greater similarity in quality of the two road sections. In both figures, the transition in desired speeds took place over approximately 1 km. The data points in Figures 7 and 8 are corrected to 800 vehicles/h, and 95 percent confidence limits are shown.

CONCLUSIONS

The results of the work reported in this paper show clearly that the transition in speed and bunching at a demerge site is considerably more rapid than that at a merge site. Traffic moving from a two-lane road onto a multilane road experiences an improvement in performance that is almost complete within 1 km downstream of the demerge. In the reverse situation, where traffic merges into two lanes, the transition is a gradual one that takes place over several kilometers.

Bunching was found to increase substantially with flow, especially on the two-lane road sections. This led to moderate decreases in mean speed as flow increased. Surprisingly, the form of the V-X and F-X relations was almost unchanged over a wide range of flow rates.

The transitions shown for bunching were directly caused by the change from two lanes to four, or vice versa. The transitions in speed, however, were also affected by changes in road quality. This effect was shown to be quite substantial at the demerge site where the two- and four-lane road sections were of very different quality. Once the effects of road quality are removed from the V-X relation, the remaining transition is entirely attributable to the change in the number of lanes.

ACKNOWLEDGMENT

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Abridgment

Development of a New Traffic-Flow Data-Collection System

LAWRENCE JESSE GLAZER AND WILLIAM COURINGTON

A recently developed hardware-software package for performing "floating-car" or "speed-and-delay" traffic-flow studies is described. The Traffic Recording and Analysis System closely approximates an ideal system. It uses a microcomputerized data recorder that almost totally automates the data-collection process. An enormous amount of data can thus be gathered by one person. No special training or computer background is required. The device uses little power, is truly portable, and is packaged in a rugged metal attaché case. The processing of data from digital cassette tapes is also almost totally automated. An IBM/360 computer analyzes the raw data and produces camera-ready printouts and digital plots. The information presented includes distance, travel time, speed, number of stops, delay time, fuel consumption, air pollution emissions, and vehicle operating costs. Digital plots available are time-speed profiles, speed contour maps, and speed perspectives. Heavy automation of data collection, analysis, and presentation means lower cost per study and thus greater productivity within existing budgets.

Traffic-flow studies have been an important traffic engineering tool for several decades, but currently used techniques are still rather primitive and limiting. Historically, the most common criterion used in measuring the quality of traffic flow has been travel time, which has sometimes included a measure of delay. But circumstances have changed drastically in the past decade, and new demands are now being made on the traffic engineer and the transportation evaluator.

Since automotive air pollution became a major social issue in the late 1960s, traffic engineers have increasingly been required to defend transportation projects with respect to air pollution impacts. Since the 1974 oil embargo, automotive energy consumption and the energy impacts of traffic improvements have also become critical social issues. The current emphasis on cost-effective transportation system management is likewise requiring more detailed project evaluations.

In all of these areas, the tools available to the practicing traffic engineer for measuring the benefits of traffic-flow improvements--including energy savings and reductions in air pollution--have not kept pace with increasing demands. Furthermore, the current economic and political environment is shrinking the budgets that make it possible to do

Figure 1. General report.

