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OPTIMUM STAGING OF PROJECTS IN COLORADO URBAN AREAS

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16. Abstract

The primary purpose of this study was to test the feasibility of employing an optimum staging of projects methodology, as developed by Schimpeler-Carradino Associates, to a larger highway network. In the calibration process it became apparent that the methodology has to be modified in order to keep down computer cost. The resulting modified effective speed method appears to satisfactorily describe a highway network that is consistent with one that has evolved during the time period in question. Of great importance to a successful evaluation of priorities are the various Transportation System files as well as the 20 year highway plan which identifies the individual improvement projects. Depending on the network size the computer charges could prove very costly, unless some future research is conducted to improve the program efficiency as discussed in this study.

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INTRODUCTION

Problem Statement

Many agencies that are charged with the responsibility of providing an efficient system of urban roadways face the dilemma of coordinating available budgets with future needs for network expansion. The most common method of project planning is based on a Five-Year Plan where the budget is applied to that time period as expansion needs dictate, based upon traffic volumes, capacity or other conventional methodologies. This method is consequently limited to this five year period and does not consider needs beyond this time until the plan is updated. The need to look further into the future is obvious, especially in areas containing complex land use patterns. Ideally, this assessment of highway needs should identify projects needed for adequate highway system expansion, construction priorities, and when an improvement should be made in relation to other proposed improvements. For reasons of efficiency and expediency, every effort should be made to utilize existing or readily obtainable data, such as information from transportation assignment models, in the staging of these highway projects.

A literature search was conducted to determine if any agency had attempted to systematically and optimally prioritize new construction or expansion of roadway networks. Most reports recommended methodologies not significantly different from those currently used in Colorado. One report entitled "Optimum Staging of Projects in a Highway Plan" appeared to satisfy the requirements. This report, Volume I (Main Report) March 1974, was prepared for the U.S. Department of Transportation by Shimpeler-Carradino Associates.(1) The methodology demonstrated the applicability of optimum staging of projects in a highway plan to small urban area transportation networks. The report included a plan for applying the staging technique to larger urban areas. This concept was pursued by the Colorado Department of Highways in this study.

Background and Significance

The research objectives of the Schimpeler-Carradino report were aimed at the following areas:

1. To define effective methods for staging a twenty-year highway system growth or development by intermediate periods.
2. To test alternative methods and to identify the one that is most appropriate for use in the analysis of large scale highway networks.

3. To conduct system tests that will demonstrate the capability of the analysis method selected.
4. To document all methods and tests, regardless of their current utility for large network applications, in order to provide subsequent researchers with a description of all research findings associated with this program.

Three methodologies were employed to arrive at a solution in that report. Two of the methods use a heuristic approach. The third is a mathematical method to define the optimal solution.

Of the two heuristic methods, the first discussed is the effective speed solution. The term "Effective Speed" as used throughout the report is based on the mean speeds of trips on each of the one to ten mile trip length. All trips are disaggregated on basis of trip lengths and when loaded onto the network using the FHWA battery of planning programs the mean speed for each trip length increment is calculated. A detailed description of this process can be found in the Research Approach section of this report. In its basic form it provides an approximation of cost effectiveness as follows:

$$\frac{VMT_I}{C}$$

where VMT_I = Vehicle miles of travel on proposed link improvements over and above their practical capacity before improvement

C = Implementation cost

The required link volumes were extracted from a traffic assignment using the battery of planning programs. Testing of the procedure involved a disaggregation of forecast year trip-tables into three components on the basis that the effective speed for each zonal interchange was lower, the same, or higher than some standard. The test network in the report was that of Hopkinsville, Kentucky, with a design year plan that identified sixteen improvement segments. Repetitive runs of the FHWA transportation battery programs and conventional transportation planning procedures identified improvements that should be implemented during the first fifteen years of the recommended twenty year program. The application of the effective speed method yielded the same staging recommendations as was obtained from more conventional techniques. Thus, it was concluded that the effective speed method was a valid and effective transportation planning tool. With some further refinement (Senju-Toyoda method, see Appendix B) the researchers of the Kentucky report obtained the optimal solution for the test problem and concluded that this approach is valid for evaluation of larger networks.

The second heuristic method involves travel time on the network links. The "Time Saved" solution is also an approximate model, utilizing the time saved as a result of improvement to the existing system. In this approach vehicle trips are loaded on the existing network using the FHWA battery of planning programs including the proposed link improvements, based on minimum time paths. In this fashion system-wide time is obtained. The decrease in travel time as a result of adding a link is then divided by its implementation cost yielding a measure of cost-effectiveness for that specific link. Total system-wide vehicle travel time saved is obtained by subtracting vehicle travel-hours, resulting from the forecast-year assignment to the existing including the proposed system, from the vehicle travel-hours produced by an assignment to only the base year system. Improvements are then inserted that will produce the greatest contribution in time saved per dollar spent. A comparison of the two heuristic methods indicated that both produced accurate answers. The research team also concluded that the "Time Saved" solution has the advantage of operational efficiency, but might create problems in large network applications if a larger percentage of the total time saved had to be allocated using approximate methods.

RESEARCH OBJECTIVES

Using data files as defined in the Kentucky report consisting of the base year highway network, a future year network, available budgets in five year increments, and a trip table for travel demands in five year increments, this study attempted to define an optimum assignment of construction projects in five year intervals to complete the twenty year highway plan within budget restrictions. To accomplish this goal, the guidelines specified in the report by Schimpeler-Carradino Associates were followed as close as practically possible.

The highway network that was found to meet most requirements was that of the City of Boulder (Figure 1). With an approximate population of 80,000 the city has experienced traffic problems that are typical of a rapidly growing city. Limited construction budgets that typically are in the order of 1 million dollars annually are not nearly sufficient to combat the ever escalating demand for more new roadway facilities and expansion of old ones. The size of the roadway network seems to fit into the framework of the Kentucky report, which suggested that the methodologies developed should be tested on a larger urban area network. The main approach used in this report was centered on the effective speed methodology. The rationale for this approach was the assumption that was made in the Kentucky report with respect to constant speed on specific links. Since an effective speed table or criteria had to be developed, it was decided to pursue the effective speed methodology to its conclusion, rather than to return to the time saved method. This approach requires much less computer time and thus becomes cost effective. The results of the analysis cannot differ drastically, since the Time-Saved method is mathematically dependent on the Effective Speed method. The savings in computer time is realized in the development of disaggregated trip tables that were computed for the development of the effective speed criteria for each network. If the Time Saved approach were pursued this Trip Table would have to be redeveloped with travel times disaggregated on the basis of mileage.

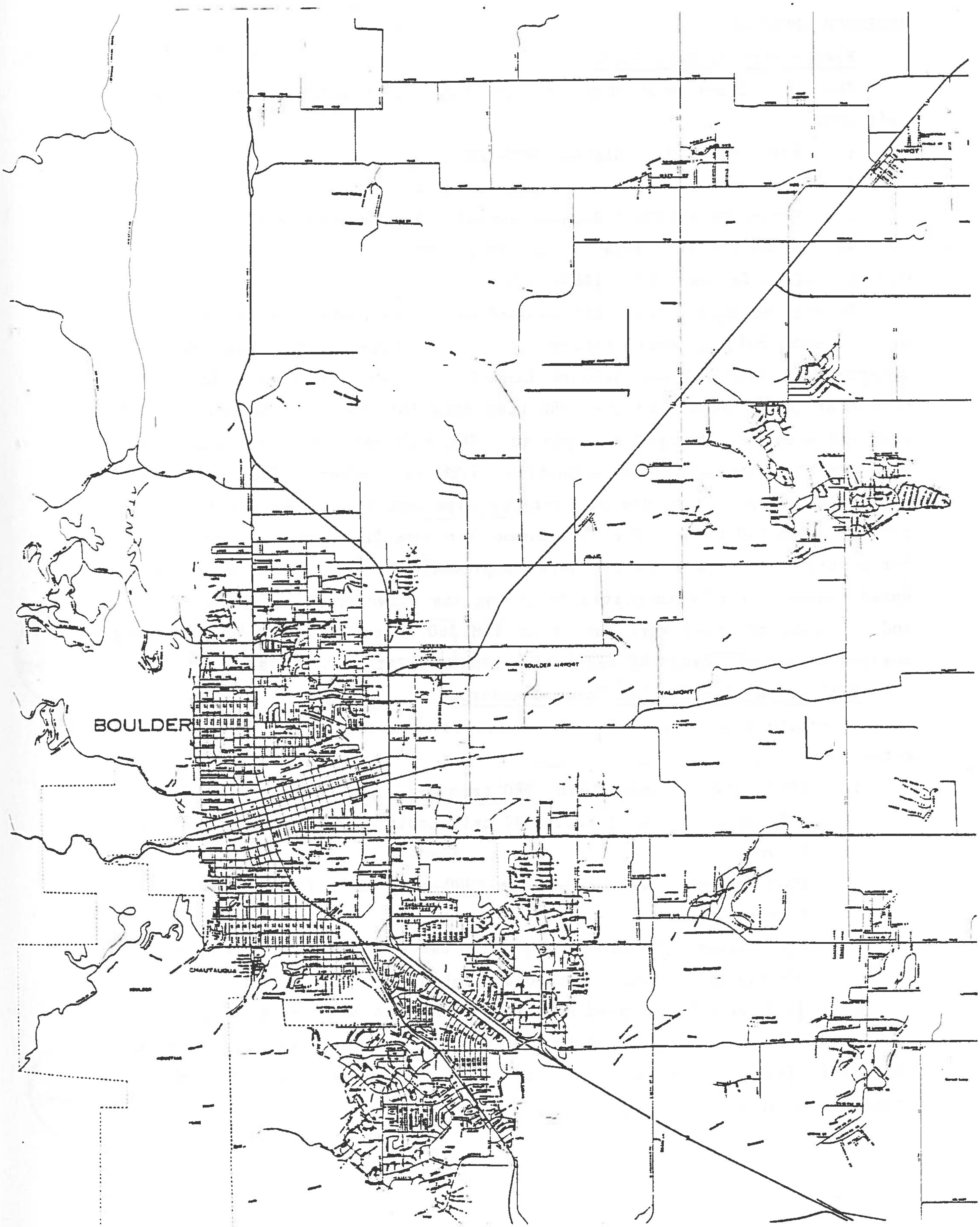


Fig 1

RESEARCH APPROACH

Preparation of Data Files

The data files available for the City of Boulder network were the following:

1. Base Year (1970) Highway Network
2. Intermediate Year (1980) Highway Network
3. Future Year (2000) Highway Network (Recommended network)
4. Socio-Economic data (1970, 1980, 2000)
5. Trip Tables (1970, 1980, 2000)

Before the data files could be used in the evaluation of the staging of project methodology, modifications had to be made to the Base Year and Intermediate Year Highway Network Link Data files. Neither file had the number of lanes coded, and the 1980 Link Data file had to have the facility code and area code changed and updated. These corrections were necessary to make the three network files compatible with each other. The main reason, besides the required update of facility type and area code, was the coding format, which had been in the UTPS format for some files and the FHWA battery for others. After all changes were completed, the development of effective speed tables could be initiated following the flowcharts (see Figures 2, 3, and 4). All programs were run on an IBM 360 computer. Program and input changes were facilitated by means of a remote teletype terminal.

