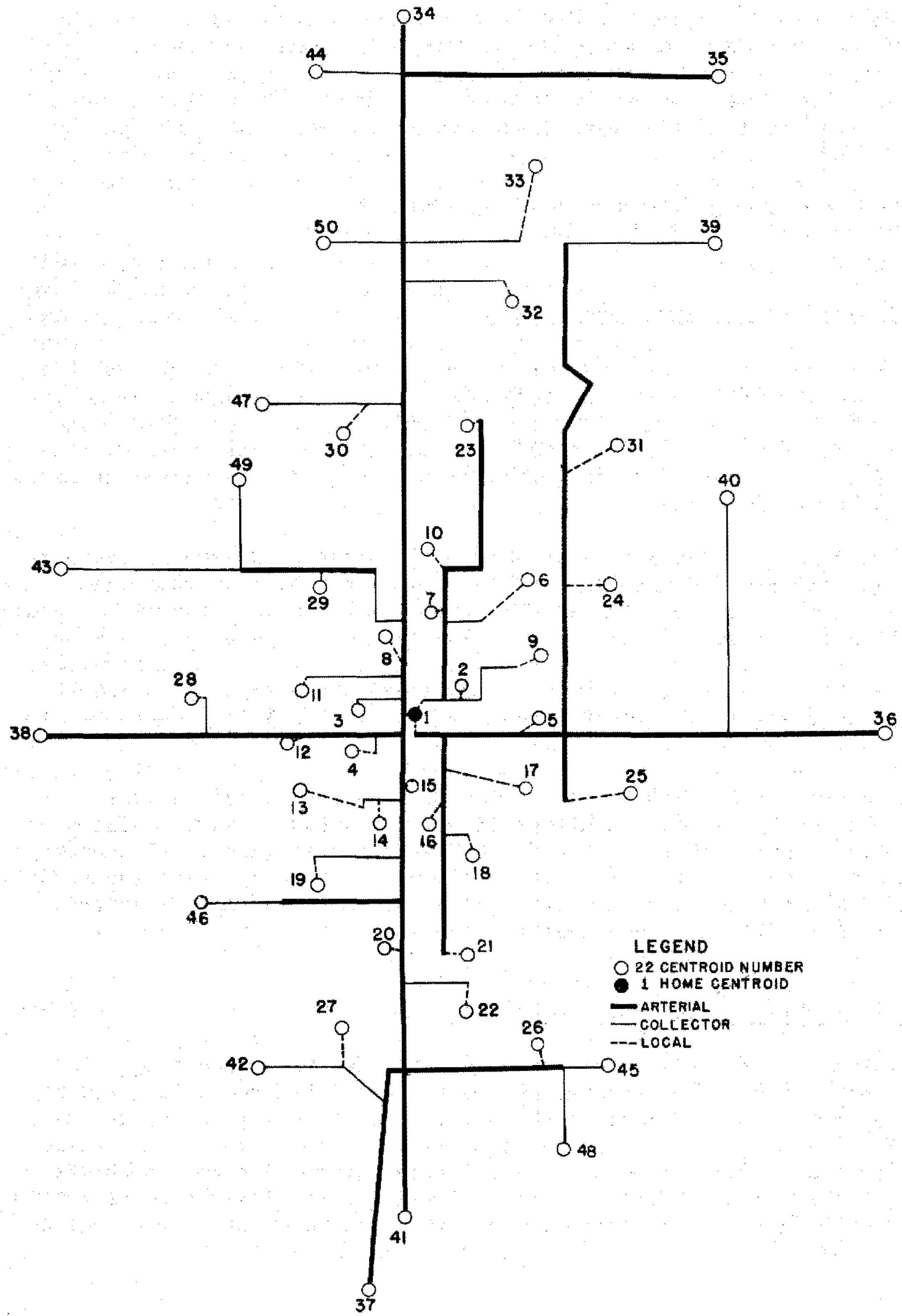



FIGURE 11 MINIMUM TIME ROUTES FOR ZONE 1.