PENINSULA TRANSPORTATION DISTR
SPEED AND DELAY STUDY - GENERAL REPORT

MIDPENINSULA REGIONAL TRAFFIC STUDY

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****************************************************************************************************************
*                                                                                                              *
* STUDY STREET:  MIDDLEFIELD RD            FROM: EMBARCADERO RD          TO: 10TH AVE                          *
* DIRECTION:  EASTBOUND            TIME LIMITS:  4:00PM -  5:36PM        DATE LIMITS:  5/12/78 -  5/18/78      *
*  10 RUNS ANALYZED                DELAY THRESHOLD =   5M.P.H.                                                 *
*                                                                                                              *
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LINK #	STREET NAME AT END OF LINK	LINK DISTANCE (FEET) MEAN	STD.DEV.	TRAVEL TIME (SEC.) MEAN	STD.DEV.	LINK SPEED (MPH) MEAN	STD.DEV.	STOP DELAY (SEC)	AVG. # OF STOPS	LEVEL OF SERVICE INDEX #1
	EMBARCADERO RD									
1	CHANNING AVE	2474	19	64.9	17.6	27.7	7.2	8.5	0.4	16
2	HAMILTON AVE	719	15	18.5	7.3	29.1	7.7	1.7	0.2	23
3	UNIVERSITY AVE	896	16	23.5	9.2	28.3	6.8	2.9	0.2	16
4	LYTTON AVE	1507	20	37.1	10.9	29.4	6.8	4.1	0.3	17
5	WILLOW RD	998	17	60.8	26.5	14.7	9.2	34.5	0.7	45
6	RINGWOOD AVE	1130	22	33.5	11.6	25.5	8.1	6.7	0.5	33
7	OAK GROVE AVE	1320	24	28.7	5.0	32.1	4.7	0.6	0.1	12
8	GLENWOOD AVE	1294	26	35.1	7.0	26.1	5.3	3.5	0.4	29
9	ENCINAL RD	431	21	11.0	1.7	27.2	3.7	0.0	0.0	25
10	JAMES AVE	987	15	21.9	2.6	31.1	3.3	0.0	0.0	4
11	MARSH RD	1342	18	28.3	2.5	32.5	2.8	0.0	0.0	4
12	5TH AVE	1505	13	48.7	15.7	23.2	7.6	13.7	0.6	23
13	8TH AVE	1331	15	41.1	5.4	22.5	3.7	6.1	0.8	39
14	10TH AVE	1341	25	55.4	15.0	17.9	6.1	16.4	0.9	42
**	ROUTE DATA:	17272	34	508.5	70.9	23.6	3.3	98.7	5.1	23

good evaluations of traffic-flow improvement projects.

Thus, there is a clear need for better and cheaper techniques for measuring and evaluating traffic flow.

One recent development should provide a partial solution for the beleaguered traffic engineer. The Traffic Recording and Analysis System (TRANS) is a new package of hardware and software for performing traffic-flow studies, sometimes called "speed-and-delay" or "floating-car" studies. The hardware is a data recorder that collects raw data on tape, and the software is a group of computer programs that analyze the raw data to produce a wealth of printed and graphical reports.

DESIGN GOALS

Based on development and extensive use of a first-generation, electronic speed-and-delay device and also on a review of most other available devices of this type, we have developed a new system that overcomes the major problems with past systems. Our major design goals were the following:

1. To improve reliability by reducing machine and operator error,
2. To improve ergonomics (the person-machine interface) for safety and ease of use,
3. To reduce downtime by improving vehicle-to-vehicle portability,
4. To provide a universal recording format plus more analysis programs and thus satisfy a wide variety of local analysis and evaluation needs, and, most important,
5. To reduce the total cost and time required to perform these studies, including data collection, analysis, and report preparation.

The ways in which these design goals were met are described below.

DATA RECORDER

The entire TRANS data recorder is packaged in a rugged, portable, metal attaché case that weighs about 16 lb and so is easily moved from one vehicle to another. In operation, it is strapped to the front seat next to the driver, and connections are made to the vehicle's electricity and speedometer cable. Since the data recorder draws less than 2 A from the vehicle, no special electrical provisions are required. The speedometer cable is fitted with a simple screw-on, electrical-pulse generator.

The data recorder consists of several major components: a "control center", a kneepad keyboard, and a display. The control center includes a read-write digital cassette deck plus a process-control microcomputer that controls all of the functions of the data recorder. The kneepad, a panel of push-buttons that straps to the driver's knee, is used to manually enter data. The display, a long, thin box that lies on the dashboard in front of the driver, supplies feedback from the computer to the driver-operator in clear, English-language messages. The kneepad and display especially demonstrate the careful attention to ergonomics that has often been lacking in previous devices of this type.

The microcomputer accepts header information (date, time, study number, etc.), using the display to "prompt" and the kneepad to read manual data. All header data are checked for error and then recorded on the tape before each run. Thus, every run is uniquely identified to eliminate any possibility of mistaken data. During each run, the microcomputer records the distance traveled each second along with any manually entered remarks (which usually serve to identify the cause of delay). This is the most universal recording format for an instrumented-vehicle data base. The microcomputer also leads the operator through the necessary calibration procedures and performs

Figure 2. Delay analysis.