Evaluation of Effective Speed Standards

Effective speed tables were computed for the following roadway network situations:

1. 1970 Network loaded with 1980 trip table (Do-nothing alternative)
2. 1980 Network loaded with 1980 trip table (Intermediate recommended Network)
3. 2000 Network loaded with Year 2000 trip table (Future recommended Network)
4. 1970 Network loaded with 1970 trip table (person trips as opposed to vehicle trips, which were unavailable)

This last effective speed table was computed with person trips only because vehicle trip tables were not available for the base year. Table 1 lists all effective speeds for all trip length increments along with their standard deviation.

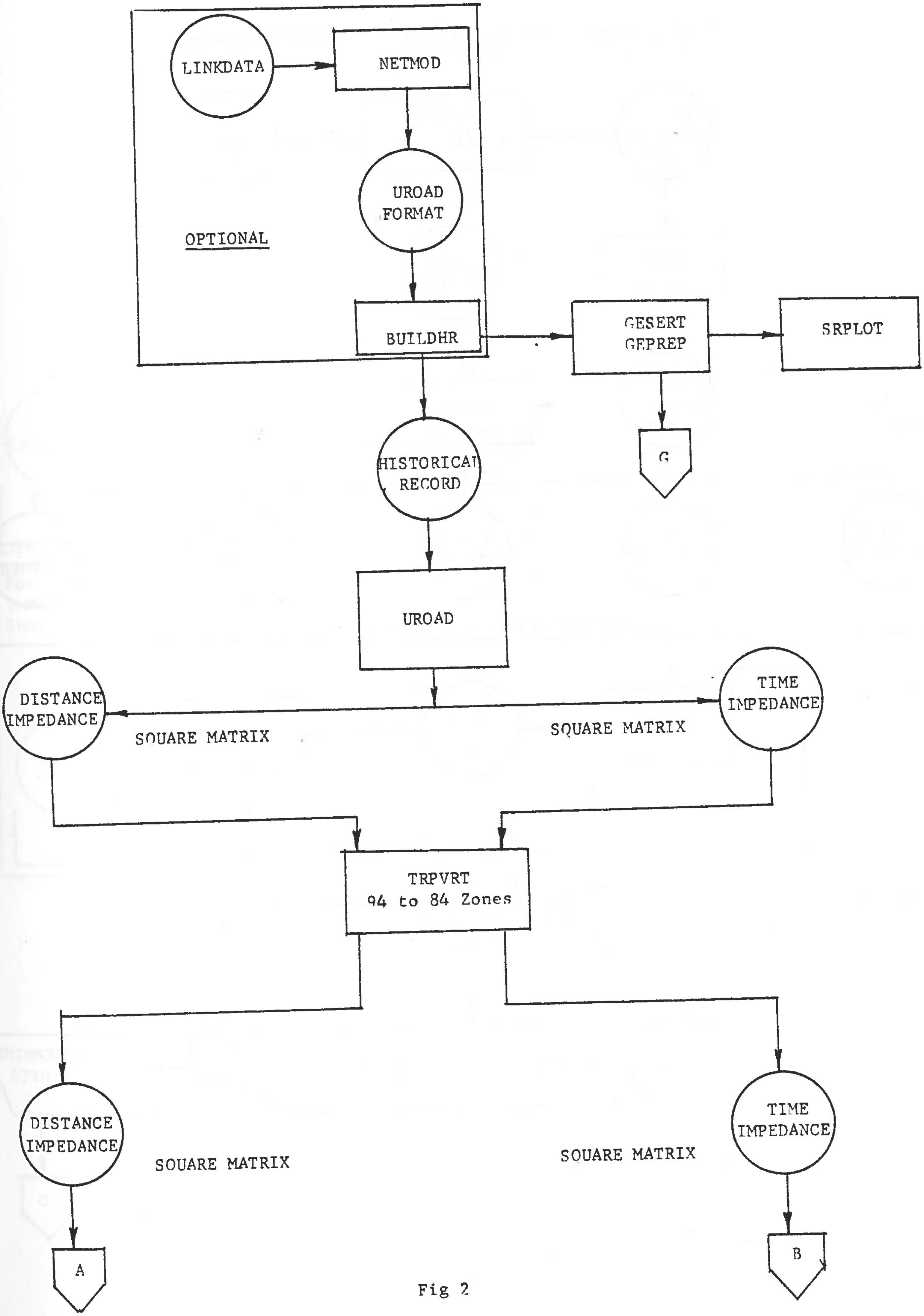

LINKDATA
NETMOD
UROAD
FORMAT
OPTIONAL
BUILDHR
GESERT
GEPREP
SRPLOT
G
HISTORICAL
RECORD
UROAD
DISTANCE
IMPEDANCE
SQUARE MATRIX
SQUARE MATRIX
TIME
IMPEDANCE
TRPVRT
94 to 84 Zones
DISTANCE
IMPEDANCE
SQUARE MATRIX
SQUARE MATRIX
TIME
IMPEDANCE
A
B

