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Development of a Highway Driving Cycle for Fuel Economy Measurements

by

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Introduction:

This report describes the program that was conducted to develop a driving cycle that represents typical vehicle operation on all types of highways.

Purpose:

The purpose of this program was to measure road speed versus time profiles of vehicle operation on all types of highways and non-urban roads and to reduce these profiles to characteristic parameters which could be used to develop a composite driving cycle.

Objective:

The objective of this program was to produce a driving cycle which could be used to measure vehicle fuel economy under typical highway operation as simulated on a chassis dynamometer.

Background:

The EPA has for several years recognized that the light duty vehicle emission certification procedure provides reliable, reproducible information which can be utilized for calculation of vehicle fuel economy[1]. The certification test procedure incorporates a chassis dynamometer that exercises the test vehicle to simulate the power required of the vehicle during an urban drive in a major metropolitan area[2]. The carbon mass emissions from these tests can be used to calculate the average urban fuel economy; this calculation equally applies to all the vehicle types tested during the certification process and permits the effect of vehicle design parameters on urban fuel economy to be assessed. Publication of these urban fuel economy data for all classes of vehicles provides the consumer with one piece of information he can include as a criterion for determining the suitability of any given vehicle for filling his needs. The fact that more than half of the total vehicle miles accumulated are traveled in urban areas reflects the importance of knowing urban fuel economy.

The average vehicle owner tends to ignore urban ("around town") fuel economy because it is usually less than highway fuel economy and because highway fuel economy is more conveniently measured. Thus, the typical vehicle owner has conditioned himself to expect fuel economy data to refer to highway type operations and the publication of urban fuel economy data does not provide the information relative to his personal experience. Highway travel accounts for more than 40% of the total vehicle miles traveled making highway fuel economy a useful and valid criterion for judging vehicle performance. An appropriate dynamometer vehicle exercise which simulates typical highway operation could also be employed to measure highway fuel economy data. Publication of both equally valid fuel economy rates would be useful information for many individuals.

Highway Driving Characterization:

The Department of Transportation segregates road systems into either of two categories on the basis of principal area characteristics. The two categories are urban and rural (highway), which are differentiated because of functional differences in land use road networks, and travel characteristics[3]. DOT experience indicates that this differentiation in characteristics occurs in places of 5,000 population. Rural (highway) road networks are adequate if place populations are less than 5,000 and urban traffic networks are required if the place populations exceed 5,000. In order to characterize road types within either category the Department of Transportation has developed a "Functional Classification Concept" which classifies each highway, road, or street according to the principal service that it renders. This system of classification develops a hierarchy of route types. Lowest in the hierarchy are the local roads and streets, where trips begin and end. These trip ends are characterized by low speeds, unlimited access, and penetration of neighborhoods. At the top of the hierarchy are the arterials designed to accommodate high volumes of through traffic. Intermediate facilities or collectors accommodate the necessary transition from local roads and streets to arterials. Outside urban areas, the main road type classifications are:

A. Principal arterial system
   a. Interstate
   b. Other principal arterials
B. Minor arterial system
C. Collector
   a. Major collectors
   b. Minor collectors
D. Local system.

The development of rural systems classification starts at the top of the hierarchy and works down. First the principal and minor arterial systems are developed on a statewide basis. Then the collector and local classifications are developed on a more localized (county) basis.

On the basis of the above classification scheme, the percent of total highway vehicle miles traveled has been calculated for each road type:

TABLE 1

Type of Highway	Percent of highway vehicle miles traveled
A. Principal arterials	39.5
B. Minor arterials	22.4
C. Collectors	23.9
D. Locals	14.2
	100 %

Highway operation represents between 40 and 50% of total vehicle miles traveled, a value which continually decreases as urbanization increases. These percentages are the basis for constructing a composite highway driving cycle to simulate all types of highway operation.

For this study, five routes incorporating each road type to be traveled during the characterization were selected by EPA personnel. Figure 1 is a map of the general area. Figure 2 illustrates a sample route which was designed to cover a variety of road types for equipment check out tests. On the first run of this route the data recording equipment functioned properly, but the vehicle experienced a fuel system failure. The test equipment was transferred to the stand-by vehicle and the replacement vehicle and equipment were checked out on the dynamometer. Since the equipment had functioned properly on the sample route and everything functioned well when checked on the dynamometer, the route shown on Figure 3 was run first. This is primarily a type B (minor arterial) route with 61% type B roads, 28% type A (major arterial) roads and 11% type C (collector) roads. The second route, Figure 4, is a type A route with 100% type A roads. Figure 5 illustrates a type C route with 44% type C roads, 22% type D (local) roads, 17% type A roads and 17% type B roads. The fourth data collection run was a rerun of the sample route, Figure 2. This route consists of 47% type D roads, 43% type C roads and 10% of type A roads. The fifth route was run on a freeway in Ohio subject to 55 MPH speed limits, consists of 100% type A roads.