The evaluation of assigned traffic volumes was separated into two parts. The first part included an analysis of traffic volumes on Arterial links that passed through two east-west screenlines and two north-south screenlines which cut planes of maximum assigned volumes. Existing traffic counts and existing traffic capacities provided a bench mark for the analysis. The second part included a relative analysis of assigned volumes on Arterial and Collector links. Both analyses are summarized in table 5, and the highlights are described below.

1. Assigned volumes on individual links of the Arterial system appeared reasonable in light of geographical locations, actual traffic counts, and traffic capacities of the links. For example, link 107-114, which is in the central business district, had an assigned volume of 8,828, a counted volume of 12,300, and a traffic capacity of 9,200; whereas link 108-115, which is a parallel link in the same corridor, had an assigned volume of 7,548, a counted volume of 3,370, and a traffic capacity of 7,600. The assignment to these two links based on proposed functional use resulted in a better balance with traffic capacity than the existing usage did as indicated by volume counts.

2. Maximum assigned volumes on Collector and Arterial links for the same directional movement in similar locations were in agreement with the level of traffic service provided by the links. Near the central business district, for example, Collector link 194-172 had an assigned volume of 3,196 as opposed to 7,224 on Arterial link 71-108. This relationship was also apparent in outlying areas as illustrated by Collector link 310-76 which had an assigned volume of 856 and Arterial link 85-216 which had an assigned volume of 1,432.

Traffic volumes on heavily traveled links of the functional network appeared to bear a logical relationship both to function and location. Although the lower volume links did not always reveal such a relationship, this does not necessarily mean that the lower volume links were incorrectly classified since the link with higher level of service might be serving longer trips as will be subsequently discussed.

## Evaluation of diminishing returns concept

The proposed functional systems were evaluated for the concept of diminishing returns (i.e., maximizing service with minimum mileage of high level systems) by comparing the percent of vehicle-miles of travel on each functional system with the percent of road mileage in the system. As illustrated in table 6, the Arterial system, with 23.8 percent of road mileage, served 78.2 percent of total VMT while the Collector and Local systems, with 18.0 percent and 58.2 percent of total road mileage, served only 11.4 percent and 10.4 percent of total VMT, respectively.

TABLE 5--COMPARISON OF ASSIGNED VOLUMES, TRAFFIC COUNTS, AND TRAFFIC CAPACITIES

| Link Number | | Assigned Volume | 1961 Traffic Count | 1961 Traffic Capacity 5/ |
|---|---|---|---|---|
| | | North-South Arterials | | |
| 306-305 | | 2,784 | 2,750 | 18,200 |
| 195-107 | | 8,404 | 12,020 | 9,200 |
| 172-108 | | 4,988 | 2,640 | 6,900* |
| 177-109 | | 1,548 | 1,910 | 4,200* |
| 305-304 | | 2,804 | 3,200 | 18,200 |
| 107-114 | | 8,828 | 12,300 | 9,200 |
| 108-115 | | 7,548 | 3,370 | 7,600* |
| 109-122 | | 1,748 | 1,370 | 4,200* |
| | Total | 38,652 | 39,560 | 77,700 |
| | | East-West Arterials | | |
| 302-146 | | 2,432 | 2,020 | 10,500 |
| 133-134 | | 916 | 2,700 | 5,300 |
| 106-107 | | 5,608 | 7,360 | 8,800* |
| 94-95 | | 1,376 | 2,130 | 4,100 |
| 146-147 | | 1,228 | 620 | 2,700 |
| 134-135 | | 2,720 | 2,590 | 4,100 |
| 71-108 | | 7,224 | 6,520 | 8,800* |
| 95-96 | | 1,072 | 1,890 | 4,400 |
| 85-216 | | 1,432 | 1,610 | 3,400 |
| | Total | 24,008 | 27,440 | 52,100 |
| | | Selected Collectors | | |
| 310-76 | | 856 | 2,290 | -- |
| 194-172 | | 3,196 | 2,970 | -- |
| 141-142 | | 1,740 | 1,580 | -- |
| 162-104 | | 1,216 | 1,140 | -- |
| 119-113 | | 1,748 | 1,640 | -- |
| 86-79 | | 932 | 1,590 | -- |

* The computation of traffic capacities reflects the removal of parking.