Fig 2

FLOW DIAGRAM TO ESTABLISH EFFECTIVE SPEED STANDARDS

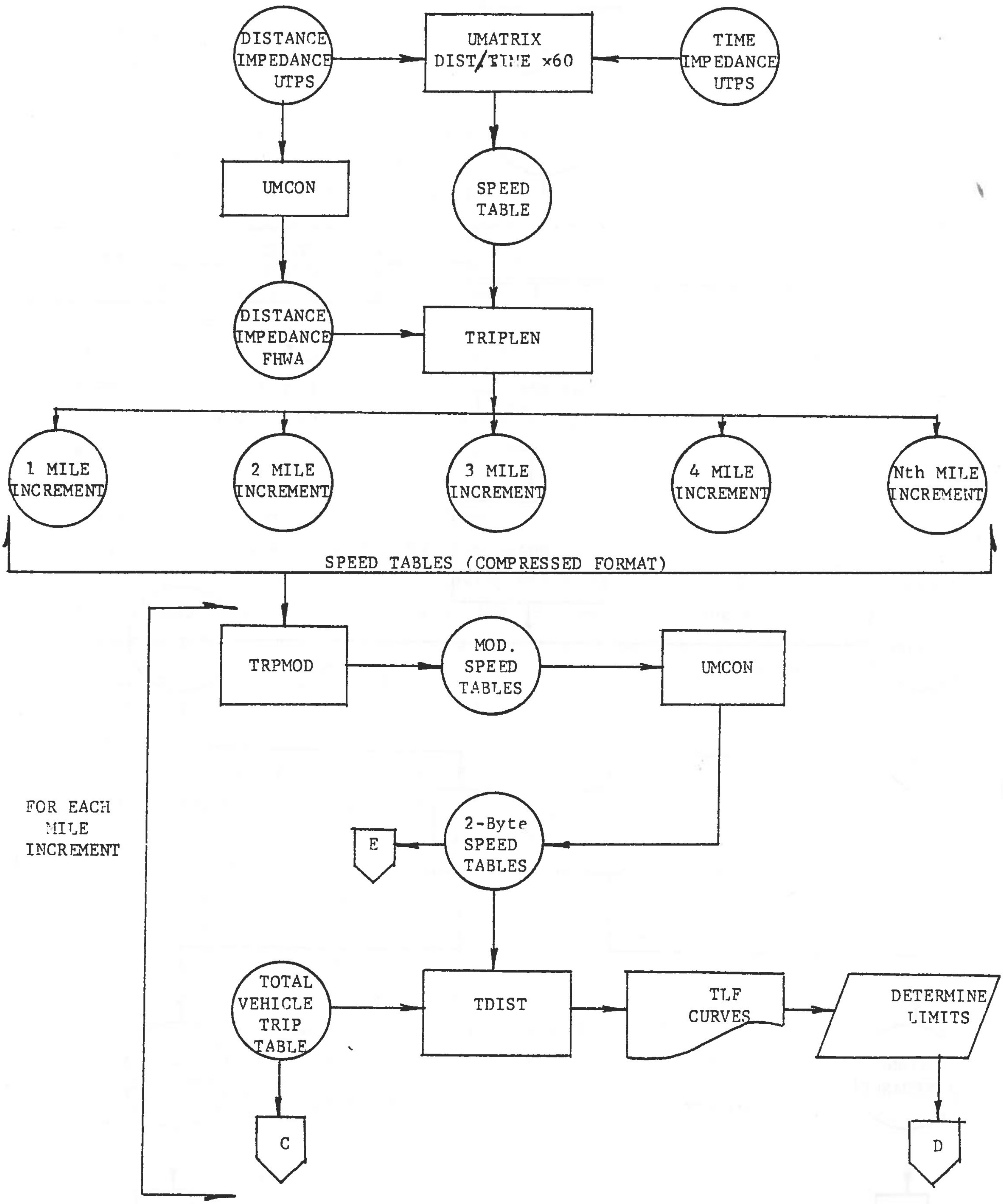


Fig. 2

FLOW DIAGRAM TO DETERMINE BELOW STANDARD LINKS

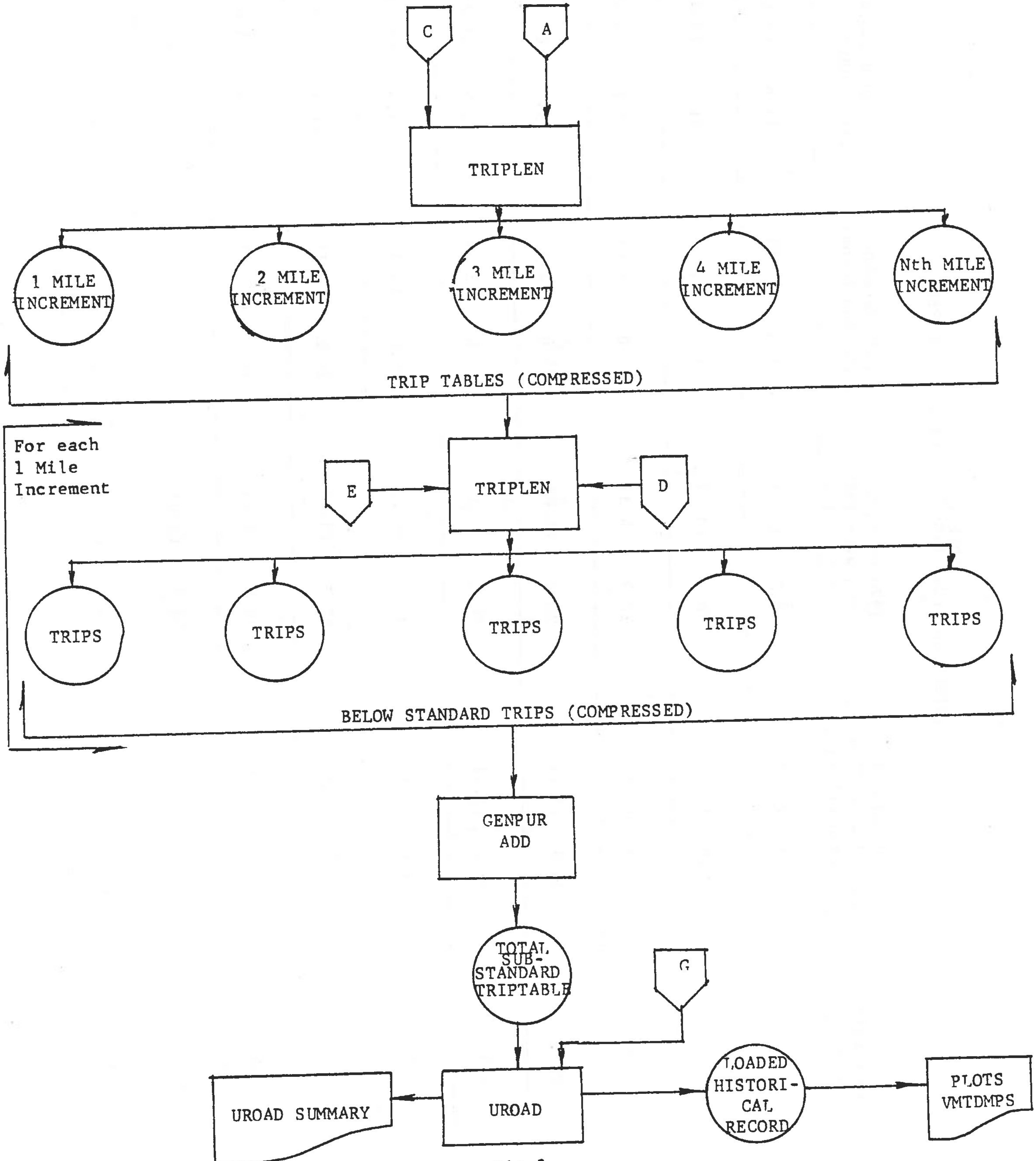
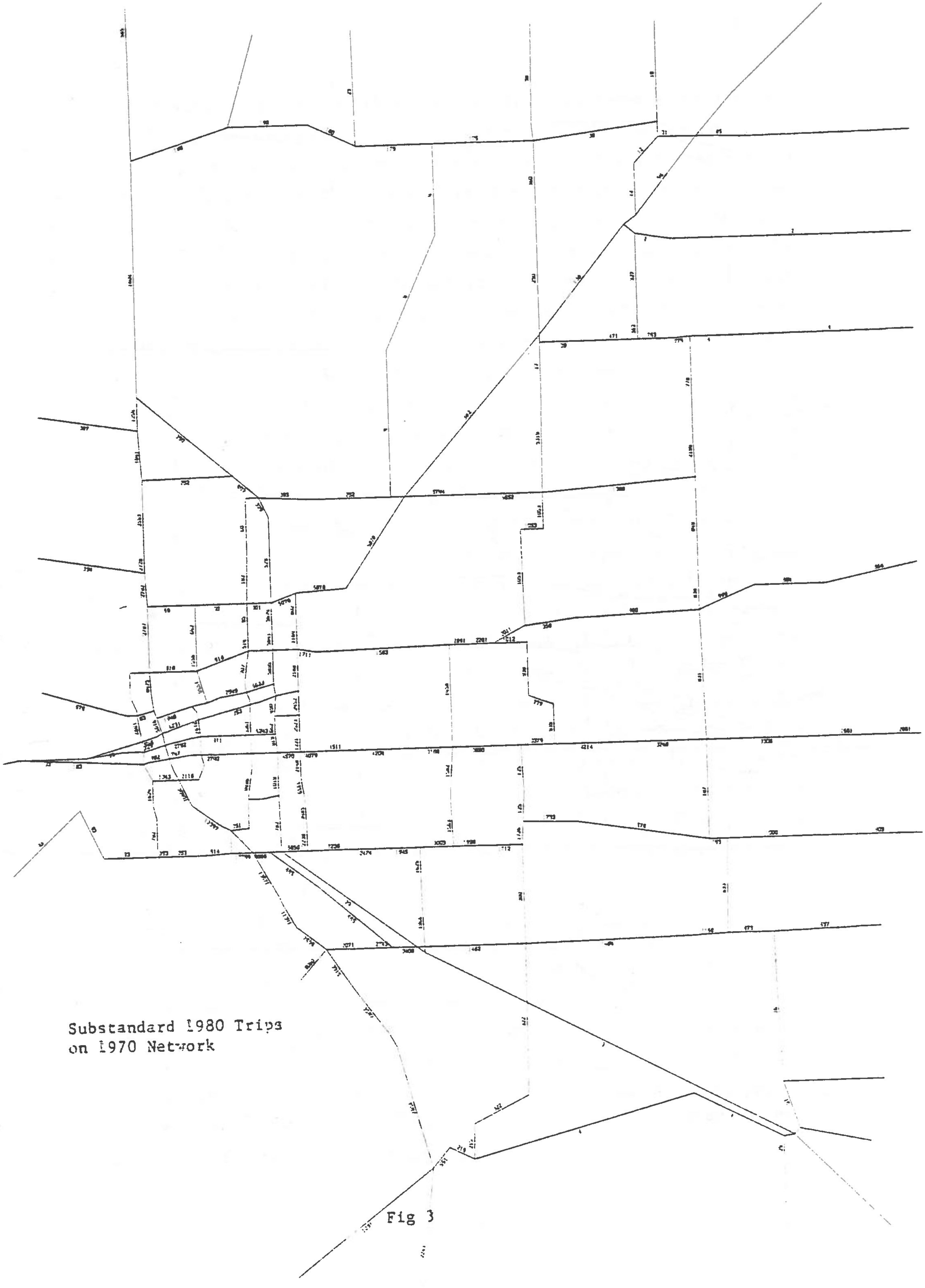


Fig 2

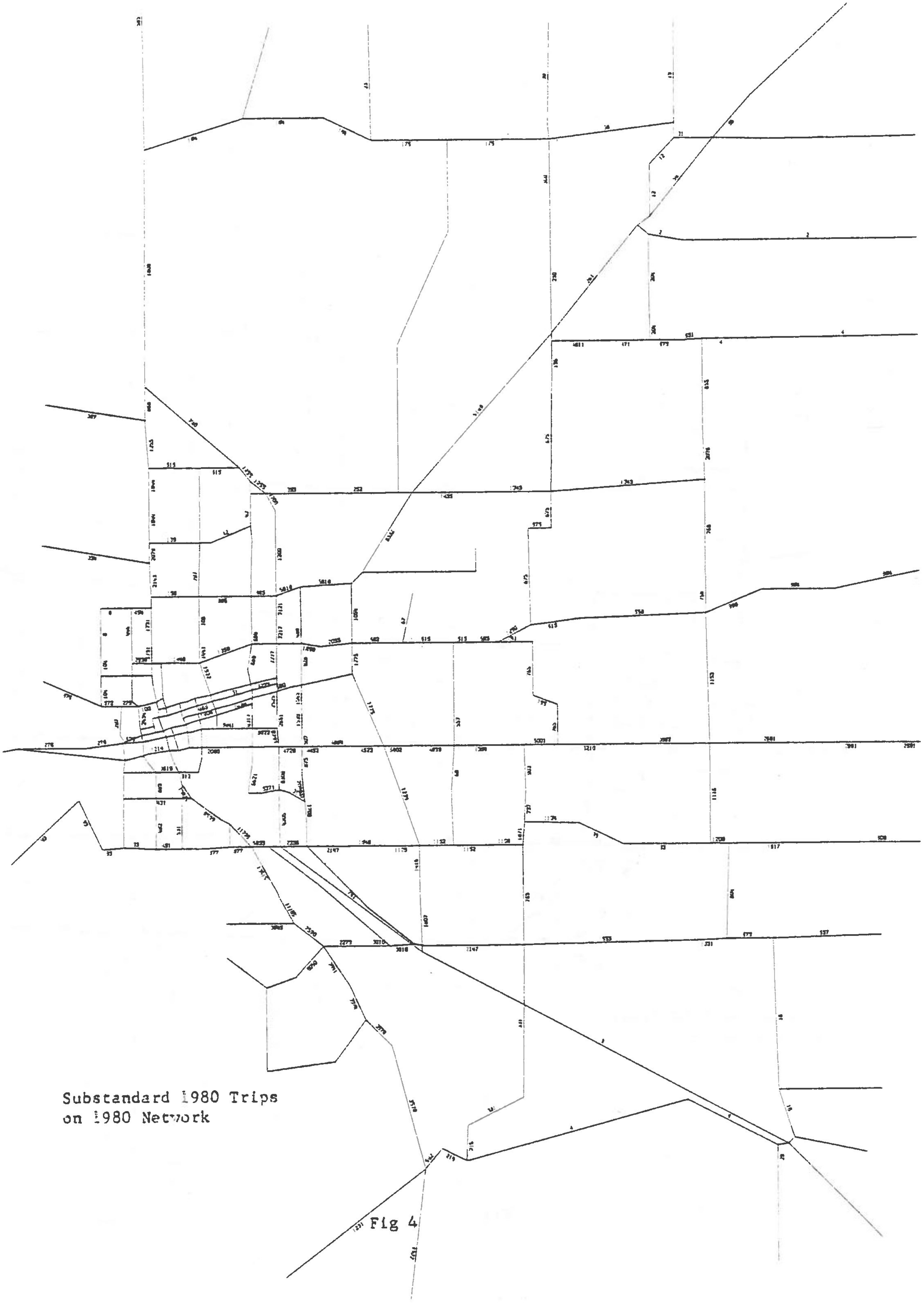
TABLE 1
EFFECTIVE SPEED TABLE FOR CITY OF BOULDER

Trip Length Miles	1970 Network (Loaded with 1970 person trips)		1970 Network (Loaded with 1980 vehicle trips)		1980 Network (with 1980 trips)		2000 Network (with 2000 trips)	
0-1	18.5	(3.7)	18.2	(3.6)	19.3	(3.5)	17.8	(2.6)
1-2	20.6	(3.2)	20.2	(3.7)	21.5	(2.6)	21.2	(3.9)
2-3	22.3	(3.1)	22.9	(4.3)	24.0	(2.6)	23.0	(3.5)
3-4	24.9	(4.1)	25.4	(5.0)	25.8	(3.9)	24.9	(4.0)
4-5	25.7	(3.4)	26.8	(4.3)	27.6	(3.5)	26.9	(3.7)
5-6	30.7	(4.3)	31.3	(4.2)	31.5	(4.3)	29.5	(4.5)
6-7	33.2	(3.2)	33.7	(3.7)	34.2	(3.7)	31.5	(4.6)
7-8	35.9	(5.8)	35.6	(5.7)	36.1	(5.4)	33.9	(5.6)
8-9	34.9	(4.2)	34.7	(4.0)	36.0	(4.1)	34.1	(4.3)
9-10	35.0	(2.7)	34.1	(3.0)	35.9	(3.4)	34.1	(3.3)



Substandard 1980 Trips
on 1970 Network

Fig 3



Substandard 1980 Trips
on 1980 Network

Fig 4

The following sequence describes how the effective speeds were attained and what programs were utilized in the process. (Refer to Figures 2, 3, and 4.) The first computer program used was UROAD to create distance and a time impedance tables from the appropriate Boulder highway network (i.e. 1970, 1980 and 2000). The distance table was then divided by the time impedance table using program UMATRIX to compute a total speed table. The distance table was also processed through program UMCON to convert it from UTPS 2—byte format to FHWA 2—byte format for program TRIPLEN. In addition to the converted distance table, the TRIPLEN program required the total speed table (DCB parameters required on TRIPSI1 dataset) to develop a speed table for each 1—mile increment (1—10 miles). Each of the 1—mile increment speed tables was then processed through program TRPMOD to replace all zero speeds with speeds of one mile-per-hour. This modification was necessary for program TDIST to function properly. Program UMCON was then used to convert each of the modified 1—mile increment speed tables from FHWA compressed format to FHWA 2—byte format. Each of the converted 1—mile increment speed impedance tables were then input to program TDIST along with a total vehicle trip table to compute trip length frequency distribution curves. These trip length frequency distribution curves then required some manual manipulation to determine a below standard speed for each of the 1—mile increments (1—10 miles). The average speeds, as specified in the TDIST output (Average Trip Length_2 minutes) are not valid since several Speed Tables were adjusted by replacing all cell values of zero. Therefore all trips at speeds zero to 1.5 had to be excluded from the TDIST output. New average speeds were then computed along with their standard deviation for each mile increment using standard statistical formulas. Table 2 shows a typical TDIST printout with all necessary modifications.

