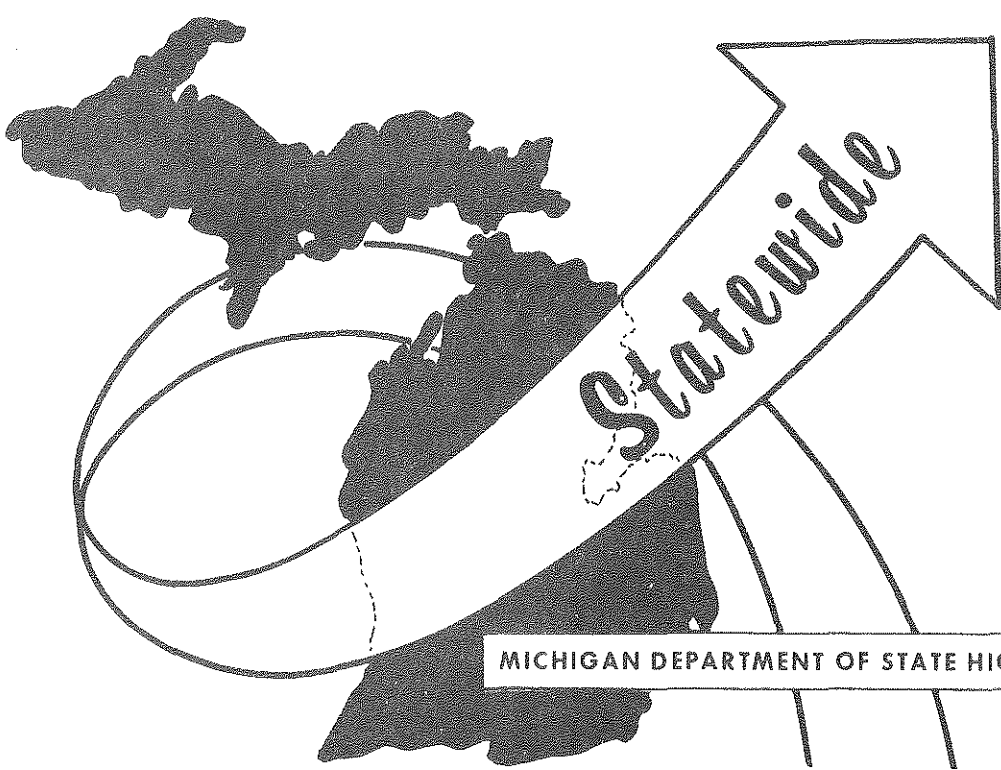
Statewide Transportation Analysis & Research

MICHIGAN'S
STATEWIDE TRAFFIC
FORECASTING MODEL

VOLUME VII-A

CAPACITY ADEQUACY FORECASTING MODEL

OCTOBER 1973
STATEWIDE STUDIES UNIT



MICHIGAN DEPARTMENT OF STATE HIGHWAYS AND TRANSPORTATION

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STATE OF MICHIGAN

WILLIAM G. MILLIKEN, GOVERNOR

DEPARTMENT OF STATE HIGHWAYS

STATE HIGHWAYS BUILDING – POST OFFICE DRAWER K – LANSING, MICHIGAN 48904

JOHN P. WOODFORD, STATE HIGHWAY DIRECTOR

October 2, 1973

Mr. Sam F. Cryderman
Engineer of Transportation Planning
Transportation Planning Division

Dear Mr. Cryderman:

This report documents the efforts put into the development of a "capacity adequacy" forecasting model. By utilizing this model, the department will be able to determine the probable magnitude of capacity deficiency which is reflected by excessive traffic congestion.

The model uses the volume to capacity ratio and the design hour volume factor as independent variable to predict the number of days on which the daily capacity of a section of road will be exceeded by the daily total traffic in some future time.

Some features of the model are listed below:

(1) The study places emphasis on practical application. All the independent variables are measurable and predictable in the existing statewide traffic forecasting model system.

(2) The model is capable of being computerized. Therefore, capacity adequacy for the entire highway network can be determined most efficiently.

(3) The forecasts from the model may serve as a complimentary criterion in evaluating future trunkline deficiencies.

This report was prepared by Benjamin Pin-fan Chu under the supervision of Richard E. Esch of Statewide Studies Unit. We would appreciate your comments.