During this data collection process, 460 feet of chart were used, which at 4 inches of chart travel per minute represents about 23 hours of data, collected over a total distance of about 1050 miles. During all travel, an observer accompanied the driver to make notes about the trip and to log pertinent data.

Vehicle Instrumentation:

The vehicle used to collect data in this program was a 1971 Ford Ranchwagon with a 429 CID-4V engine, 3 speed automatic transmission, and a 2.75 ratio rear axle. This vehicle had been previously instrumented for a study of vehicle operation and driving profiles. The instrumentation included a manifold vacuum transducer, digital timer (seconds), driveshaft torquemeter, and driveshaft speed pickup. The signals from the driveshaft were scaled and recorded on a stripchart moving at a rate o 4 inches per minute to produce the same time base as the federal urban driving cycle. All of the instrumentation was calibrated and checked on a chassis dynamometer to verify true speed and torque readings. The vehicle contained a static inverter power supply to provide 120 volt, 60 cps electricity. This supply was used on all calibrations and testing.

The true road speed was checked against the vehicle speedometer to permit a quick calibration of the recorder on the road. A panel meter which indicated driveshaft speed also facilitated a third check on true speed and calibration stability. Calibration checks indicated good stability throughout the entire program.

The torquemeter had a shunt resistor which was used to calibrate the gain of the torquemeter. The torque readings were scaled to measure from -200 to +800 foot-pounds. Torque readings were used to assess the variation in throttle position for various velocity profiles. No problems were incurred with this measurement.

Data Verification and Analysis:

For ease of analysis, the 460 feet of recorder chart gathered during this experiment were displayed on the walls of the office hallway at the EPA Ann Arbor laboratory. The charts were properly identified according to route number and were reviewed and verified by the route observers. There was one observer on each drive and three observers were used in the program. These observers reviewed their own traces and verified comments. They identified route segments according to type of road, A through D, determined which segments represented urban (population above 5,000) driving and deleted the urban segments. Data reduction consisted of tabulating route speeds at 15 second (1 inch) intervals to determine the maximum, minimum and average segment speeds. Total segment time, distance, number of stops, number of major speed deviations per mile for each segment were calculated. A speed deviation was defined as an excursion greater than ± 5 MPH from a line connecting end-point velocities on six inch intervals (1.5 min) of the entire segment.

These data were compiled from all of the charts for each road type and the average characteristics were determined for each road type. These data are presented in Table 2.

TABLE 2

Average Highway Characteristics

Road Type	Average Speed MPH	Stops/mile	Speed Deviations/ mile
A	57.16	0.0100	0.070
B	49.42	0.0575	0.439
C	45.80	0.1260	0.484
D	39.78	0.2360	0.598
Composite[3]	49.43*	0.08	0.327

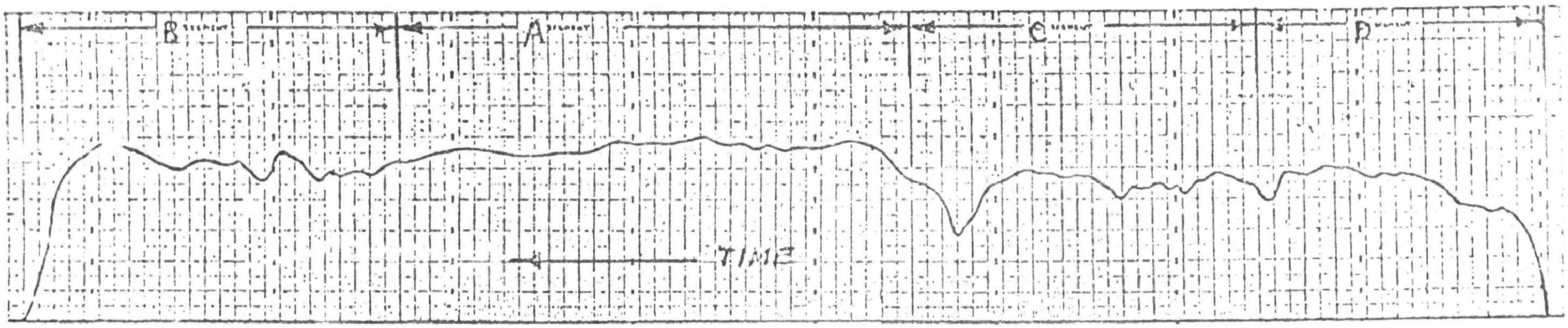
$$\text{*Composite Speed} = \frac{1}{(.395/A + .224/B + .239/C + .142/D)}$$