Computation of Below Standard Speed Trips

The effective speed table served as a criteria to establish standard speeds for each mileage increment. Standard speed intervals are obtained by taking the average speed for a particular distance interval and subtracting one standard deviation from it to represent the lower limit of the standard speed interval. Since we were primarily concerned with substandard trips, only the lower class limit needed to be established. Program TRIPLEN was then used to develop ten trip tables (one table for each 1—mile increment) based on distance. Each of these ten tables was then processed through program TRIPLEN

BOULDER YR1970 TLF CURVES (MILE 9-10) 1/11/79

TRIP LENGTH DISTRIBUTION - PURPOSE NO. 1 PAGE 1

SEQUENCE NUMBER	TRIP ~~LENGTH~~ SPEED (MPH) FROM	TO EXCLUDING	TRIPS	Percent of Total	PERCENT OF TOTAL	Accumulated Percent	ACCUMULATED PERCENT
1	ZERO	1.50	~~351,436~~		98.412		98.412
2	1.50	2.50			0.0		98.412
3	2.50	3.50			0.0		98.412
4	3.50	4.50			0.0		98.412
5	4.50	5.50			0.0		98.412
6	5.50	6.50			0.0		98.412
7	6.50	7.50			0.0		98.412
8	7.50	8.50			0.0		98.412
9	8.50	9.50			0.0		98.412
10	9.50	10.50			0.0		98.412
11	10.50	11.50			0.0		98.412
12	11.50	12.50			0.0		98.412
13	12.50	13.50			0.0		98.412
14	13.50	14.50			0.0		98.412
15	14.50	15.50			0.0		98.412
16	15.50	16.50			0.0		98.412
17	16.50	17.50			0.0		98.412
18	17.50	18.50			0.0		98.412
19	18.50	19.50			0.0		98.412
20	19.50	20.50			0.0		98.412
21	20.50	21.50			0.0		98.412
22	21.50	22.50			0.0		98.412
23	22.50	23.50			0.0		98.412
24	23.50	24.50			0.0		98.412
25	24.50	25.50			0.0		98.412
26	25.50	26.50			0.0		98.412
27	26.50	27.50	3	0.1	0.001	0.1	98.413
28	27.50	28.50	43	0.8	0.012	0.9	98.425
29	28.50	29.50	10	0.2	0.003	1.1	98.428
30	29.50	30.50	458	8.1	0.128	9.2	98.556
31	30.50	31.50	222	3.9	0.062	13.1	98.618
32	31.50	32.50	309	5.4	0.087	18.5	98.705
33	32.50	33.50	614	10.8	0.172	29.3	98.877
34	33.50	34.50	144	2.5	0.040	31.8	98.917
35	34.50	35.50	1,288	22.7	0.361	54.5	99.278
36	35.50	36.50	1,372	24.2	0.384	78.7	99.662
37	36.50	37.50	386	6.8	0.108	85.5	99.770
38	37.50	38.50	285	5.0	0.080	90.5	99.850
39	38.50	39.50			0.0		99.850
40	39.50	40.50	537	9.5	0.150	100.0	100.000

TOTAL TRIPS THIS PURPOSE	357,107
TOTAL TRIP HOURS OF TRAVEL	~~9,162~~
AVERAGE TRIP LENGTH (MINUTES)	~~1.54~~
STANDARD DEVIATION	~~4.28~~
TOTAL INTRA TRIPS THIS PURPOSE	~~91,435~~

$\mu = 35.0$ (average speed)

$\sigma = 2.7$

TABLE 1

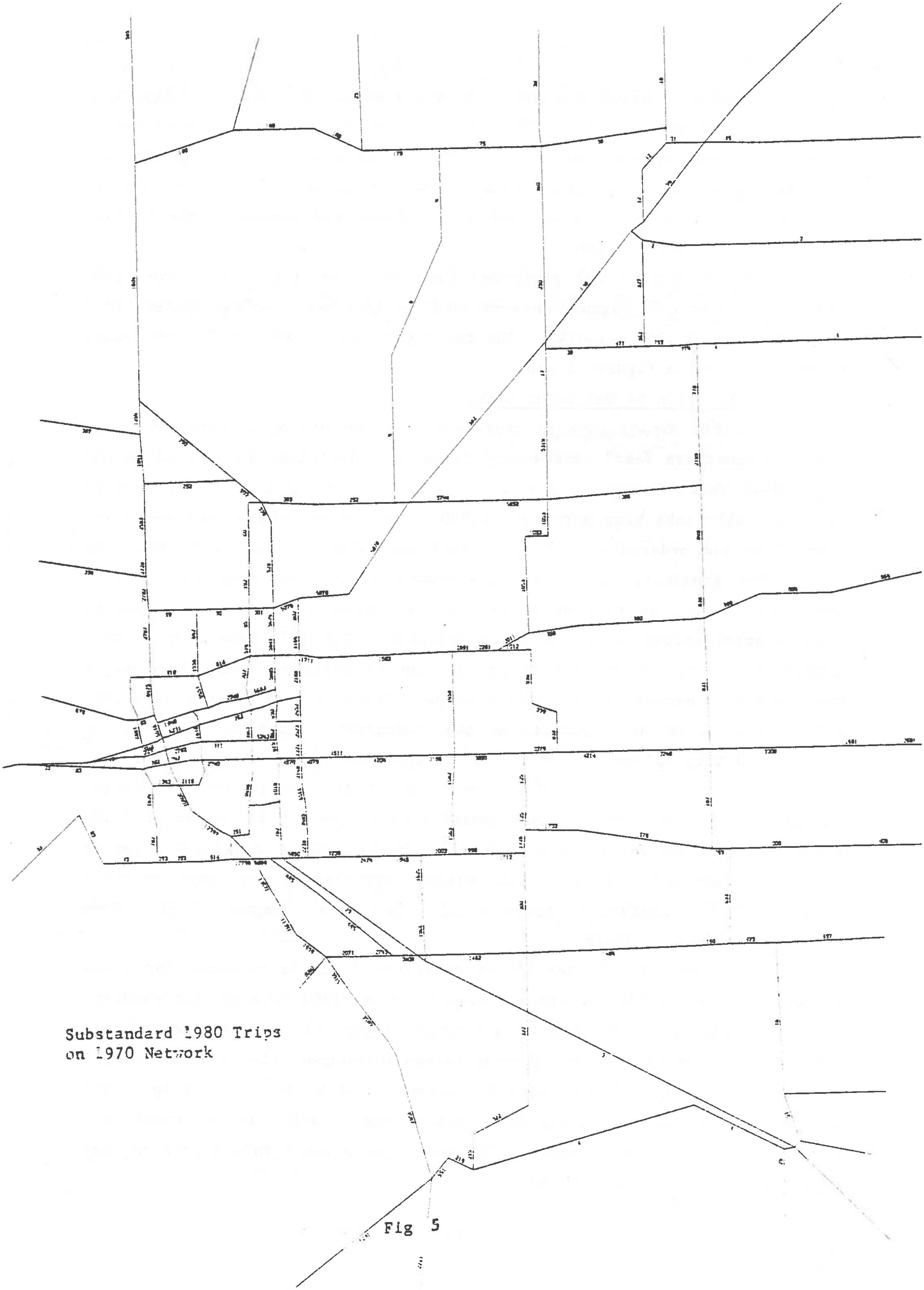
again to develop 10 below standard trip tables using the lower class limits of the standard speed intervals. The resulting ten below standard speed tables were then summed together using program GENPUR and loaded onto the appropriate highway network using program UROAD. The output from UROAD was used to generate a plot of vehicle volumes with substandard speeds on the highway network under consideration.

The above process was performed for the Do-Nothing alternative (1980 vehicle trips on 1970 highway network) and the Intermediate-Year System (1980 vehicle trips on 1980 network). The two system maps loaded with substandard trips are shown in Figures 5 and 6.

Identification of Deficient Links

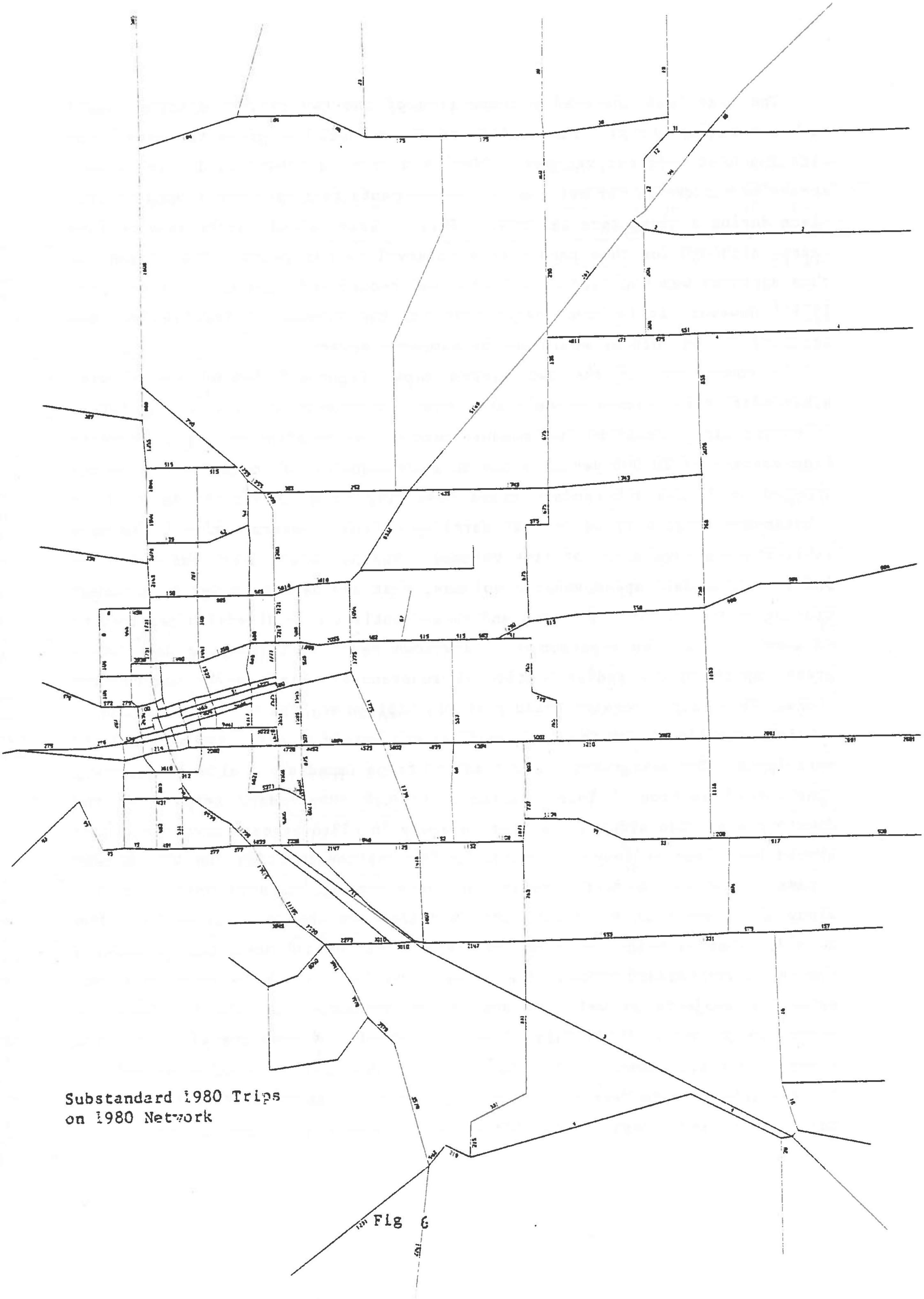
The system map (Figure 5) represents the do-nothing alternative where 1980 (Intermediate Year) substandard trips are identified and loaded on the 1970 (Base Year) Network. The most seriously deficient links are easily located. All links with more than 2,000 trips having substandard speed are identified and ordered according to deficient link volumes, with the link having the greatest number of substandard trips receiving the rank 1. Individual links, or in some cases, entire corridors can be identified as problem areas according to the above criteria. The 1970 Base Year Network loaded with 1980 substandard trips, as can be observed, show three major corridors with excessive substandard trips. Critical link volumes of 20,000 substandard trips are evident on the south-north corridor as well as substandard trip volumes of 18,000 at one intersection on the same corridor. All these links are within close proximity of the University of Colorado Campus. Other links exhibit substandard trip volumes in the order of 5,000 trips. These links serve business establishments such as Crossroads Shopping Center. Other corridors with link volumes approaching the lower criteria limit of 2,000 substandard trips mainly serve the commuter traffic from outlying residential areas.