Sincerely,

Keith E. Bushnell

Keith E. Bushnell
Engineer of Transportation
Survey and Analysis Section

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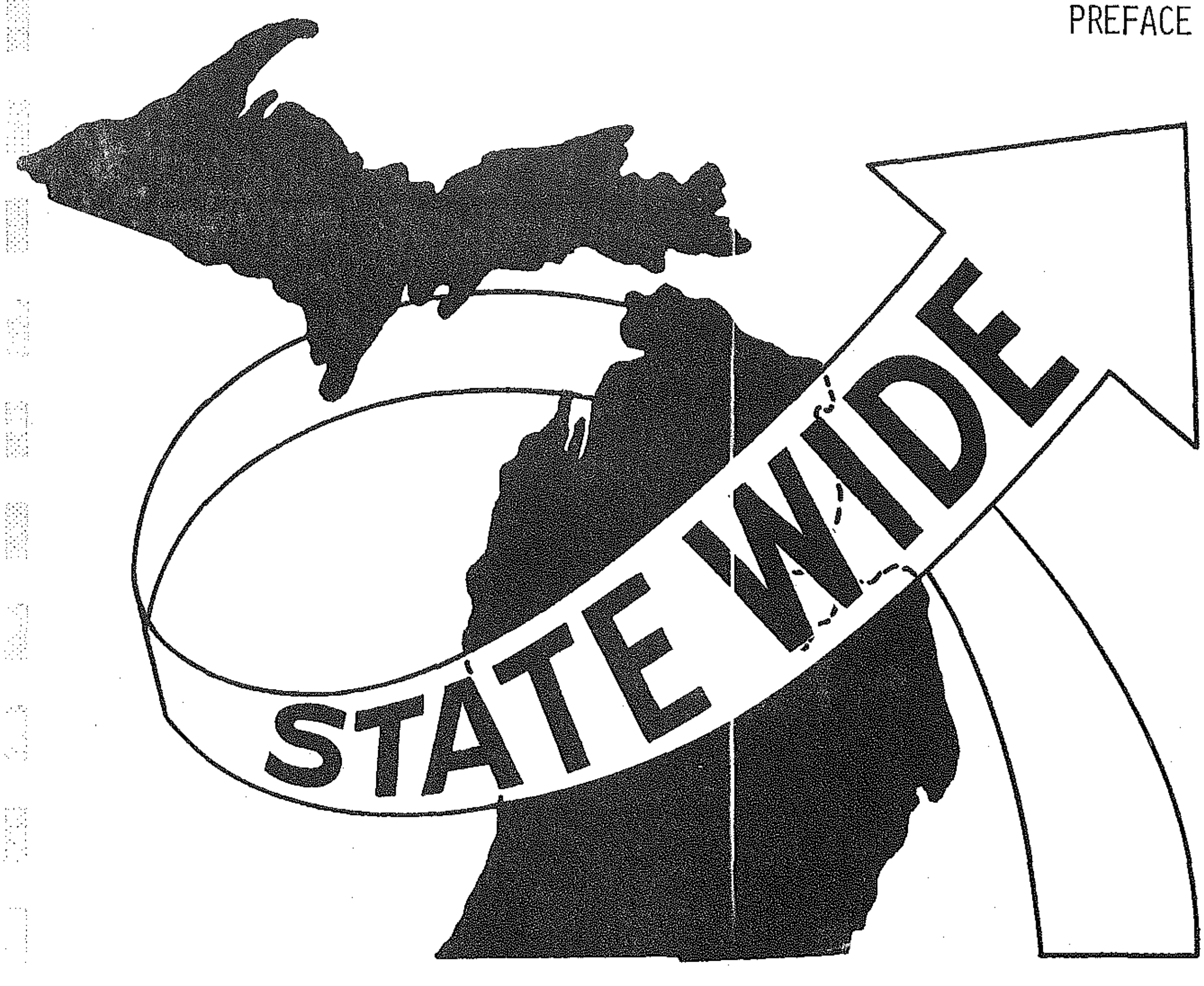

This report describes a model which is a direct offshoot of the development of the Michigan Statewide Traffic Forecasting Model.