After these road type characteristics and the composite highway trip characteristics had been determined, a driving cycle selection committee was designated. This committee was composed of the three observers and three other EPA staff engineers. The committee reviewed the data, decided that a nominal 10 mile highway route would be optimum for laboratory testing and agreed on a method for obtaining the route. The committee split into three groups of 2 persons each, one observer and one other engineer. Each group was to select and combine the appropriate lengths and types of road segments to produce a route with characteristics equivalent to the actual composite characteristics. Each group traced the selected sections of the actual speed versus time charts to come up with the composite route. After the three candidate routes were prepared, the committee reconvened and evaluated the relative merits of each route. As might be expected, the three routes were quite comparable, with each having special features which that group felt were particularly important. After a thorough analysis and discussion, the committee constructed a composite route which contained the best features of all three routes. Table 3 presents the average characteristics of the composite route. Figure 7 is a photoreduction of the driving chart and presents a graphical illustration of the speed-time trace as read from right to left, because of the direction of chart paper travel.

TABLE 3

Characteristics of Composite Highway Driving Cycle

Segment Length (IN)	Segment	Average Speed (MPH)	Distance Traveled (Miles)	Elapsed Time (MIN)	% Total Miles
9.5	D	41.157	1.629	2.375	15.93
11.5	C	43.841	2.101	2.675	20.55
17.0	A	56.096	3.973	4.250	38.85
12.5	B	48.421	2.522	3.125	24.67
50.5 Inches	Overall Total	48.595 MPH	10.225 Miles	12.625 Minutes	100.0 %



END START

FIGURE 7

Composite Highway Driving Trace

TABLE 4

Comparative Analysis of Cycle Characteristics

Road Type	Average Speed Goal	Actual	Diff.	% Miles Traveled Goal	Actual	Diff.
A	57.16	56.10	-1.06	39.5	38.8	-0.70
B	49.42	48.42	-1.00	22.4	24.7	+2.30
C	45.80	43.84	-1.96	23.9	20.6	-3.30
D	39.78	41.16	+1.38	14.2	15.9	+1.70
Composite	49.43	48.59	-0.84	100.0	100.0	0.00

Table 4 compares the final characteristics of Table 3 with the goals shown in Table 2. It is readily apparent that the highway driving cycle closely approximate the real world conditions. All average speeds are within ± 2.0 MPH of the real world average and the percentages of the distance traveled in each segment are within ± 4% of the DOT values.

During the construction of this cycle, the committee decided to use actual on-road traces to represent each segment. This decision placed two restrictions on the end points of the segments; the slopes and speeds had to be continuous at the segment junctions. Furthermore the committee thought the most realistic sequence of road segments would be DCAB. The cycle would start from an idle, contain four speed deviations (one each in B and D, two in C) and end with a deceleration to a stop and idle. For the convenience of the driver, who also controls the CVS sampling, a 2 second idle period was included at the beginning and the end of the cycle. The on-road data indicated the average idle time was 0.063 minutes/mile for all road types traveled.

Obviously, a change in any of these criteria for one segment impacts on the characteristics of the adjacent segments as well as the overall composite cycle characteristics.

One general observation about the B and C segments should be made. It was sometimes difficult to distinguish whether a road was strictly a type B or type C. Since their characteristics are very similar, a rigid distinction and duplication in the cycle was not considered critical.

The driving cycle shown in Figure 7 was constructed from all of these criteria and is considered to be an accurate representation of all the types of highway driving normally encountered.

The characteristics of this highway driving cycle were determined by tabulating the velocities at each .1 inch of chart which represents 1.5 seconds.

This tabulation was converted to a digital table which listed the highway driving cycle velocities for each of the 758 one second intervals. The trace was then scaled to the same chart paper used for the federal urban cycle.

References

1. A Report on Automotive Fuel Economy, U. S. Environmental Protection Agency, Office of Air and Water Programs, Mobile Source Air Pollution Control, October 1973.