The same process of identifying deficient links is repeated for a new scenario. Specifically, we are now looking at the 1980 Network (Intermediate network) loaded with 1980 substandard trips (Figure 6). The new network was obtained from the Boulder 1980 highway system historical file, as are the trip volumes. These trip volumes were disaggregated with respect to trip length for the purpose of generating an effective speed table, as explained in a previous section of this report. The resulting below standard trip volumes were then loaded on the 1980 Network.



Substandard 1980 Trips
on 1970 Network

Fig 5



Substandard 1980 Trips
on 1980 Network

Fig 6

The next task involved a comparison of the two network systems loaded with substandard trips. Particular attention should be given to those links with the most critical volumes. Ideally a drop in substandard trip volumes should be noticed to reflect roadway improvements that were envisioned to take place during a given time interval. This interval should preferably be five years, although for this report this interval is ten years. The reason for this approach was the lack of a historical record and trip file for the year 1975. However, it is conceivable that for the purpose of this report, the accuracy of the outcome would not be hampered severely.

A comparison of the two system maps (Figures 5 and 6) loaded with substandard trip volumes reveals that some improvement has been accomplished. Of particular interest is the Broadway corridor which after having substandard link volumes of 20,000 vehicles has as a consequence of improvement projects dropped to 13,000 substandard trips resulting in a 35 percent decrease in substandard vehicle trips on that particular link. Several other links have similar percentage drops of link volumes. One particular link has a drop of 30% in substandard speed vehicle volumes, that can be attributed to a street closing on the University Campus and consequently a trip diversion resulted to adjacent links. The creation of a downtown pedestrian shopping mall had a great impact on the redistribution of substandard trips to the neighboring links. This trip diversion could possibly explain why the new construction of a bypass facility (47th Street bypass) is not nearly as effective as one would anticipate. The assignment of substandard trips immediately affects the newly constructed section. This redistribution of substandard trips from the downtown area also affects the State Highway 36 (28th Street) corridor, which should have been relieved of excess traffic by constructing the 47th Street bypass. However, a fairly heavy concentration of business establishments along 28th Street is evidently more convenient to the motoring public. One corridor that is mainly serving the eastern residential areas barely shows a change in substandard trips. The explanation for this is the absence of any expansion projects as well as lack of new projects that would induce any diversion of trips along this route (Arapahoe). A complete list of links along with their substandard trips for the Do-Nothing alternative as well as for the Intermediate Year can be found in Table 3. As can be observed in this table, there are several links that evidently have a great percentage drop of

TABLE 2

Name of Street & extent of substandard link	Number of Sub-standard trips 1980 trips on 1970 Network	Number of Sub-standard trips 1980 trips on 1980 Network
Broadway; University Ave. to Euclid	20,401	13,875
Baseline; 20th St. to Broadway	17,799	877
Broadway; Baseline to Ash	13,671	13,615
Broadway; Euclid to Baseline	12,397	11,796
Broadway; Ash to Dartmouth Ave.	11,341	11,165
Folsom; Arapahoe to Colorado Ave.	9,496	6,621
Broadway; Pine to Pearl St.	9,105	0
Broadway; Dartmouth to Table Mesa Drive	7,697	7,520
Baseline; Broadway to 28th	6,866	6,833
Broadway; Balsom to Pine	6,475	0
Canyon Blvd; 28th to Folsom	6,243	8,022
Table Mesa Drive; Vassar (Node 603) to Broadway	6,050	6,050
28th Street; Pine to Valmont	5,895	7,777
SH 119; 30th St. to Jay Rd.	5,878	5,818/6,332
Jay Rd.; SH 119 to 63rd St.	5,744/5,652	1,435/1,343
Pine; 28th St. to 24th St. (Folsom)	5,693	0
28th St.; Valmont to SH 119	5,674/5,641	7,217
Baseline; 28th St. to 30th St.	5,650	2,336
63rd St.; Jay Rd. to Lookout Rd.	5,319	675
SH 119; 28th St. to 30th St.	5,076	5,818
Arapahoe; 28th St. to 30th St.	4,570	4,728
Arapahoe; Centroid 528 - 529	4,511	4,884
Pearl; Broadway to 15th Ave. & to 17th Ave.	4,231	closed/465
Arapahoe; Centroid 529-531,532 & 63rd to Westview Dr.	4,204/4,214	4,523/5,802/5,210
Arapahoe; 30th to Centroid 528	4,079	4,452
24th Street (Folsom); Canyon to Pearl	3,961	689
S. Broadway; Table Mesa Drive to Darley Ave.	3,915	3,841
Arapahoe; Centroid 532 to N. Cheryvale Rd.	3,690/3,686	4,384
S. Broadway; Darley Ave. to SH 170	3,587	3,578
30th Street; from Aurora Ave. to Colorado Ave.	3,485	2,086
Table Mesa Drive; US 36 to Moorhead Ave.	3,408	3,010
Arapahoe; Cheryvale Rd. to 63rd Ave.	3,379	5,001
30th Street; Colorado Ave. to Colorado Circle	3,359	2,086
Arapahoe; 75th Street to Willow Creek Dr.	3,308	2,691
Arapahoe; Westview Dr. to 75th St.	3,248	3,882
Baseline; 30th St. to 35th St.	3,236	2,147
17th Street; Canyon to Pearl	3,197	0
Arapahoe; Commerce St. to Valley View	3,186	1,152
Baseline; SH 157 to Valley View Rd.	3,003	1,152
Valmont Rd.; 55th St. to Centroid 321	2,891	615
N. Broadway; Linden Ave. to Balsam Ave.	2,797/2,792	1,731/2,143
Canyon Blvd; 17th Ave. to Broadway	2,782	0
Table Mesa Drive; Moorhead Dr. to Martin Dr.	2,743	3,010
Arapahoe; 17th to 28th Street	2,740	2,080
N. Broadway; Quince to Linden Ave.	2,728	2,079

Name of Street & extent of substandard link	Number of Sub-standard trips 1980 trips on 1970 Network	Number of Sub-standard trips 1980 trips on 1980 Network
Arapahoe; Centroid 543 to 540	2,691	2,691
N. Broadway; Buena Vista Ave. to Quince Ave.	2,593	1,944
Pine; 24th Street to 19th Street	2,549	0
30th Street; Walnut to Peak Ave.	2,523	1,599
Baseline; 35th Street to Inca Pkwy	2,474	1,848
30th Street; Pearl to Walnut	2,452	1,545
S. Broadway; SH 170 to Node 648 (south limit of network)	2,243	2,243
30th Street; Aurora Ave. to Baseline	2,239	1,708
Valmont; Centroid 321 to Node 333	2,201	603
75th Street; Lookout Rd. to Heatherwood Dr.	2,199	2,076
30th Street; Valmont to Pearl	2,188	928
30th Street; Arapahoe to Colorado Circle (Node 554)	2,148	1,545
Table Mesa Drive; Martin Drive to S. Broadway	2,071	2,273
Valmont Rd.; Node 333 to Node 325	2,011	1,290

substandard trips. This must be viewed with caution as there have been some discrepancies in the historical record files with regard to facility type and area code that had been overlooked in the initial screening of the record files with respect to consistency between the networks under consideration.

The approach used here to identify deficient links deviates from the methodology described in the Kentucky report. The reason for this difference is that one of the primary goals in this study was to see if the improvements recommended by the Kentucky methodology were the ones that were actually built in Boulder during the period between 1970 and 1980.

Comparison of Projects Predicted by the Computer Program to Projects as Built

A comparison of projects that are deemed necessary on the basis of the computer program with projects that have been built during the time interval under consideration should show whether or not the computer program is predicting needs that are relatively consistent with the conventional expansion of the highway network. To accomplish this task, all projects that had been built on the Boulder highway network from the base year to the intermediate year had to be investigated. The information on construction projects was obtained from State Highway records as well as from the City of Boulder. Table 4 shows all projects including cost and construction year. It should be pointed out here that the list only includes projects that are an integral part of the highway network as it is coded on the particular road maps. Consequently the costs that appear in Table 4 do not constitute the total required budget for the entire network of city streets. As can be observed in Table 4 several of the projects involve paving only. This type of project, although ultimately serving to promote possibly higher speeds and consequently higher capacity, are not responsive to the program, as long as the facility code or area type code is not altered. Some of the projects are stage construction. For example, the structure and approaches for the 47th Street bypass were built in 1972, whereas the road construction was not completed until 1978. Similar situations are found on the list of proposed projects, which includes all improvements from the intermediate year to the future year recommended network. Of particular importance in that listing (Appendix A, Table A-1) is the Pearl Street Extension to 47th Street which cannot be scheduled for construction until it can be tied into State Highway 157 (47th Street Parkway) as well as the Pearl Street Extension from

TABLE 4

STATE AND CITY PROJECTS (1970-1978)

Project	Description	Length (miles)	Year	Cost
SH 7 from 11th St. to 17th St.	Asphaltic paving	1.1	1970	18,482
47th St. Parkway	Structures & approaches	N/A	1972	335,178
SH 36 at Colorado Ave.	Modify intersection	N/A	1972	74,660
SH 36	Pedestrian underpass	N/A	1972	251,573
47th St. Parkway	Structures & paving	N/A	1973	351,486
SH 7, various intersections	Paving	.66	1973	20,068
SH 36, various intersections	Paving	.55	1973	27,877
SH 93, various intersections	Paving	.32	1973	14,125
47th St. Parkway	New construction	1.01	1974	2,896,354
Pearl Street	Widening, 2 to 4 lanes	1.1	1974	500,000
South link Bypass & Broadway	New construction and modification	N/A	1977	1,200,000
9th Street	Widening, 2 59 3 lanes	N/A	1978	400,000
Arapahoe	Widen lanes & turn lanes	N/A	1978	469,065

S.H. 157 to 63rd Street which must be scheduled for construction after completion of the parkway facility. The closing of streets has certainly a great effect on traffic patterns, as it tends to create circuitous routes causing increases of vehicle volumes on one facility as well as decreases on some others. Under special circumstances this type of traffic control can shift trips from an overloaded link to another facility. Implementation cost for this activity is virtually negligible. Only one new project was identified by the computer program that was also built during the time interval under consideration. This was the continuation of State Highway 157 (47th Street Parkway) from Baseline to Arapahoe. The 1980 Network map (Figure 6) also shows the 47th Street Parkway continued to S.H. 119 as well as Pearl Street extension to the parkway. Neither project has been completed to the extent that was deemed necessary on the basis of the computer program. The city of Boulder built a south link bypass in conjunction with a Broadway intersection modification at Baseline. This project was not included in the 1980 network map, even though the computer program shows that a critical need existed for this portion of the network, but was not listed in the recommended Highway Plan for the time interval that this study dealt with. The widening of 9th Street greatly alleviated substandard speed trips on that facility. The widening of Pearl Street along with the closing of the downtown portion of the link had the result of keeping substandard speed trips on this facility to an absolute minimum. The intersection modification at US 36 and Colorado Avenue, although not anticipated to be necessary based on the relatively low number of substandard speed trips, was accomplished in 1972. The result of this venture is somewhat inconclusive, as the apparent consequence is a vast increase of substandard trips. This by no means is an indicator of a poor intersection redesign, rather it is a result of redistribution from adjacent links, possibly due to the closure of Regent Drive that had connected Folsom Street with Broadway. Further aggrevating the situation was the shifting of shopping trips from the downtown area to 28th Street (U.S. 36). The implementation costs of the various projects as described in Table 4 constitute only a part of the total highway budget for the City of Boulder as defined in the system network, as there are many city projects that were funded during the given time interval. Some of the city streets are not included in the system network and consequently have no apparent effect on trip distribution. One project of this type is the Goss-Grove Neighborhood

Improvement project which has approximately $400,000 earmarked in the 5 year budget. This type of project will certainly affect the traffic pattern in at least the proximity of the neighborhood, but could also result in shifting of trips elsewhere.