The study in this report directs itself at developing a preliminary forecasting process that will give the department the type of information required to identify the magnitude of future traffic congestion on a statewide basis. Undoubtedly, this type of information should be taken into consideration during the evaluation phase of the transportation planning process.

Until now, few capacity studies have been set up on a pure empirical basis. The study in this report will serve the purposes of a practical planning application.

Furthermore, the capability of being computerized as part of the statewide forecasting process will allow the department to carry out a more systematic and rapid planning process.

This report is Volume VII-A of a series of reports dealing with the statewide traffic forecasting model development. Other reports in the series are listed below for reference:

Volume	I	Objectives and Work Program
Volume	I-A	Workshop Topic Summaries
Volume	I-B	Traffic Forecasting Applications Single and Multiple Corridor Travel Analysis
Volume	I-C	Model Application Turnbacks
Volume	I-D	Proximity Analysis: Social Impacts of Alternate Highway Plans on Public Facilities
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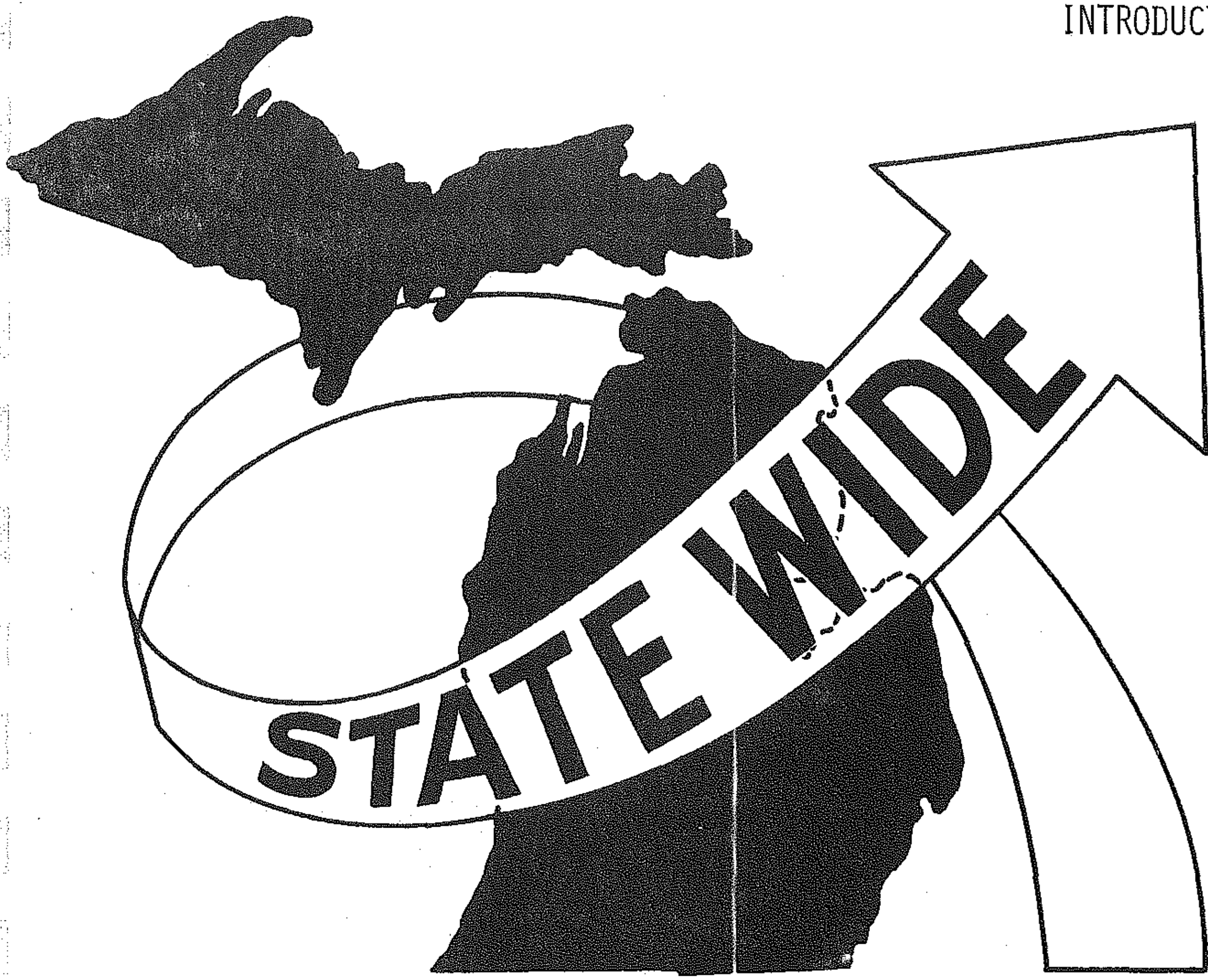
INTRODUCTION