5/ Peak hour traffic capacities were expanded to 24-hour traffic capacities by means of a factor based on a peak hour of 9 percent and a directional split of 60-40.

With the exception of a slightly larger percentage of road mileage in the Collector system and a slightly lesser percentage in the Local system, the above findings compared quite favorably with results of conventional classification studies in urban areas of similar size. This indicated that perhaps an analysis and reclassification of marginal Collectors would have been appropriate. Although a reclassification was not undertaken, it would not have been difficult to accomplish with the detailed data from the traffic assignment process.

TABLE 6--COMPARISON OF ROAD MILES, VEHICLE-MILES OF TRAVEL, AND VEHICLE-HOURS OF TRAVEL *

| Functional System | Percent Road Mileage | Percent Vehicle-Miles Of Travel | Percent Vehicle-Hours Of Travel |
|---|---|---|---|
| Arterial | 23.8 | 78.2 | 65.6 |
| Collector | 18.0 | 11.4 | 12.9 |
| Local | 58.2 | 10.4 | 21.5 |
| Total | 100.0 | 100.0 | 100.0 |

* Road mileage scaled from maps
VMT and VHT do not include intrazonal travel

It was interesting and significant that the Arterial system served a percentage of total VMT that equaled the percentage of total VMT produced by the top 40 percent of total zones. These zones formed the basic framework in the schematic network which served as the basis for laying out the Arterial system. Such a relationship between VMT produced by an increment of zones and VMT served by a functional system connecting those zones is implied in the concept of diminishing returns. There, however, is little more than inference to support the relationship in this particular case, and its general applicability should await the results of more detailed analysis during the proposed second phase of this project.

The relative level of traffic mobility of each system was reflected in the relationship between percent of vehicle-miles of travel and percent of vehicle-hours of travel on each system. As shown in table 6, the Arterial system served 78.2 percent of VMT while involving only 65.6 percent of VHT. The Collector and Local systems, on the other hand, revealed an opposite relationship in that they respectively served 11.4 percent and 10.4 percent of VMT while involving 12.9 percent and 21.5 percent of VHT.

Evaluation of trip length concept

The evaluation of the functional network for the concept of trip length (i.e., the relationship between length of trip and level of service) was separated into two parts as described below.

In the first part of the analysis, each functional system was analyzed for the effect of assigning trips of selected time length. The logic was to initially assign all trips and to follow with successive assignments which deleted increments of shorter trips. The results of these assignments are summarized in table 7.

TABLE 7--ASSIGNMENT OF TRIPS OF SELECTED TIME LENGTH

| Selected Time Length * | Percent Total Trips | Percent Total Vehicle-Miles Of Travel | Percent Of Assigned Vehicle-Miles Of Travel | | |
|---|---|---|---|---|---|
| | | | Arterial | Collector | Local |
| 0 - Max. | 100.0 | 100.0 | 78.2 | 11.4 | 10.4 |
| 3 - Max. | 68.0 | 88.0 | 82.0 | 10.0 | 8.0 |
| 5 - Max. | 35.0 | 64.0 | 87.5 | 7.2 | 5.3 |
| 8 - Max. | 13.0 | 35.0 | 92.5 | 4.2 | 3.3 |

* Maximum trip length = 16.0 minutes
Average trip length = 5.2 minutes

As illustrated in table 7, there was a substantial difference between the rates of change of percent total trips and of percent total VMT as successive increments of trips of shorter time length were deleted. The fact that percent total VMT decreased at a much slower rate reflects the influence of long trips on VMT. With the relationship between trips and

VMT in mind, it was significant to note the effect on relative rates of change of percent VMT between functional systems. As successive increments of trips of shorter time length were deleted, the percent VMT on the Arterial system increased while the percent VMT on the Collector and Local systems decreased. This demonstrates the relationship between length of trip served by a system and level of service provided by a system.