RESEARCH FINDINGS AND CONSLUSIONS

The modified effective speed method used in this report adequately defined a highway network for the city of Boulder indicating links with substandard trips (on the basis of effective speed). A comparison between critical links and construction projects that were completed during a given time interval, which for this study spanned 10 years, indicates that the computer program is capable of defining critical links, provided the necessary data files are available. Another measure of system effectiveness or efficiency that was developed in the study is the average speed for each mileage increment of travel. The effective speed table (Table 1) is an indicator of travel speed increases due to system improvement. This last approach could be used to measure overall system time saved as compared to a different network configuration. However the computer costs for development for each different network could prove prohibitively expensive. The computer facility needed to run the available programs without major modifications is an IBM 360 (preferable with a teletype connection for programming control). In the process of testing the applicability of the research results of the Kentucky report no specific attempt was made to optimize the computer program. Consequently several subprograms had printouts that were not needed. The only programs that had to be evaluated, and therefore needed a printout are TRIPLEN and TDIST. For all other programs the printout can be omitted. The printout for program TRIPLEN had to be examined if any of the cell values were zero, since program TDIST would give an error message if it was processed using unmodified speed tables (Using speed tables that had zero speeds on any of the links). Since program TDIST evaluated all trips (including the zero speed trips that were replaced with one mile per hour speed trips in TRIPMOD) the printout of TDIST had to be manually adjusted to compensate for the fictitious (1 mph) trips, and a new speed distribution had to be evaluated for each 1-mile increment in trip length. This process is rather time consuming, both for the computer as well as the manual adjustment. Some time saving could be achieved by limiting the disaggregation process to a 2 mile increment. The time saving could be important if accuracy is not jeopardized too greatly. No attempt has been made in this report to test this reduced approach, since it was felt that a narrow class interval in trip lengths would constitute a fine-tuning approach to the Kentucky method of either effective speed or time saved research methodology. One procedural method that would alleviate manual adjustment and computations could be achieved by subprograms that can be written to interface with the FHWA and UTPS programs, so that programs are executed in sequence automatically depending on the results or error codes of the preceeding program. Printout options can be deleated throughout the entire program eliminating unnecessary volumes of paper. The success of prioritizing projects in an urban highway system depends primarily on the availability of various data files to evaluate how efficient one scenario is when compared to an alternate system. The primary ingredient is the 20-year highway plan, which identifies a number of individual projects that are planned to be newly constructed, widening of existing streets, or similar strategies designed to alter the assignment of trips. Other data files as listed in an earlier section not only must be available but also compatible with each other before they can be used in the optimum staging process. The "Buildup" procedure (See Appendix C) is possibly more suitable, since budgets can be estimated with greater certainty for a five-year interval as compared to a fifteen-year interval that is required for the "Tear down" procedure (See Appendix C) that was developed in the Kentucky report. The evaluation of cost-effectiveness of each improvement project could be a decisive factor if this type of staging process is a valuable tool. The methodology of alternately adding an improvement project to the base network, computing its effect on the system on basis of either time saved or effective speed weighted against the improvement cost could prove too costly for many municipalities. This process can be shortened somewhat by considering a combination of improvement projects and computing their combined effect on the system network. It should be realized that the accuracy of the results will be compromised which in turn could diminish the fine-tuning that is attempted by disaggregating the trip lengths into 1-mile increments.

SUMMARY

A great portion of time was devoted to the collection of data files and modification thereof to assure compatibility. It was apparent that with this type of research work the outcome was dependent on the completeness of files as specified in a similar report on optimum staging of projects. The primary purpose of this report was to test the feasibility of applying established methodologies that had been applied successfully on a small urban network to a larger urban area. It soon became apparent that because of the magnitude of the network, an alternate approach had to be developed. The logical choice was a modified effective speed methodology. The basic routine required the development of an effective speed standard for a Do-Nothing alternative and Build as projected. Disaggregated trips were examined if they fell into a below standard speed category for each network, and after summing all deficient trips they were assigned to the respective network to define deficient links. A comparison between the Do-nothing system and Build as recommended should show the redistribution of deficient trips to alleviate critical substandard link volumes. The Do-Nothing system in this study was simply the Base-Year (1970) network loaded with substandard speed 1980 trips, while the Build as recommended was the 1980 network loaded with 1980 substandard speed trips.

Improvement projects that were built during this time interval to a large extent were the same as those identified by the computer program by exhibiting high deficient trip volumes in the Do-nothing analysis and an appreciable drop of deficient trips in the Build as recommended analysis. The modified effective speed approach used in this study is basically structured after the Buildup procedure using the 1970 network (Base year) as the starting point. The utility of an optimum staging program is limited to those urban areas that have the necessary data files along with a recommended 20 year Highway plan. Depending on the network size, computer charges as well as manpower cost to synthesize the optimum highway network improvement could well be discouraging unless the computer programs are improved. No environmental considerations have been included in the analysis to keep the process as simple as possible. Neglecting this aspect of planning could very well offset any gain realized from the optimum staging program in a real world situation where environmental issues have a great impact on improvement projects.

SUGGESTED FURTHER RESEARCH

In order to assess future needs more efficiently and accurately additional research should be performed on two specific areas in the optimum staging program. The first deals with the computer program itself. As was pointed out earlier in the report, some parts of the programs had to be examined manually and their output had to be modified to be acceptable to other programs that were integral parts of the total evaluation system. This procedure not only resulted in extensive delays but also errors in failing to spot some of the zero cell values in program TRIPLEN which in turn caused program TDIST to fail. A computer program could be designed to rectify this situation. The future research should also investigate the possibility of interconnecting all programs that are needed in the optimum staging program as opposed to the disjointed procedure that was unavoidable in this report. Research time should also be devoted to the inclusion of environmental aspects of transportation needs, although the 20-year Highway Improvement Plan usually is developed with due respect to the environment.

IMPLEMENTATION

This research effort has noted that the optimum staging program could be applied to the urban areas of the state provided that sufficient data is available. The reader must once again be cautioned and reminded that prioritization of projects should not be based solely on time savings alone, but should also include such criteria as air quality and safety.

Computer costs as experienced in the analysis of this report can be expected to amount to approximately $800 per analysis. This cost could be increasing by using interface programs yet to be developed. These interface programs should off-set the increased computer costs by eliminating many manual steps now required in obtaining the final results.

This report will be distributed to the various Metropolitan Planning Organizations (MPO) throughout the state for review and comment. If an MPO should express interest in pursuing this program further, the Department will provide the necessary modifications to the procedures to streamline and reduce the amount of manual process that is currently required.

REFERENCES

Schimpeler-Carradine Associates, "Optimum Staging of Projects in a Highway Plan," March 1974.

SOURCE OF APPENDICES

APPENDIX A - Boulder Valley Transportation Plan, Highway Alternatives Analysis

APPENDIX B AND C - Optimum Staging of Projects in a Highway Plan by Schimpeler-Carradino Associates, March 1974

APPENDIX A

LIST OF PROPOSED PROJECTS

Project	Description	Length	Lanes	Lane Miles Added	Estimate Cost Millions
SH 119 Iris Ave. to 75th Street	Add 4 lanes to existing expressway	4.5	4	18.0	4.0
SH 157 - 47th Street Parkway	New 4-lane parkway	3.0	4	12.0	8.0
Pearl Street Extension to 47th Street	Extension and realignment to 47th Street Parkway with interchange	1.0	4	4.0	1.8
Pearl Street extension from 47th Street to 63rd Street	New 4-lane arterial	2.0	4	8.0	1.3
Colorado Avenue 28th Street to 47th Street Parkway	New 4-lane collector	1.0	2	2.0	0.60
63rd Street Cherryvale Road from SH 119 to US 36	Add 2 lanes and realign existing arterial	6.75	2	13.5	4.5
63rd Street - US 36 interchange	Provide interchange at US 36	N/A	N/A	N/A	0.9
Jay Road from SH 119 to 63rd Street	Add 2 lanes to existing arterial	1.5	2	3.0	1.6

Table A-1

LIST OF PROPOSED PROJECTS

Project	Description	Length	Lanes	Lane Miles Added	Estimate Cost Millions
Folsum Street from Jay Road to Colorado Avenue	Upgrade to 4-lane arterial	3.0	4	2.4	1.3
Ash Street from Marshall Road to US 36	New 4-lane collector	0.5	4	N/A	0.7
9th Street from Baseline Road to Iris Avenue	Upgrade to 4-lane arterial	2.5	4	N/A	1.9
47th Street from US 36 south to SH 93	New 4-lane extension of 47th Street Parkway	1.0	4	4.0	2.7
30th Street from SH 119 north to US 36	Provide one-way connection to US 36	.3	4	1.2	.3
Jay Road from SH 119 to 19th Street	Add 2 lanes to existing arterial	2.0	2	4.0	1.2
Jay Road from SH 119 to 25th Street	Add 2 lanes to existing arterial	1.3	2	2.6	1.1