THE PROBLEM

In recent years, the concept of highway user benefits has been emphasized in the area of transportation planning analysis. There may be many factors that can be utilized to measure the user's benefits from highway facilities. It seems that good highway operational condition affects the individual highway user to a great degree.

Attempting to avoid congestion on highways seems to be very much relevant to improving highway user benefits. The lack of congestion makes travel more rapid and more efficient. Moreover, the extent of congestion gives the drivers not only a sense of freedom of movement but also a sense of travel safety. Therefore, the benefits resulting from reduction in travel time and increase in travel safety must be taken into account when designing new highways or scheduling highway improvements.

If the capacities of the existing highways accommodate traffic all the time (as the case when they were in the opening stage), then there is no capacity adequacy (or, deficiency*) problem at all. However, the traffic is ever expanding. It is estimated that by the year 2000 the state of Michigan will have at least 8.5 million vehicles in registration.** Congestion would

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* An evaluation of the future capacity adequacy may be expressed as an identification of either the merits or the deficiencies.

** According to a regression trend analysis on the state vehicle registration data from 1944 to 1971. The data are obtained from "Highway Statistics" published annually by U.S. Department of Transportation and Federal Highway Administration.

be a serious problem in the future if highway capacity condition designed and/or operated at the present time could not accommodate the expanding future traffic.

In fact, the analysis of congestion and its influence plays an important role in many transportation planning studies. In general, the problem of congestion is studied along with capacity analyses.

The capacity of a given section of road is defined as the maximum possible traffic volume which pass over the given section under prevailing conditions during a specified time period (generally, an hour or a day).* Roughly speaking, when the capacity is not exceeded by traffic flow (expressed in number of vehicles per hour), the drivers can travel with reasonable speed, comfort and safety. When the capacity is exceeded by some high rate of flow for a period of time, according to the definition of capacity, the prevailing traffic condition has been broken down**. In this case, the average speed would be forced to slow down and the average density (expressed in

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* Refer to "Highway Capacity Manual" published in 1965 by Highway Research Board, Page 5; for the definition of prevailing conditions refer to Page 14. It is essential to specify the prevailing condition of roadway and traffic under which the capacity is implied. The capacity data used in this report have been assumed under level service C.

** Traffic flow is commonly regarded as flow movement in a river. Therefore, capacity breakdown may be regarded as flood.

number of vehicles per mile) to increase.* Congestion is therefore taking place.

The daily capacity may be obtained from the hourly capacity by an expansion factor of 10. This is assumed due to the regularity that exists in the hourly traffic distribution during each day. The daily total traffic volume** is generally about ten times as high as the traffic in the most heavily travelled hours of the day***, and therefore, if the daily capacity is exceeded by the daily traffic, the hourly capacity is most likely exceeded by the hourly traffic and congestion will occur frequently in the most heavily travelled hours.

Now, a question arises naturally as to whether the daily capacities of the existing highways would not become indaequate by the expanding traffic in the future. In other words, if the highways in operation or designed at the present remain unimproved, the number of days of daily capacity breakdown in a given future year is our main concern. This is an extremely pertinent consideration in the problem dealing with future highway adequacy.

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* Due to the theoretical relationship between speed, flow and density

Flow (vph) = Average Speed (mph) X Average Density (v/mile),

the values of any two of the three variables determine the value of the other variable.

** Traffic, represented as Flow or Rate of Flow when measured for a period of less than one hour the number of vehicles passing over a section of road, while expressed as Volume when measured for a period of an hour or more.

*** For the annual average hourly traffic distribution of the day, refer to "Hourly Percent of Yearly Traffic For the 7 Days of the Week" in a series of publication titled "Automatic Traffic Recorder Analysis" published by Michigan Department of State Highways.