PENINSULA TRANSPORTATION DISTR
SPEED AND DELAY STUDY - DELAY ANALYSIS

MIDPENINSULA REGIONAL TRAFFIC STUDY

```
****************************************************************************************************
*                                                                                                  *
* STUDY STREET: MIDDLEFIELD RD        FROM: EMBARCADERO RD        TO: 10TH AVE                     *
* DIRECTION: EASTBOUND          TIME LIMITS: 4:00PM - 5:36PM      DATE LIMITS: 5/12/78 - 5/18/78   *
*  10 RUNS ANALYZED             DELAY THRESHOLD =   5M.P.H.                                        *
*                                                                                                  *
****************************************************************************************************
```

LINK #	STREET NAME AT END OF LINK	LINK TRAVEL TIME (SEC)	TOTAL STOP DELAY (SEC)	AVG. # OF STOPS	SIGNALS STOP DELAY (SEC)	SIGNALS AVG. # OF STOPS	LEFT TURNS STOP DELAY (SEC)	LEFT TURNS AVG. # OF STOPS	RIGHT TURNS STOP DELAY (SEC)	RIGHT TURNS AVG. # OF STOPS	PEDESTRIANS STOP DELAY (SEC)	PEDESTRIANS AVG. # OF STOPS	OTHER STOP DELAY (SEC)	OTHER AVG. # OF STOPS
	EMBARCADERO RD													
1	CHANNING AVE	64.9	8.5	0.4	8.5	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	HAMILTON AVE	18.5	1.7	0.2	1.7	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	UNIVERSITY AVE	23.5	2.9	0.2	2.9	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	LYTTON AVE	37.1	4.1	0.3	4.1	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	WILLOW RD	60.8	34.5	0.7	34.5	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	RINGWOOD AVE	33.5	6.7	0.5	6.7	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	OAK GROVE AVE	28.7	0.6	0.1	0.6	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	GLENWOOD AVE	35.1	3.5	0.4	3.5	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	ENCINAL RD	11.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	JAMES AVE	21.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	MARSH RD	28.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	5TH AVE	48.7	13.7	0.6	13.7	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	8TH AVE	41.1	6.1	0.8	5.5	0.7	0.0	0.0	0.0	0.0	0.6	0.1	0.0	0.0
14	10TH AVE	55.4	16.4	0.9	16.1	0.8	0.0	0.0	0.0	0.0	0.3	0.1	0.0	0.0
**	ROUTE DATA:	508.5	98.7	5.1	97.8	4.9	0.0	0.0	0.0	0.0	0.9	0.2	0.0	0.0

Figure 3. Energy/emissions/user-cost report.

PENINSULA TRANSPORTATION DISTRICT
SPEED AND DELAY STUDY - ENERGY & AIR POLLUTION ANALYSIS

MIDPENINSULA REGIONAL TRAFFIC STUDY

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****************************************************************************************************
*                                                                                                  *
* STUDY STREET: MIDDLEFIELD RD        FROM: EMBARCADERO RD        TO: 10TH AVE                     *
* DIRECTION: EASTBOUND          TIME LIMITS: 4:00PM - 5:36PM      DATE LIMITS: 5/12/78 - 5/18/78   *
*  10 RUNS ANALYZED             DELAY THRESHOLD =   5 MPH                                          *
*                                                                                                  *
****************************************************************************************************
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LINK #	STREET NAME AT END OF LINK	LINK DISTANCE (FEET)	TRAVEL TIME (SEC.)	AVG. SPEED (MPH)	STOP DELAY (SEC)	AVG. # OF STOPS	FUEL USED (GAL/100)	HYDRO-CARBONS (LBS)	CARBON MONOXIDE (LBS)	NITROUS OXIDES (LBS)
	EMBARCADERO RD									
1	CHANNING AVE	2474	64.9	27.7	8.5	0.4	2.87	0.0047	0.0285	0.0057
2	HAMILTON AVE	719	18.5	29.1	1.7	0.2	0.88	0.0014	0.0083	0.0017
3	UNIVERSITY AVE	896	23.5	28.3	2.9	0.2	1.06	0.0017	0.0103	0.0021
4	LYTTON AVE	1507	37.1	29.4	4.1	0.3	1.88	0.0029	0.0174	0.0035
5	WILLOW RD	998	60.8	14.7	34.5	0.7	1.29	0.0019	0.0115	0.0023
6	RINGWOOD AVE	1130	33.5	25.5	6.7	0.5	1.41	0.0022	0.0130	0.0026
7	OAK GROVE AVE	1320	28.7	32.1	0.6	0.1	1.47	0.0025	0.0152	0.0030
8	GLENWOOD AVE	1294	35.1	26.1	3.5	0.4	1.60	0.0025	0.0149	0.0031
9	ENCINAL RD	431	11.0	27.2	0.0	0.0	0.40	0.0008	0.0050	0.0010
10	JAMES AVE	987	21.9	31.1	0.0	0.0	1.09	0.0019	0.0114	0.0023
11	MARSH RD	1342	28.3	32.5	0.0	0.0	1.54	0.0026	0.0155	0.0031
12	5TH AVE	1505	48.7	23.2	13.7	0.6	1.84	0.0029	0.0174	0.0035
13	8TH AVE	1331	41.1	22.5	6.1	0.8	1.65	0.0026	0.0154	0.0031
14	10TH AVE	1341	55.4	17.9	16.4	0.9	1.69	0.0026	0.0154	0.0032
**	ROUTE DATA:	17272	508.5	23.6	98.7	5.1	20.69	0.0332	0.1993	0.0372