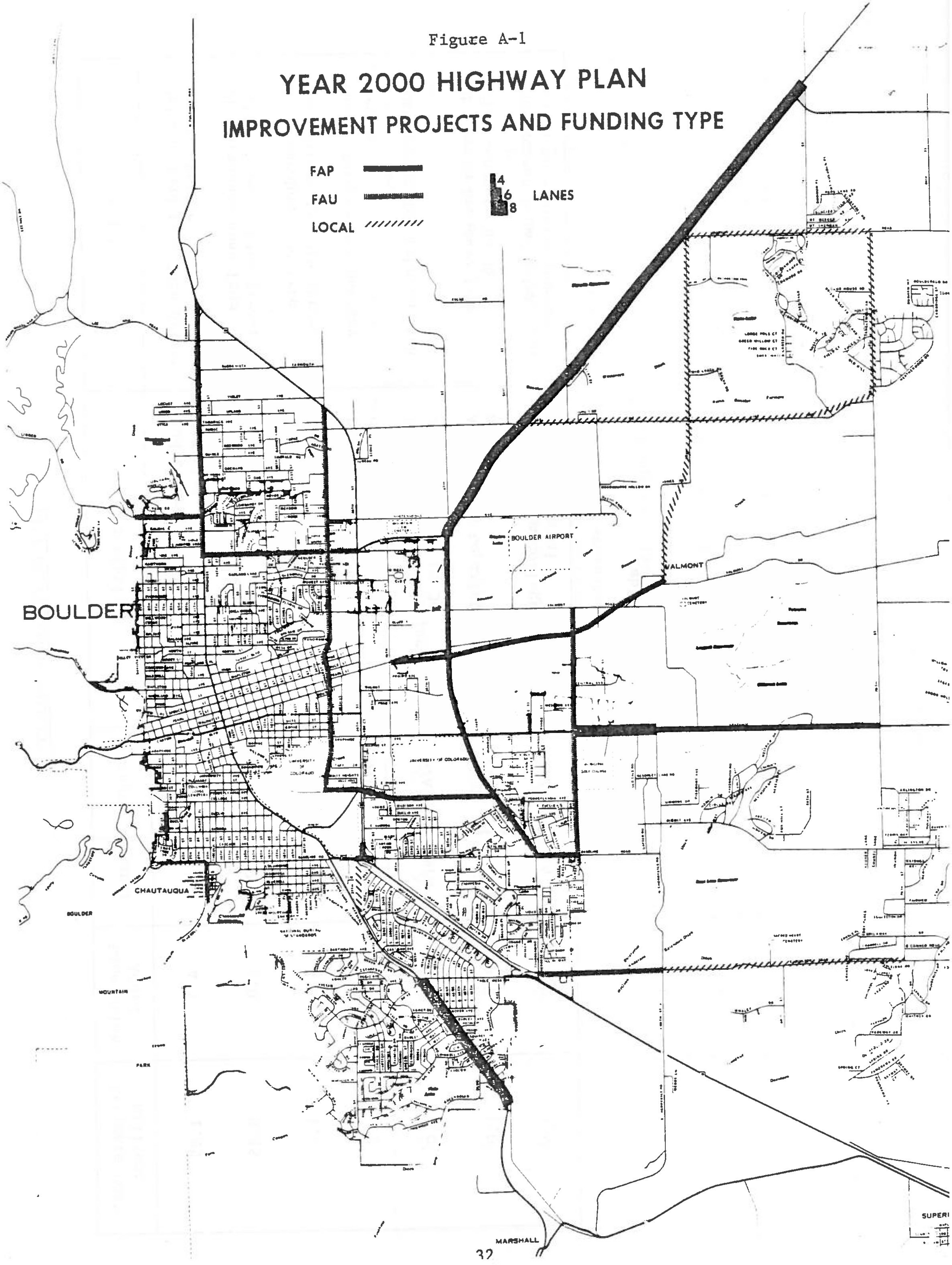
Table A-1 (cont)

LIST OF PROPOSED PROJECTS

Project	Description	Length	Lanes	Lane Miles Added	Estimate Cost Millions
Valmont Road from 30th Street to 63rd Street	Add 2 lanes to existing arterial	2.25	2	4.5	1.85
SH 7 Arapahoe Road from Valley View to 63rd Street	Add 2 lanes to existing arterial	0.5	2	1.0	0.35
SH 7 Arapahoe Road from 63rd Street to 75th Street	Add 2 lanes to existing arterial	1.5	2	3.0	1.7
28th - 30th Street one-way couple	Provide traffic controls to obtain one-way movements	5.0	N/A	N/A	1.2
30th Street Interchange with US 36	Provide structure to 30th Street to US 36	N/A	N/A	N/A	1.0
SH 7 north Broadway from Iris Avenue to US 36	Add 2 lanes to existing arterial	2.0	2	4.0	1.0
19th Street from Violet Avenue to Mapleton Avenue	Upgrade from collector to 4-lane arterial	2.2	4	4.4	2.0

Table A-1 (cont)

Figure A-1


YEAR 2000 HIGHWAY PLAN
IMPROVEMENT PROJECTS AND FUNDING TYPE
FAP
FAU
LOCAL
4
6
8
LANES
BOULDER
BOULDER AIRPORT
VALMONT
CHAUTAUQUA
UNIVERSITY OF COLORADO
MARSHALL
SUPERI

STEP 2. For each link improvement compute a cost effectiveness (CE) ratio given by

$$CE = \frac{\text{Cost}}{\text{Adjusted Vehicle Miles}}$$

that is;

$$CE = \frac{\text{Cost}}{(\text{Volume-Initial Capacity})\text{Length}}$$

STEP 3. Successively discard link improvements, in descending order from the largest (poorest) CE ratio, from the period-k network until the cumulative budget through period k-1 is no longer exceeded.

STEP 4. From the improvements just discarded in Step 3, successively add back, in descending order of CE ratio, those link improvements where addition will not cause the cumulative budget through year k-1 to be exceeded.

STEP 5. The set of links in the k-period network which were either not discarded (in Step 3) or added back (in Step 4) constitute the (k-1)-period network.

STEP 6. Set k=k-1. If k=0, STOP. Otherwise, iterate the complete process beginning at Step 1.

The result of the above process is a near-optimal staging of a p-period highway plan. The links discarded from a k-period network are precisely the link improvements that must be constructed between period (k-1) and period k.

In the following paragraphs, we shall proceed to demonstrate that this process is an application of the Senju-Toyoda method for finding near-optimal solutions to linear integer programming problems (with only one troublesome constraint).

<u>The Senju-Toyoda Method for A Single Constraint: Generalized Discussion</u>

These paragraphs illustrate the Senju-Toyoda method (for one constraint) with an example. Suppose decision-makers have the opportunity to select from among eight projects in which to engage. Each project requires a certain amount of some resource (possibly money) and returns a specified profit (or savings as the case may be). One either decides to undertake the <u>jth</u> project or not. Table 9 summarizes the results. One has a limit of 24 units of the available resource and desires to allocate them most profitably among the projects: that is, one wishes to determine which projects to undertake.

TABLE 9

DEFINITION OF RESOURCES, RETURNS

Project	1	2	3	4	5	6	7	8
Profit (or Time Saved)	100	400	200	800	300	600	400	500
Resource Required	6	2	3	4	9	6	5	1

If one associates a variable, X_j, with the jth project and allows X_j to take only the values) and 1, then it is possible to write the following linear integer programming problem whose optimal solution provides the answer to the decision-maker's question. The model is:

Maximize: $100X_1 + 400X_2 + 200X_3 + 800X_4 + 300X_5 + 600X_6 + 400X_7 + 500X_8$

such that; $6X_1 + 2X_2 + 3X_3 + 4X_4 + 9X_5 + 6X_6 + 5X_7 + X_8 \leq 24$

$X_1, \ldots, X_8 = 0 \text{ or } 1.$

There are various ways to find an optimal solution[2] to this problem. All these methods display prohibitive computer run times on large problems. However, one particularly effective method for finding a near optimal solution to such a problem is that of Senju and Toyoda.

STEP 1. Find out how much resource all of the projects taken together will use.

In the example, this sum equals 6 + 2 + ... + 1 = 36 units, which is more than the 24 units available. Thus, it is necessary to decide which of the projects are to be discarded (which X_j to set to 0). This is done as follows:

STEP 2. For each project, compute a profit/unit of resource ratio. E_j = \$/Unit. (Objective/Resource)

For the above example, the profit per unit of resource for project 1 is 100/6 = \$16.66 per unit. A particularly effective project is one that returns the highest profit per unit of resource used. Table 10 gives a summary of these ratios for all projects in the example:

TABLE ~~10~~

PROFIT/RESOURCE COMPUTATIONS

Project	1	2	3	4	5	6	7	8
$/Resource	16.66	200	66.66	200	33.3	100	80	500

[2]That is, deciding which X_j's are 1 and which are 0.

From Table 11 it is seen that project 8 is the most effective project, while project 1 is the least effective in its use of the given resource.[3] Discard project 1 from the list of projects, i.e., set $X_1 = 0$. However, the remaining projects require 36 - 6 = 30 units of resource. Since this exceeds available supply, discard the next most ineffective project (project 5). One is now within limits of theavailable resource, using 30 - 9 = 21 units of resource. This series of exchanges may be summarized as follows:

STEP 3. Successively discard projects with the lowest effectiveness ratios until the available supply of resource is no longer exceeded.

As occurred in this case, it is possible to reach this point with excess resource available. Since the problem deals with ratios, and the projects are of an all or nothing character, it is also possible that certain of the projects which have been discarded can be re-added to the list if their addition does not cause the total resource required to exceed that available.

Thus:

STEP 4. Successively add back in order of highest effectiveness ratio those discarded projects which do not cause the available resource to be exceeded.

In the example above, Step 4 results in no changes to the project list to be undertaken. In other exampels, changes will result.

It is possible to display this entire process graphically as follows: The length of each arrow indicates its use of the resource. A forward (left to right) arrow indicates a project to be added to the list of projects to be executed. A reverse arrow (right to left) indicates a project to be deleted from the list. In the jargon of mathematics, these arrows are called "vectors" (Figure 2).

3. Application To The (Near) Optimal Staging Algorithm: General Discussion

One immediately sees that the staging algorithm presented earlier is precisely the Senju-Toyoda method applied to the network design problem. There, the resource is budget ($) and the objective coefficient is adjusted vehicle-miles on an improvement. Of course, the projects are the network improvements. In the staging algorithm, one chooses to state the ratios as resource/objective, but as mentioned earlier, the net result is the same.

This use of cost-effectiveness ratios is not new, and was not, in fact, first used by Senju and Toyoda. Their contribution has been for the case of several different resources which constrain the problem. Briefly outlined below is their method for two or more constraints. The method has potential use in an

[3] One might just as well compute resource/objective, in which case everything would be turned around.

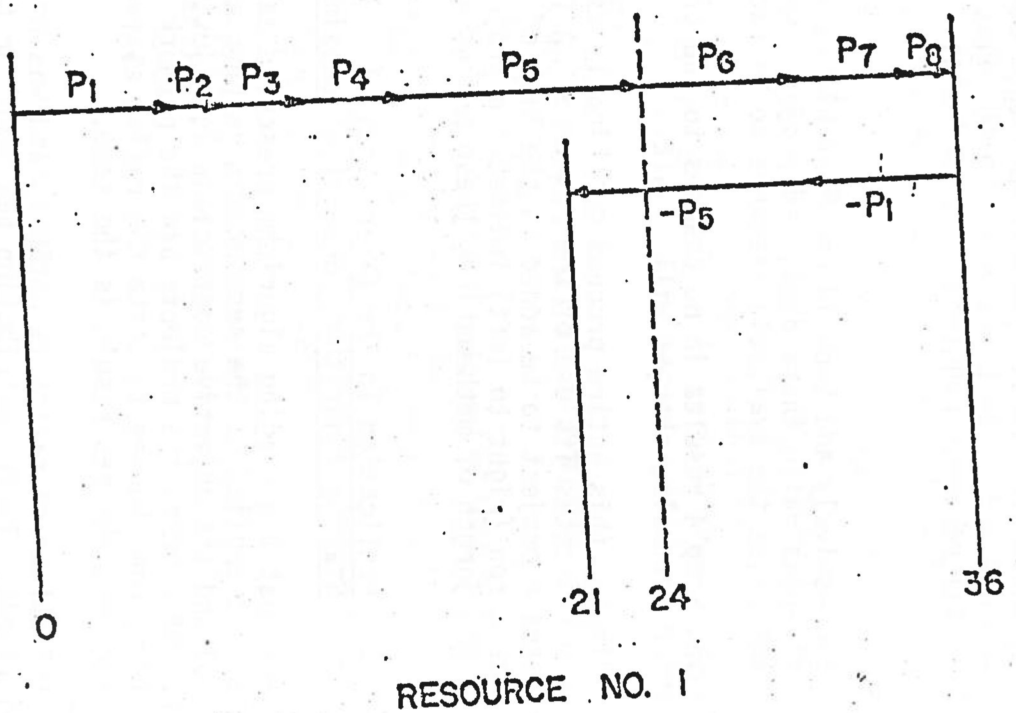


Figure 2

VECTOR REPRESENTATION
OF THE SENJU-TOYODA METHOD
WITH ONE CONSTRAINT

extended staging algorithm.