The study in this report has been centered around establishing a model which may be utilized to forecast the number of days of capacity breakdown in the future for each of the highways on the network system. The resulting information provided by the model should serve as a criterion for dealing with the magnitude of highway deficiencies in addition to other standards.

DATA BASE

The travel data are obtained from two sources.

The capacity data are based on the capacity rating supplied by the Michigan Department of State Highways.* The capacity rating gives the measure of adequacy of all highways on a control-section system to allow the Department to determine priorities in scheduling highway improvements.

The traffic data were collected by the electronic Permanent Traffic Recorder (P.T.R.) stations.** These P.T.R. stations were operated continuously throughout the counting year recording the number of vehicles passing over.

Thirty eight stations (for station location refer to Figure 1) have been chosen because emphasis has been placed on the trunklines on which these stations were located. The observation period is from 1966 up to 1971 during which the capacity data are available.

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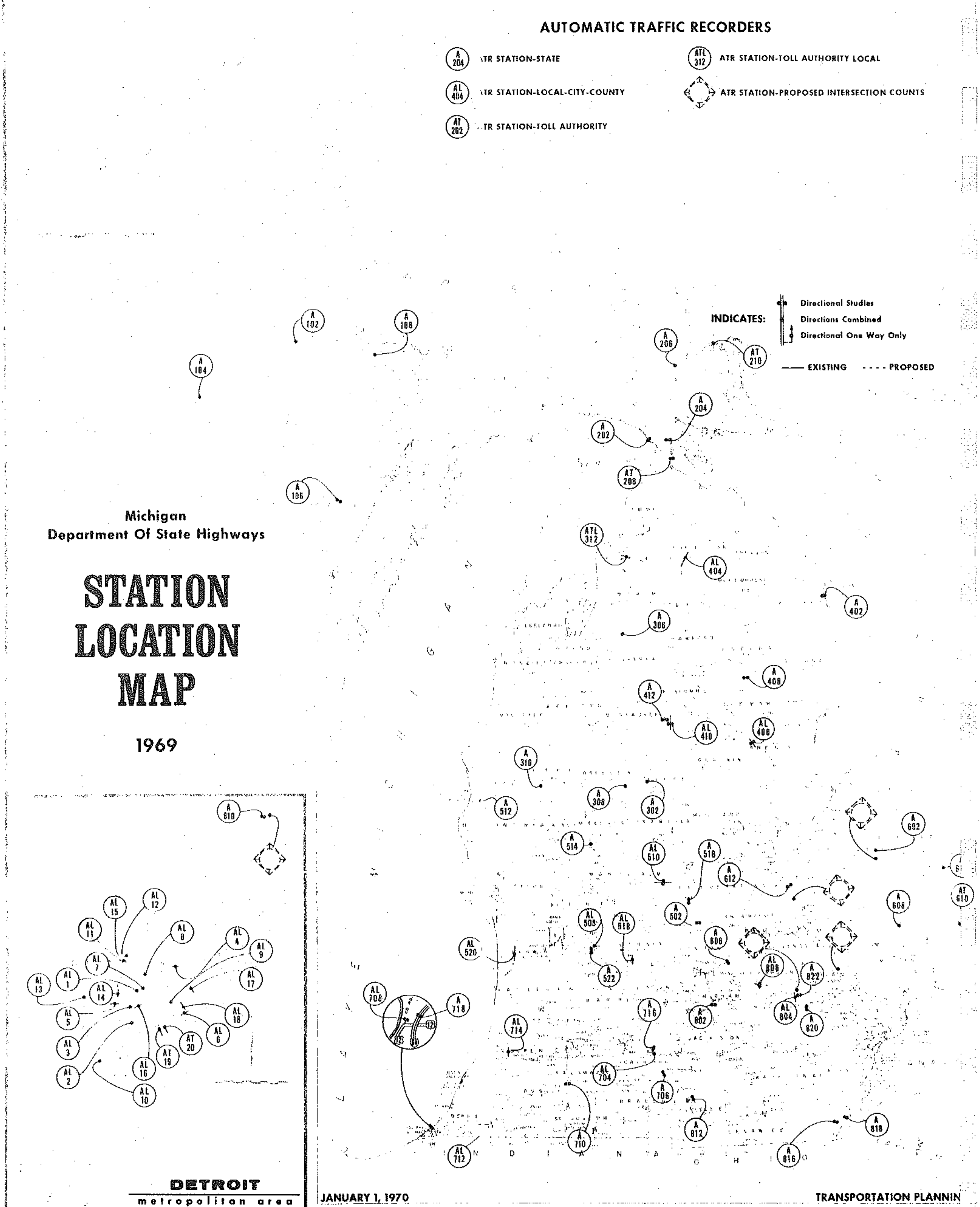
* Refer to "Sufficiency Rating Computations for Michigan Highways" published by the Michigan Department of State Highways. Factors based on percent sight restrictions, lane width, percent commercial traffic, and DHV are included in the computation of the capacity rating. The computation has been computerized.