2. Development of the Federal Urban Driving Schedule, Society of Automotive Engineers 730553.

3. Part II of the 1972 National Highway Needs Report, House Document No. 92-266, Part II.

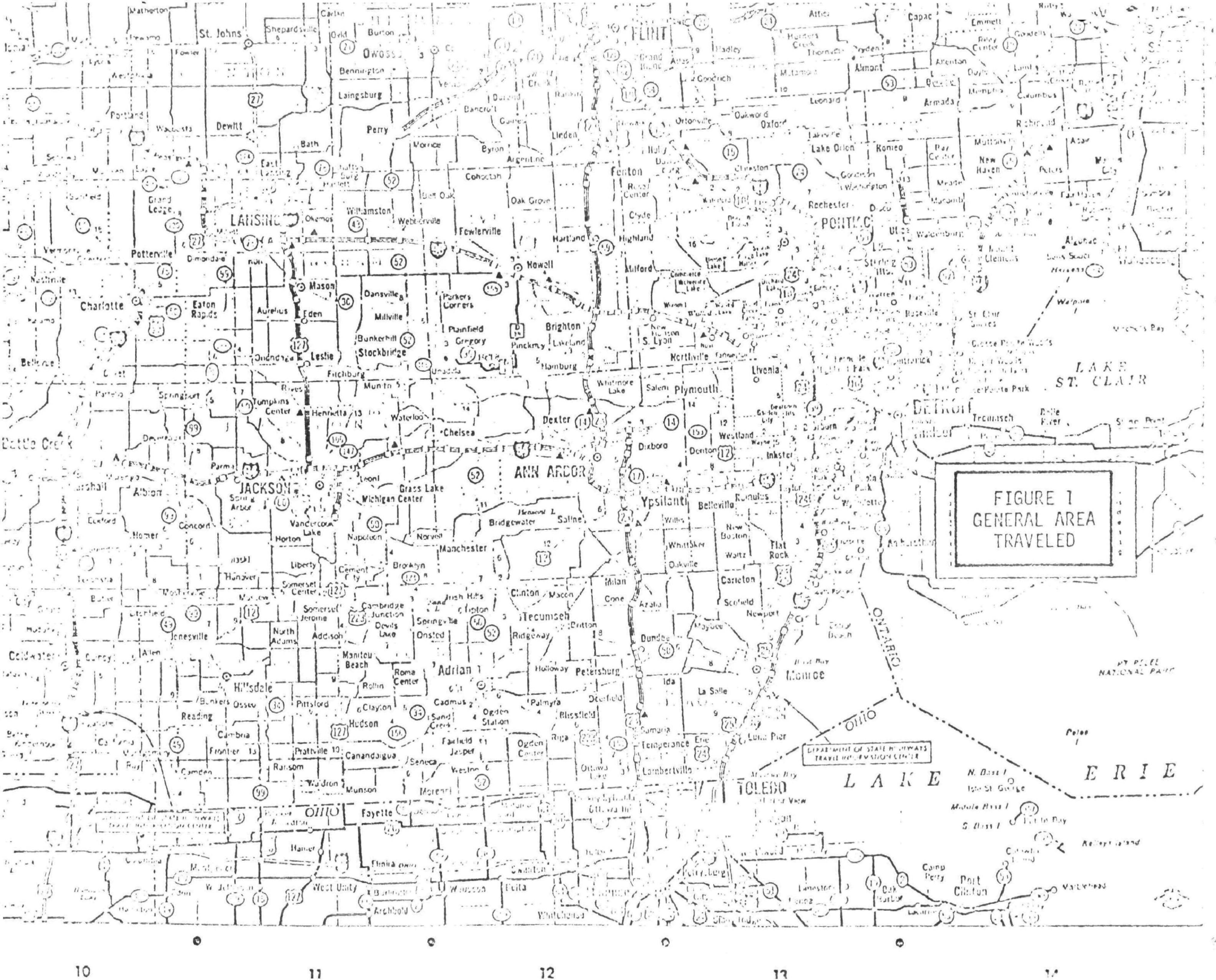


FIGURE 1