4. The Senju-Toyoda Method for Two or More Constraints: General Discussion

The Senju-Toyoda method for two or more constraints follows the steps for the case of one constraint. The only difficulty arises in Step 2, when it is necessary to compute the effectiveness ratios (objective/resource) with more than one resource. For example, in Table 11, project 1 has a profit of $100, so the numerator is 100. Project 1 uses 6 units of resource 1, and 2 units of resource 2. What does one use for the denominator? Senju and Toyoda have utilized the theory of vector projection in mathematics to combine the individual resource rates into a single resource rate which indicates how rapidly all the resources will be used in aggregate. Although the calculations require only a few multiplications and a division, the details are not presented in this description, since only the idea is sought at this point.

TABLE 11

TWO RESOURCE CONSTRAINTS

Project	1	2	3	4	5	6	7	8	Limit
Profit	100	400	200	800	300	600	400	500	
Use of Resource #1	6	2	3	4	9	6	5	1	24
Use of Resource #2	2	8	2	6	3	5	6	7	30

One may again utilize an arrow (vector) diagram to view the process. Figure 5 displays a sequence of steps in which one first adds all projects to the list (requiring 36 units of resource 1, and 39 units of resource 2). Following this method, based on extended effectiveness ratios, we must discard projects 1, 5, and 7, in that order, whereupon the requirements for individual resources are not excessive. At this point, the method (see Figure 3) indicates that project 1 may be added back to the list. The final solution is to undertake all projects except 5 and 7.

5. Importance of the Multi-Dimensional Method: Generalized Discussion

To date the team has developed algorithms and procedures for the optimal staging problem when only one constraint (budget) was present. The concepts underlying the multi-dimensional Senju-Toyoda method would allow the team to extend available algorithms (with negligible increase in run times) to handle several constraints. Examples of other constraints, besides "budget," are "esthetics," "noise," "other environmental conditions," and "local awareness factors." In the previous example, Constraint 2 could represent the contribution of each of the projects to ecological imbalance as measured on some appropriate scale.

It is suggested that this extension is deserving of further consideration and ultimate development.

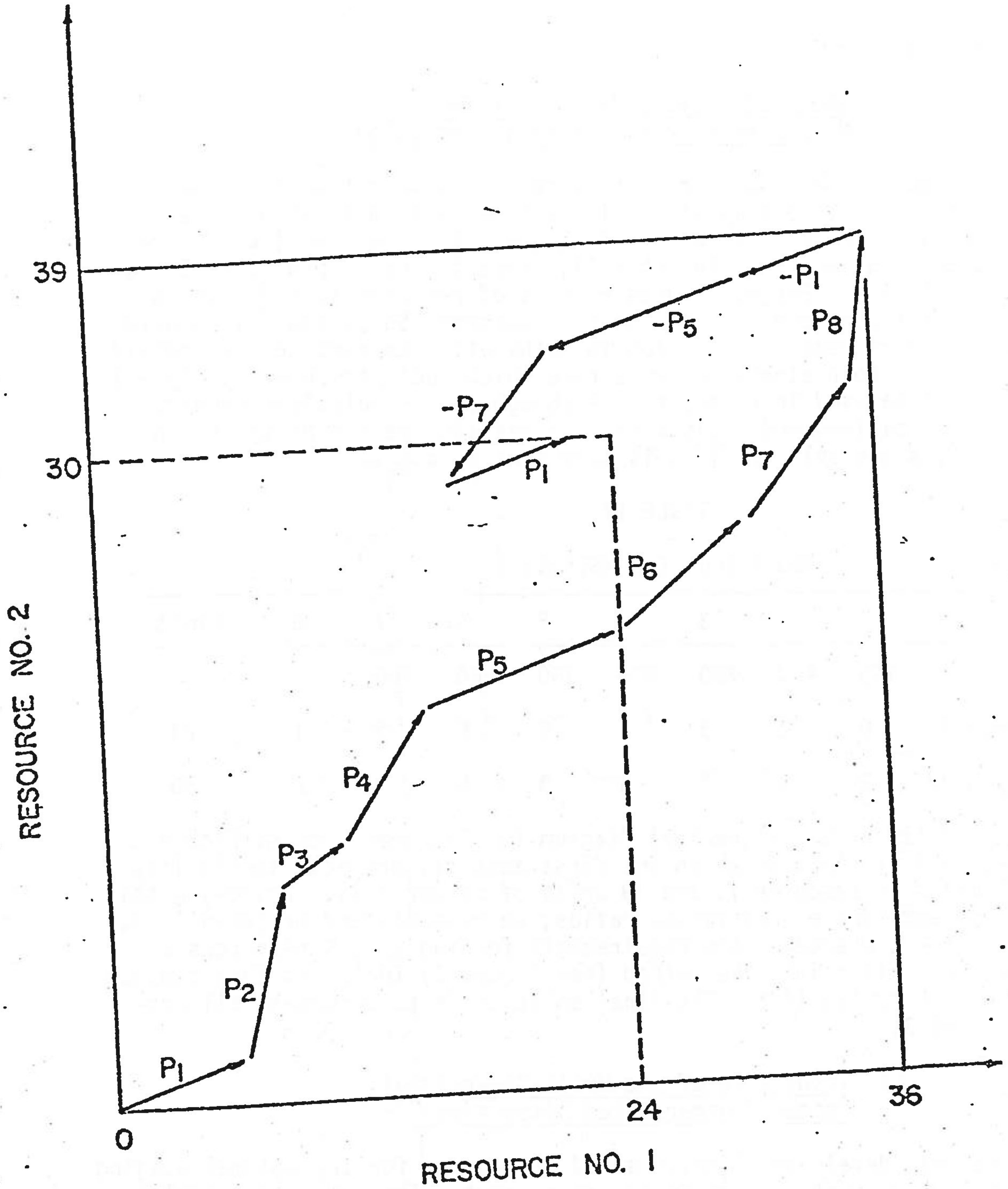


Figure 5

VECTOR REPRESENTATION
OF THE SENJU-TOYODA METHOD
WITH TWO CONSTRAINTS

~~test results are accumulated, statistical methods will be employed to test for signifiean differences between the effectiveness measures. Additional analysis might be used to determine whether certain measures were more effective for a given network configuration or structure than others. Thus, if it were possible to categorize networks by certain characteristics, it would then be possible to determine which effectiveness measure, if any, yielded better results for any given network configuration.~~

~~3. Treatment of Comprehensive Environmental Factors~~

~~The basic methods presented in this report utilize a ratio of cost to travel time in order to establish an optimal staging of links in a twenty-year plan. In previous discussion, a method was described by which several comprehensive environmental factors might be treated by extending the basic model.~~

~~The requirement to bring this extended method into operation is additional effort directed toward refining and tuning the model.~~

"Buildup" Versus "Tear Down" Procedures

The procedures developed under this contract for optimal staging of highway projects may be characterized as "tear down" approaches. The procedures start with the recommended final twenty-year highway system. To obtain the fifteen-year network, improvement links are deleted, based on cost-effectiveness or time-saved criteria, until the remaining link improvements are within the fifteen-year budget. When the fifteen-year network is established, the procedure is repeated until the ten-year budget is satisfied. Finally, the process is repeated to obtain the five-year network.

An alternative procedure to this "tear down" concept is a "buildup" approach. Such a procedure starts with the initial or zero-year network and then selects subject to budget constraints, improvement links to add to create a five-year network. The set of improvement links selected from is a set of those belonging to the final or twenty-year network. Given the five-year network, this is then used as the base network, and the process is repeated to obtain the ten-year network. The fifteen-year network is created in the same manner and, as the twenty-year network, is the final recommended network; hence, no computations are required beyond the fifteen-year period. Given a measure of cost effectiveness for the improvement arcs, the arcs may be ranked in order of cost effectiveness. The procedure then starts by adding those links with the lowest cost effectiveness ratios until the budget available for the given period is used up. To initiate such an approach, it is necessary to determine cost effectiveness ratios for each improvement arc. These ratios may be recalculated for each period.

As an example, consider the determination of cost effectiveness ratios for the five-year network. The five-year demands can be added on the recommended twenty-year network and cost effectiveness ratios calculated for each improvement link based on traffic loadings or time saved. Another alternative is to evaluate each improvement link on a one-at-a-time basis rather than all simultaneously, as discussed above. This might be accomplished by selecting an improvement link from the twenty-year network, adding it to the base year network, then calculating its cost effectiveness ratio. That arc would then be removed from the base network and another improvement link from the twenty-year network added in order to evaluate its contribution to time saved on some other measure of effectiveness. This process continues until each improvement arc has been evaluated, and then the cost effectiveness rankings are used to add arcs to create the five-year network.

Once a five-year network is created, additional analysis of that network can be undertaken to determine whether any changes in the set of improvement links added should be made. One approach to this is to load the five-year demands on the proposed five-year network, and, based on this loading, determine new cost effectiveness measures for each of the improvements arcs in the five-year network. The remaining improvement arcs can then be evaluated on a one-at-a-time basis against the proposed five-year network. Should any of these remaining arcs have a better cost effectiveness ratio than those included in the five-year network, the links can be exchanged, subject to budget considerations.

As procedures are developed, they should be tested against the "tear down" procedure to determine which approach, if any, yields the better results. Multivariate statistical analysis, such as analysis of variance, could provide a sound technical approach for making such comparisons and drawing conclusions on the relative effectiveness of the two approaches.

Methods for Determining Time Saved

Chater II described the concept of measuring travel time saved for each improvement. In Chapter III, one heuristic method of determining time saved for each link was developed, programmed, and tested with extremely favorable results. A very important area of future involvement is development and testing of more accurate methods of allocating time saved.

The problem of allocating system-wide time saved to individual links is not unlike that of allocating statewide population growth figures to individual counties. The essential difference, however, is that more information and structure is available in the time saved problem.

Additional effort should be allocated to the development of understanding of the factors contributing to time saved and to the utilization of this derived understanding in the creation and testing of procedures for determination of individual link time saved. Described below are several potential methods to be considered in such a follow-on project.

Factor Analysis and Other Statistical Methods

Each link improvement in a highway network possesses various attributes that can be correlated with total system-wide time saved in order to determine strength of attractiveness to additional trips in a given trip table. Such factors as distance from an origin, distance from a destination, time from an origin, time from a destination, distance, speed, etc. are attributes (factors) of an improvement which can be tested in strength of relationship to system-wide time saved.

The ultimate importance of various statistical procedures is isolation and identification of those factors an improvement possesses which cause it to attract trips and contribute to total time saved.

PUBLICATIONS

.Department of Highways-State of Colorado
Division of Transportation Planning

66-1	Final Report - Denver SE Pavement Study I 25-3(20)
66-2	Interim Reports on the Experimental Base Project At Ordway, Colorado #1
66-3	Interim Report on the Clifton-Highline Canal Experimental Project I 70-1(14)33 #1
66-4	Final Report on Statistical Research Project - Quality Control Study on Asphalt Pavement
66-5	Final Report on the Automatic "Icy Road" Sign Study
66-6	Interim Report on Crawford-South Experimental Project S 0125(9) #1
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