** The P.T.R. data and analysis were published annually by the Michigan Department of State Highways, in a series of publications with a general title "Automatic Traffic Recorder Analysis".

The daily traffic distribution can be found in the volume "Daily Volumes By Month Including Averages and Percent of A.D.T.", and the DHV data in the volume "Listing of 200 High Hours By Date, Day, and Hour" from the series.

FIGURE 1

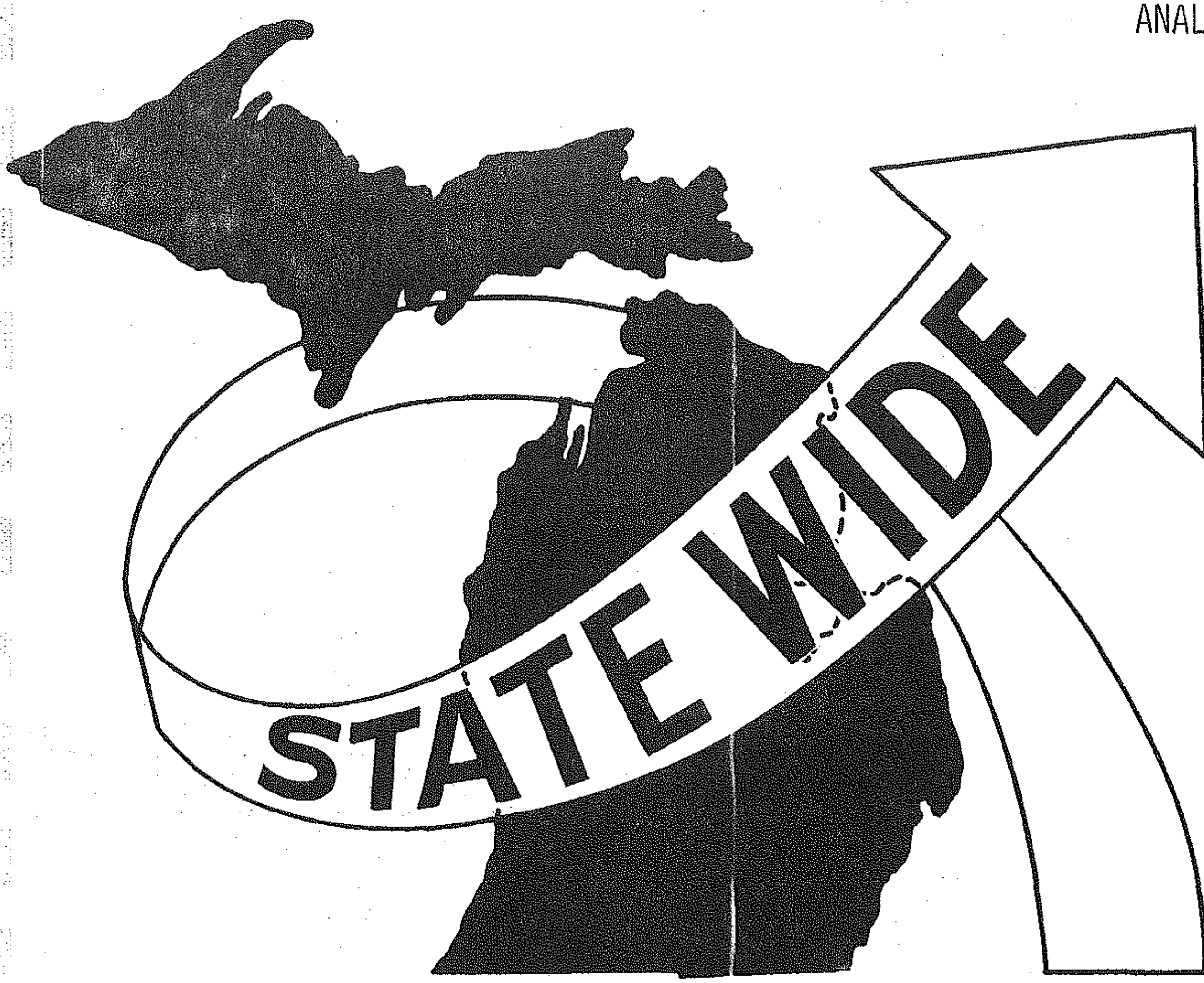

AUTOMATIC TRAFFIC RECORDERS
ATR STATION-STATE
ATR STATION-LOCAL-CITY-COUNTY
ATR STATION-TOLL AUTHORITY
ATR STATION-TOLL AUTHORITY LOCAL
ATR STATION-PROPOSED INTERSECTION COUNTS
INDICATES:
Directional Studies
Directions Combined
Directional One Way Only
EXISTING
PROPOSED
Michigan
Department Of State Highways
STATION
LOCATION
MAP
1969
DETROIT
metropolitan area
JANUARY 1, 1970
TRANSPORTATION PLANNIN

All of the data used in this report are presented in lists in the Appendix.

The capacity data are listed in column 3.

The traffic data include Annual Average Daily Traffic (AADT), Design-Hour Volume (DHV), and the daily traffic distributions for each of the chosen P.T.R. stations. The DHV data, represented as DHV factors, are listed in column 5. Data in columns 6 and 7 are obtained from the daily traffic distributions.

ANALYSIS



BASIC CONCEPT

Once the number of days on which the daily capacity is exceeded by the daily traffic volume has been adopted as a measure of the relative magnitude of congestion, some locations of traffic congestion in the past can be identified based on our P.T.R. records.

Since the most reliable data base used in the traffic forecasting process is the traffic records from P.T.R. stations, the more accurate investigation of these records, the better the model development is likely to be. A detailed investigation on the traffic data should therefore be a significant part of an empirical analysis.

The current approach to the forecast of future traffic conditions has been based on the prediction of future annual average daily traffic (AADT) on the existing statewide trunkline system. The prediction of AADT has been an essential element in the field of highway planning and design. AADT has also been recognized of crucial importance in establishing a capacity adequacy forecasting model.