GENERAL AREA
TRAVELED

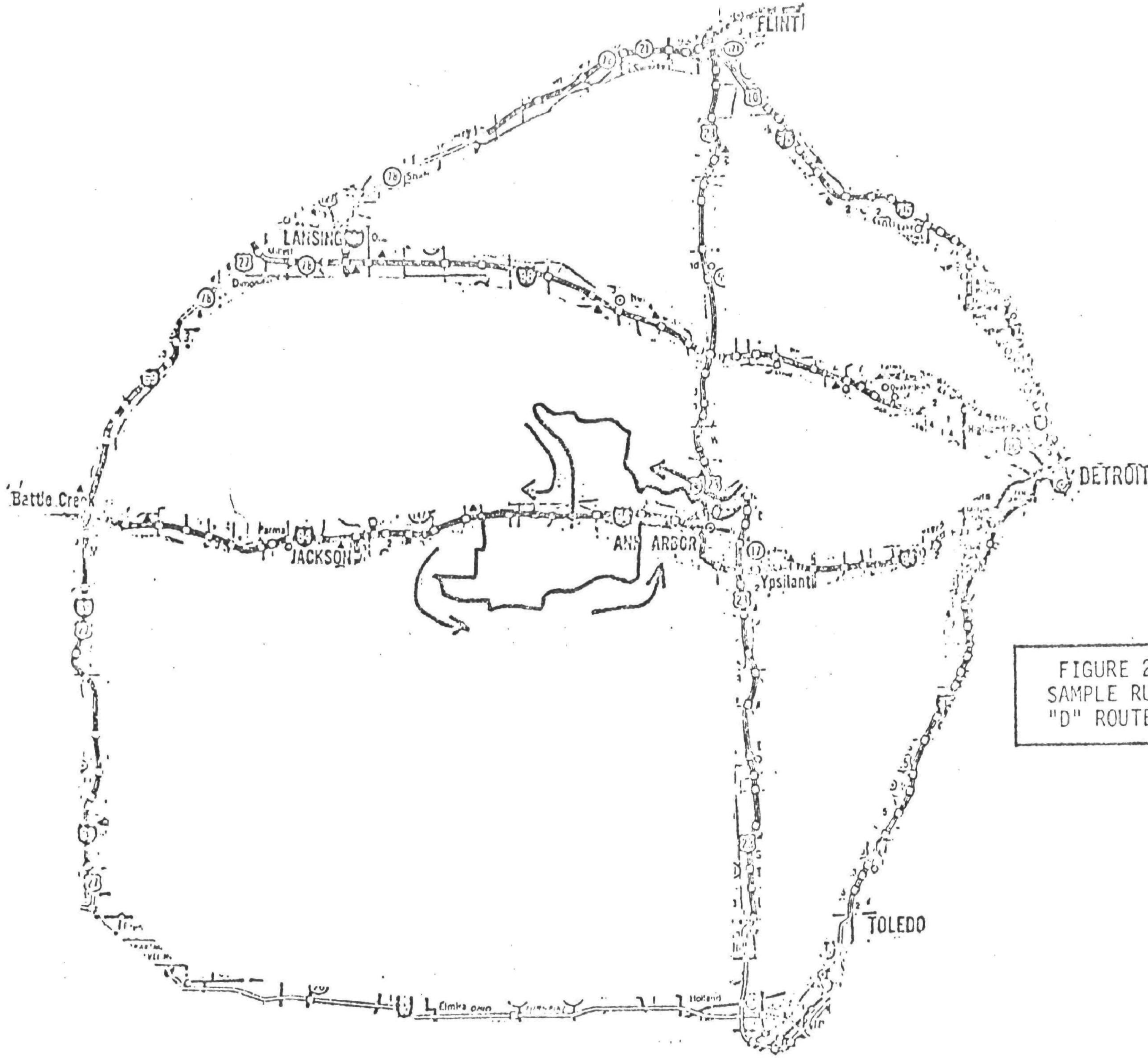


FIGURE 2
SAMPLE RUN
"D" ROUTE