numerous error checks during all phases of the operation.

SYSTEM OUTPUTS

A wide variety of outputs can be produced from the raw data on cassettes. A data base maintenance program stores all runs in a single master file and permits retrieval of any combination of runs (e.g., by study number, dates, or times) for subsequent analysis. The analysis software produces both tabular (printed) and graphical (plotted) outputs.

Figure 4. Time-speed profile.

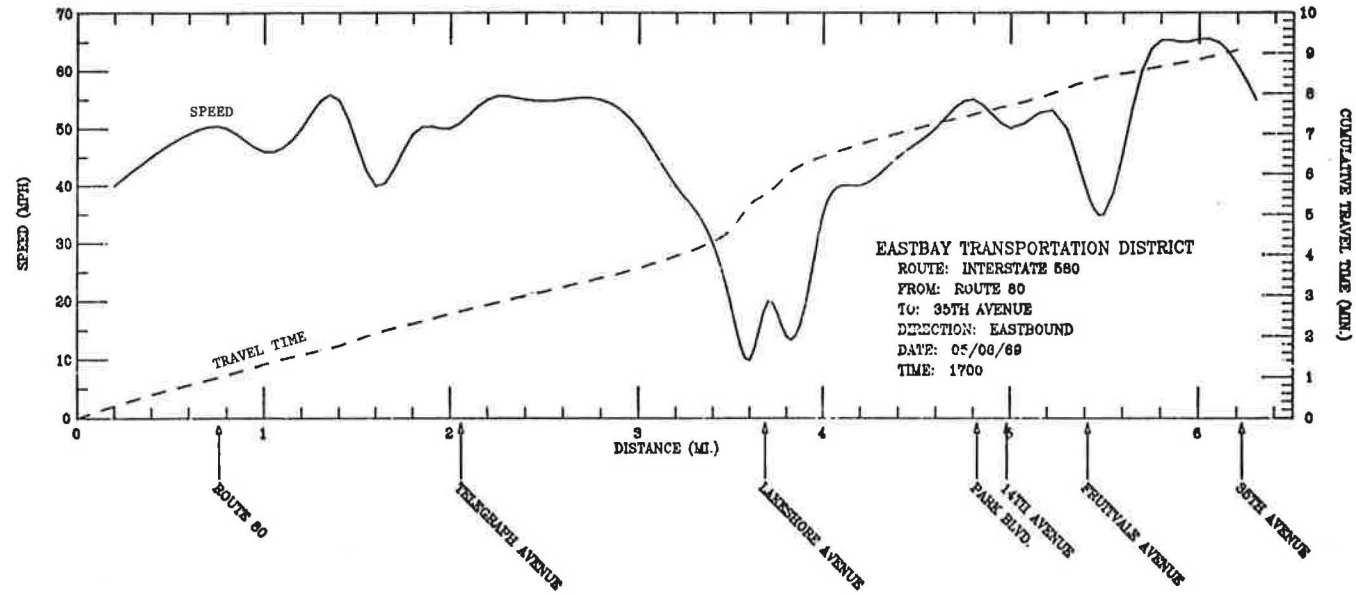
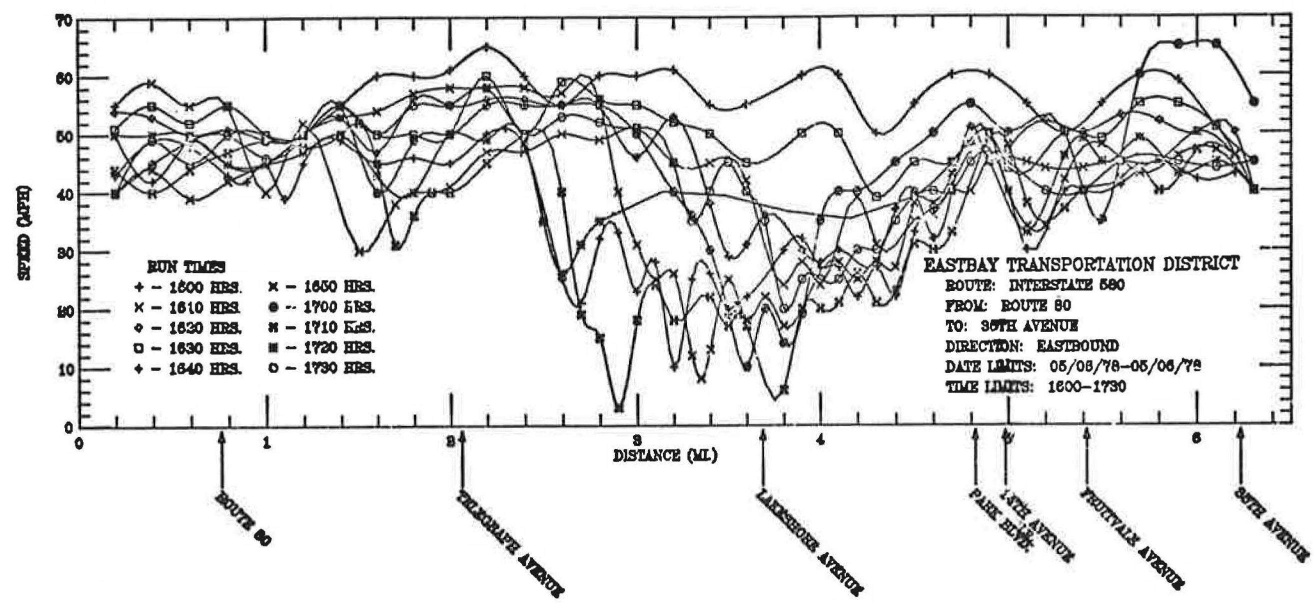