The above relationship was further substantiated through an analysis of link volumes. The principal finding here was that the effect on assigned volumes from the deletion of increments of shorter trips was much less pronounced on Arterial links than was the case for Collector links. The effect, however, was not uniformly distributed over the network. The basic reasons for the nonuniformity are discussed in the second part of the evaluation concerning average trip length [6/] on links.

The analysis of average trip length not only verified the basic relationship between length of trip and functional system but it also refined the relationship by showing that for a given study area the length of trips varies by geographical location or trip density and by the physical configuration of the study area or network. This refinement in conjunction with traffic volumes provides an important key to the functional analysis of highway networks.

Table 8 illustrates the above discussion by comparing average trip lengths and traffic volumes on pairs of links in relation to function, geographical location, and cardinal direction of the links. The principal points illustrated are described below.

1. For a specific pair of links, values for average trip length and traffic volume on the Arterial link exceeded values on the Collector link.

2. Average trip lengths increased and traffic volumes decreased as the distance of location from the central business district increased. Consequently, values for average trip length and traffic volumes on Collector links in a particular location did exceed values on Arterial links in a different location.

3. Values for average trip lengths and traffic volumes on east-west links were generally lower than values were on north-south links. This can be attributed to the fact that travel and the physical configuration of the study area are oriented to the north and south.

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6/ Average trip length in miles was determined through a process of (a) developing a VMT table, (b) assigning the VMT table to the network, and (c) dividing the assigned VMT on a link by the assigned volume on the link. (The assigned VMT on a link represents the total VMT from origin to destination of all trips which traversed the link. Therefore, dividing this value by the number of trips which traversed the link gives the average or mean trip length on the link.)

TABLE 8--AVERAGE TRIP LENGTH ON LINKS

| Link Number | Functional System | Cardinal Direction | Location In Relation to CBD | Assigned Volume | Average Trip Length |
|---|---|---|---|---|---|
| 309-85 | Arterial | N-S | Outlying | 6,800 | 5.2 |
| 79-86 | Collector | N-S | Outlying | 932 | 2.1 |
| 107-114 | Arterial | N-S | Near | 8,828 | 1.9 |
| 106-192 | Collector | N-S | Near | 2,716 | 1.4 |
| 305-304 | Arterial | N-S | Outlying | 2,804 | 6.2 |
| 116-123 | Collector | N-S | Outlying | 756 | 2.0 |
| 104-210 | Arterial | E-W | Intermediate | 2,212 | 2.0 |
| 193-202 | Collector | E-W | Intermediate | 876 | 1.1 |
| 106-107 | Arterial | E-W | Near | 5,608 | 1.6 |
| 222-170 | Collector | E-W | Near | 1,128 | 0.6 |
| 108-203 | Arterial | E-W | Intermediate | 3,456 | 2.0 |
| 198-175 | Collector | E-W | Intermediate | 708 | 1.1 |

In addition to a few cases being brought to light where routes were incorrectly classified, there were exceptions to the above points. These exceptions, however, can usually be traced to some peculiarity of the study area or traffic simulation process. An isolated zone, for example, might produce relatively long trips which would result in a relatively long average trip length on a Collector route serving the zone. The fact that external trips are terminated at the external centroids can result in a distortion of average trip lengths near these centroids.

## PART IV--CONCLUSIONS AND ACKNOWLEDGEMENTS

### Conclusions

Although the conclusions set forth below are based on an analysis of one small urban area, they are believed to be of sufficient basic soundness to be generally applicable. Further evaluations using data from statewide studies or larger urban areas, however, may result in refinements or additions to the techniques. The conclusions follow:

1. The basic concepts of functional highway classification and the computer techniques of traffic simulation are completely compatible. When applied as a team, they complement each other and provide a powerful tool for highway network analysis.

2. The evaluation of a functionally classified highway network by means of traffic simulation provided excellent verification of the concept of how traffic should flow in such a network.

Acknowledgements

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