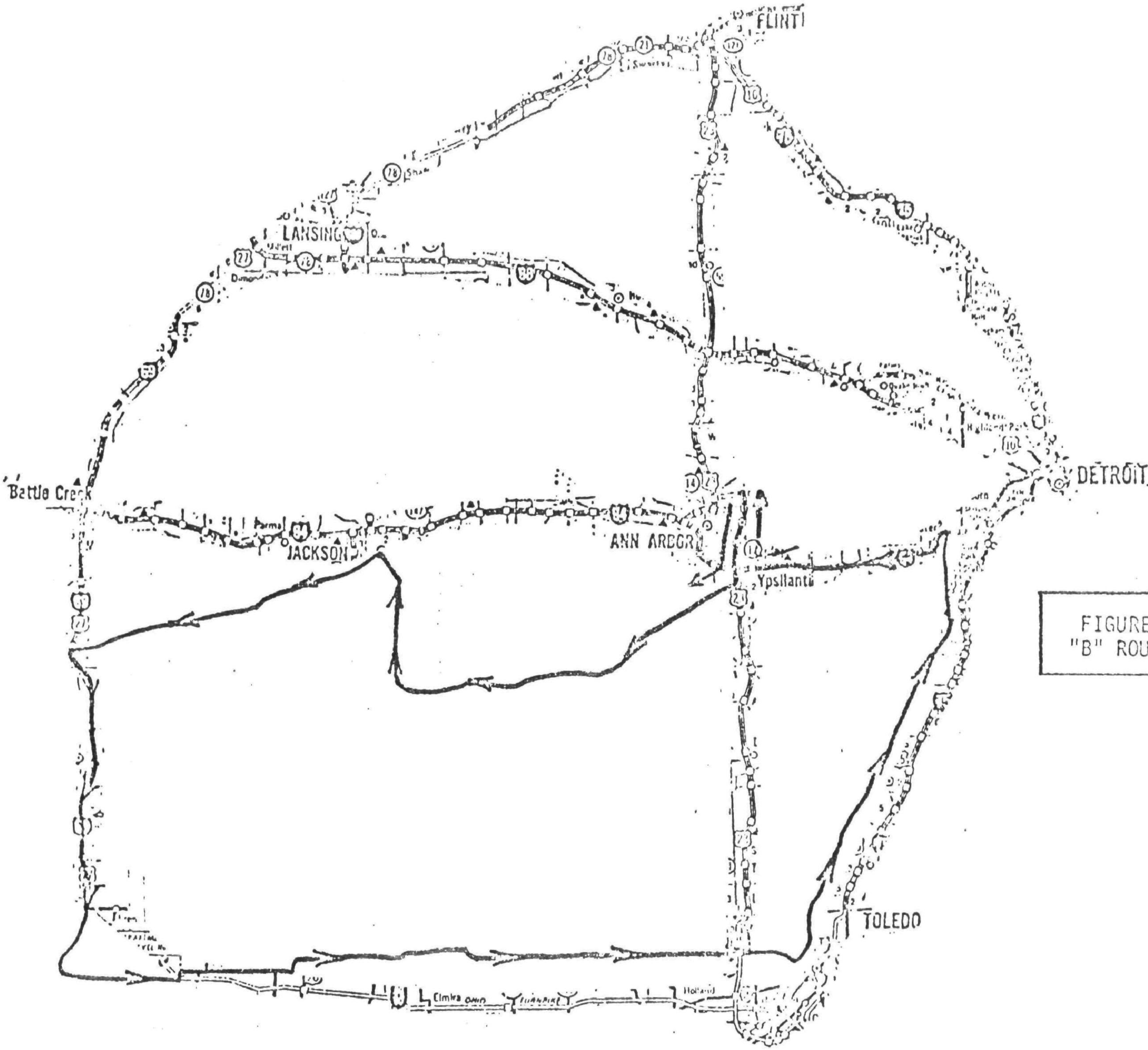


FIGURE 3
"B" ROUTE

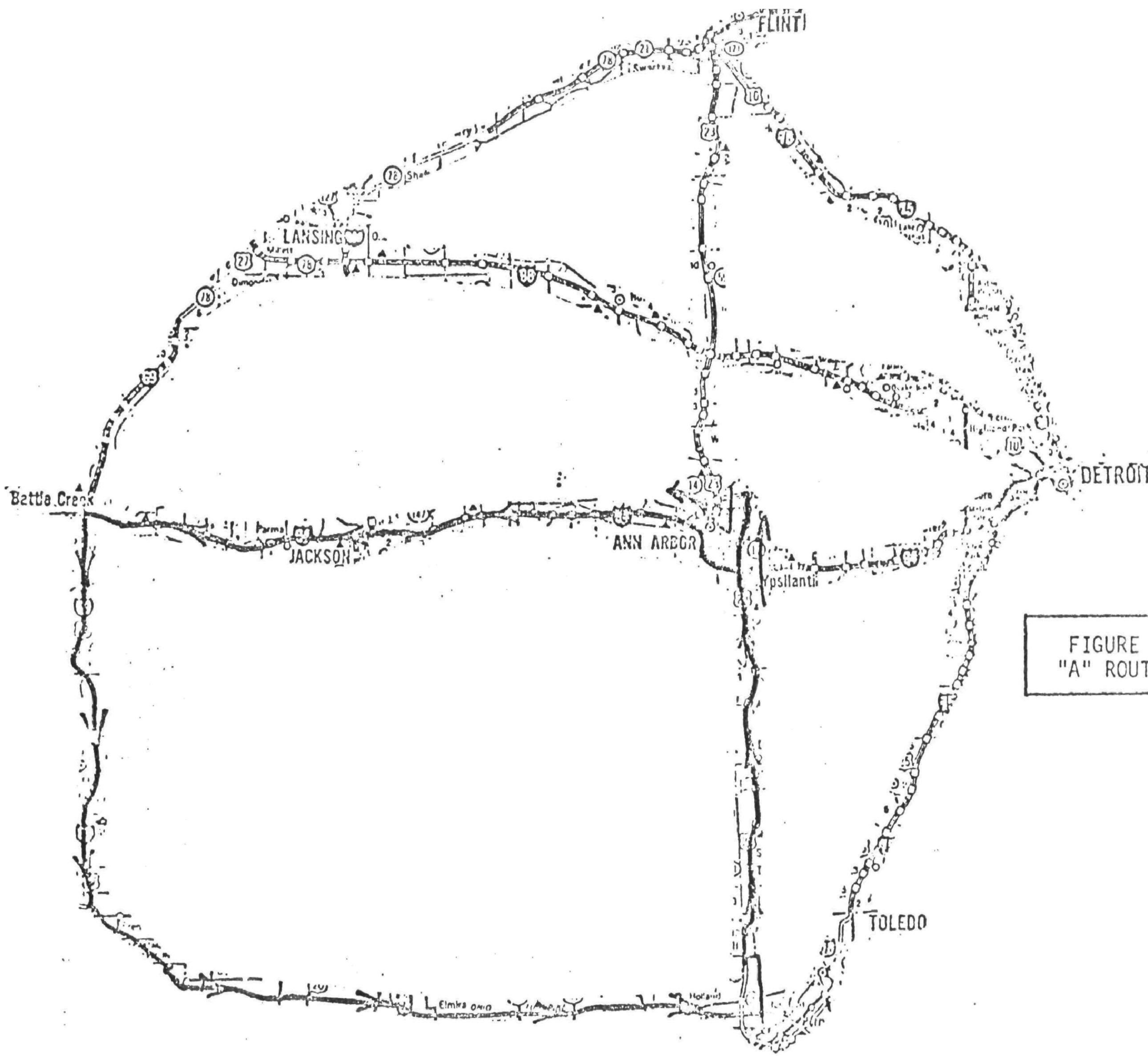


FIGURE 4
"A" ROUTE