Figure 5. Speed profiles.



With one minor exception, all outputs are of camera-ready quality. Thus, substantial time and cost savings are possible in both the analysis and report-writing phases of traffic-flow studies. For example, the semiautomated RUNCOST procedure described by Parsonson (1), requires 4 h to code and keypunch each hour of tachograph field data. This high degree of automation is probably the major advantage TRANS has over its predecessors, which have tended to concentrate more on hardware than on data analysis and presentation.

Printed Reports

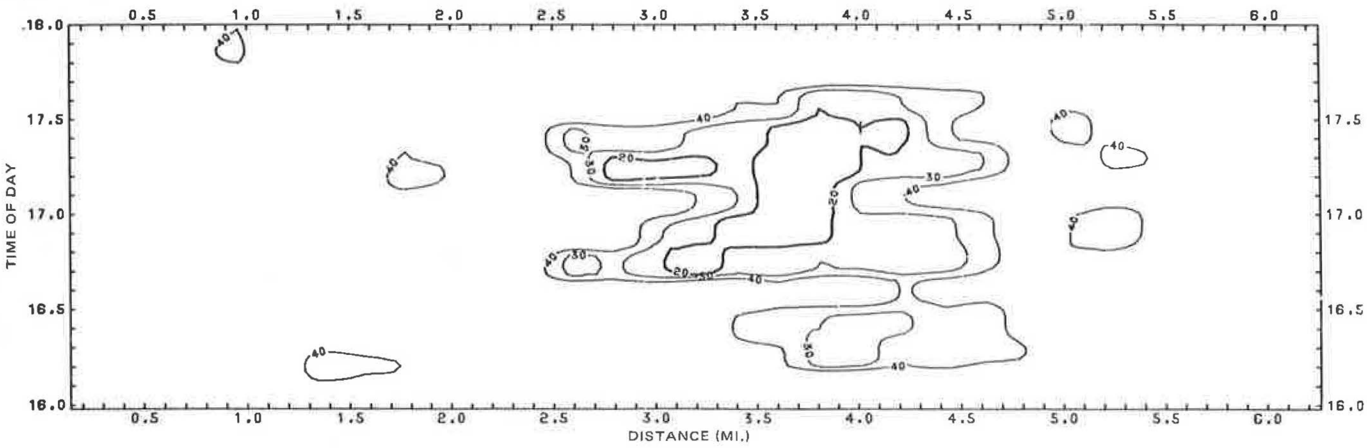
TRANS printed reports include the general report, the delay analysis, and the energy/emissions/user-cost report. Examples of these reports are shown in Figures 1-3.

The general report (Figure 1) supplies basic operating information: distance, travel time, speeds, delays, stops, and an index of quality of service. The delay analysis (Figure 2) breaks down total delays and number of stops into categories that correspond to the causes of these delays (e.g., signals or pedestrians). The energy/emissions/user-cost report (Figure 3) shows fuel used plus emissions (HC, CO, NO_x). Because the user-cost algorithm is currently under development, these data are not yet shown on the report. Other printouts, such as a run-by-run data matrix, are also available.

Graphical Outputs

The basic plotted output is the time-speed profile for each run (see Figure 4), which shows both cumulative time and speed versus distance. A

Figure 6. Speed contour map.



related plot is the speed profile (see Figure 5), which shows as many as 10 runs on the same plot, for ease of comparison. A different plot is the speed contour map (see Figure 6), which shows speed isopleths (contours) versus distance and time of day. Because it pictorially portrays magnitude, location, and duration of congestion, this is probably the most powerful output. It is meaningful to both the traffic engineer and the layperson.

Any of these outputs are available for any desired combination of runs.

CONCLUSIONS

TRANS uses advanced computer and traffic engineering techniques to achieve dramatic improvements in both the cost and the effectiveness of traffic-flow data collection. Costs are reduced because TRANS automates all three of the steps required for traffic-flow studies: data collection, analysis, and presentation. Effectiveness is greatly improved because TRANS measures all of the traffic-flow parameters that are currently of concern: distance, travel time, speed, number of stops, stop time, flow smoothness, fuel consumption, air pollutant emissions, and user costs. Several valuable digital plots, including the well-recognized speed profiles and the more striking speed contour maps, are also available.

TRANS can be a powerful analysis and evaluation tool for traffic-signal-system projects, freeway ramp-metering projects, roadway channelization and geometric improvement projects, inventories of travel time and operating speed, and energy and air pollution studies.

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Publication of this paper sponsored by Committee on Traffic Flow Theory and Characteristics.

Revision of NCHRP Methodology for Analysis of Weaving-Area Capacity

ROGER P. ROESS, WILLIAM R. McSHANE, AND LOUIS J. PIGNATARO

As part of an effort sponsored by the Federal Highway Administration (FHWA) to revise and update procedures for freeway capacity analysis, the weaving-area methodology developed as a result of National Cooperative Highway Research Program (NCHRP) Project 3-15 was revised with two objectives in mind: (a) to recalibrate the procedure to reflect modified service-volume concepts developed in other parts of the FHWA effort and (b) to simplify the structure of the NCHRP procedure to make it easier to apply and understand while retaining its demonstrated accuracy and sensitivity to lane configuration, a major factor in highway operations. The revised method was developed by using standard multiple regression techniques and a data base consisting of results of the 1963 U.S. Bureau of Public Roads study of weaving-area capacity and the results of extensive data collection on NCHRP Project 3-15. The procedure consists of calibrated relations governing (a) the operation of nonweaving vehicles in weaving areas; (b) the maximum number of lanes that can be occupied by weaving vehicles for various configurations; (c) the "share", or percentage, of weaving-area lanes occupied by weaving vehicles under "balanced" operation; and (d) the relation between the average speed of weaving vehicles and that of nonweaving vehicles. To simplify the application of these relations in design and operational analysis, a series of nomographs has been developed.

In 1973, a major study of weaving-area operations was completed at the Polytechnic Institute of New York for the National Cooperative Highway Research Program (NCHRP) (1,2). The study resulted in the formulation of new procedures and relations for analysis of weaving-area capacity. These were (a) substantially more accurate than the procedures of the 1965 Highway Capacity Manual (HCM) in their representation of field conditions, (b) based on