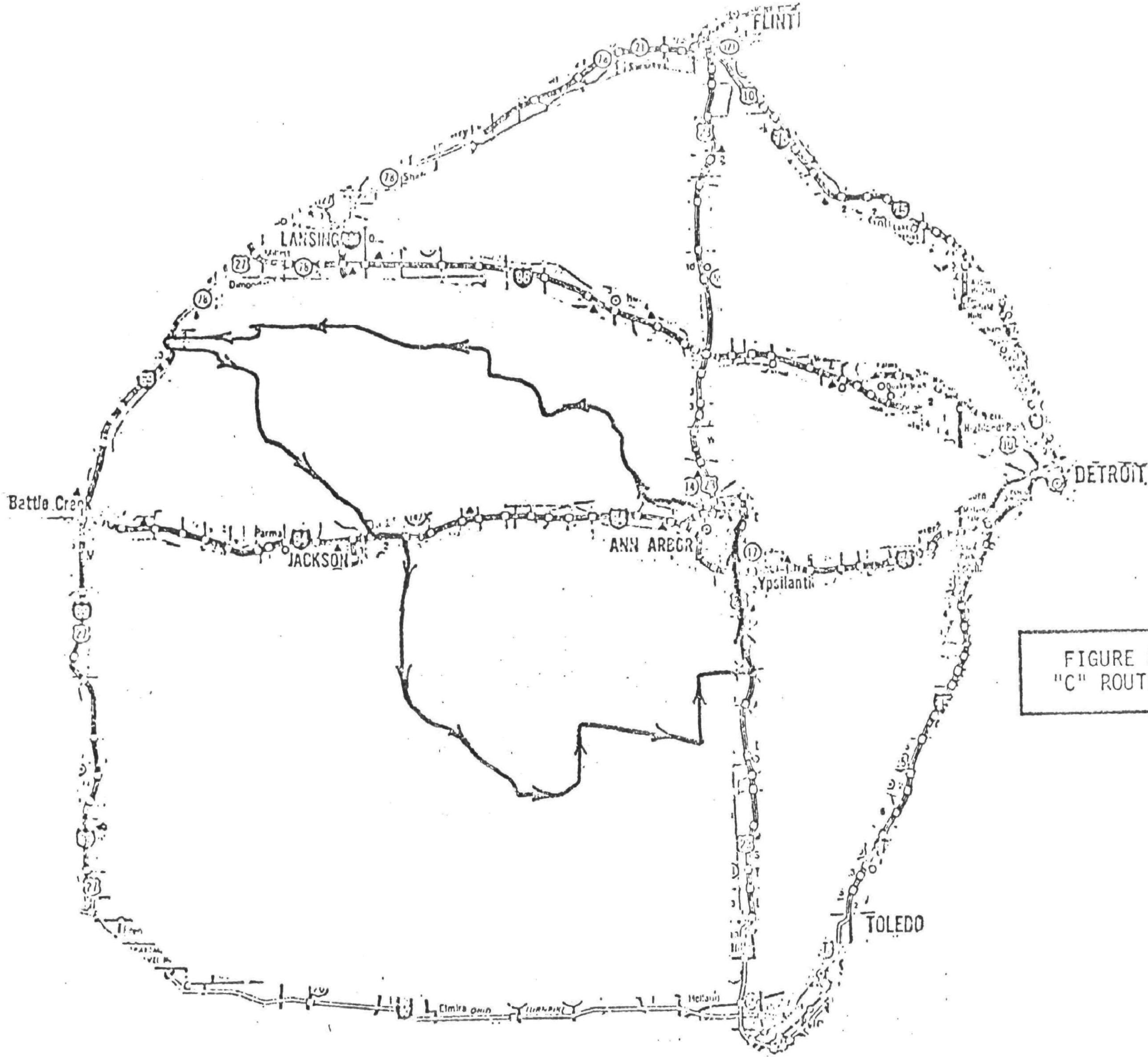


FIGURE 5
"C" ROUTE

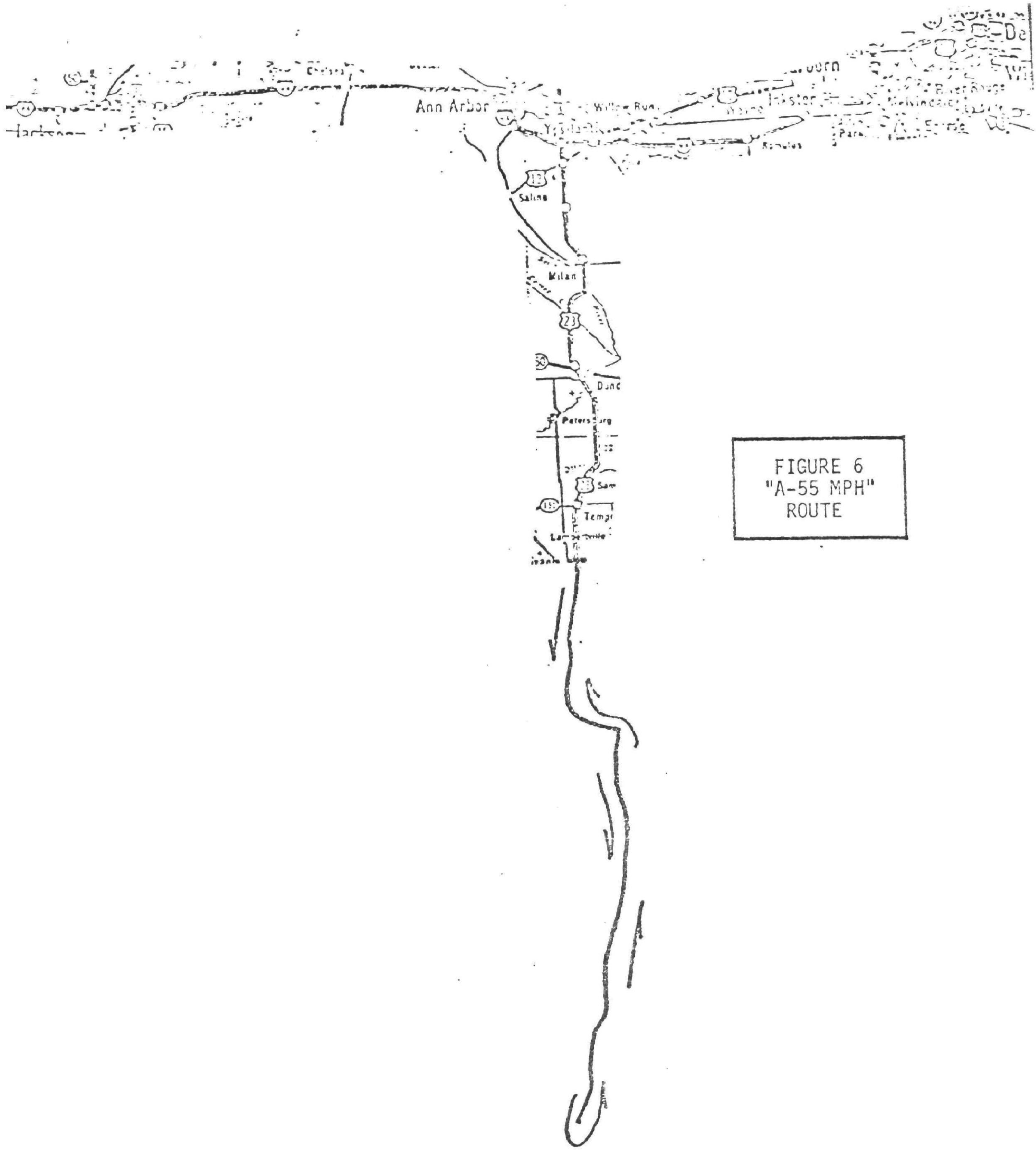


FIGURE 6
"A-55 MPH"
ROUTE