Indeed, if two roads had almost identical capacities, the one with lower AADT should possess the higher capacity adequacy (regardless of other possible influencing factors). For example, the P.T.R. stations 3029 and 3089 had similar capacities (5980 vph and 5210 vph respectively) in 1970 but distinct AADTs (3364 vph and 1243 vph respectively) in the same year, station 3029 had 44 days on which the daily traffic exceeded the capacity, while not a single day exceeded the capacity at station 3089.

This functional relationship between capacity and AADT existed in the past, seems to be reasonable to hold true in the future and therefore can be considered as a reliable way to measure highway deficiency. As a result of this concept, the comparison of future AADT with daily capacity is an apparent approach to the prediction of possible future capacity breakdown. This suggests the use of v/c ratio, which is the ratio of AADT to capacity, as a useful tool in the process of establishing our forecasting model.

Now, it is observed that the number of days of capacity breakdown on two roads could still be different even with similar capacities and v/c ratios. For example, P.T.R. station 6089 had capacity 6580 vph and v/c ratio 0.50 in 1970, but the capacity was not exceeded at any time during the year. This is a significantly different case when compared with station 3029 which had a v/c ratio of 0.56 and 44 capacity breakdown days as observed in the previous example. It appears that there may well be another factor which had significant influence on the capacity adequacy of a particular section of road.

Probably the relationship between this additional traffic variable and capacity breakdown can be more clearly revealed by the investigation of a graphical presentation. For this purpose, the distribution of daily traffic with respect to the passage of the days of the year has been found most appropriate. Some plot diagrams of these distributions at the P.T.R. stations which have been discussed are presented in Figures 2 and 3 as samples.

FIGURE 2

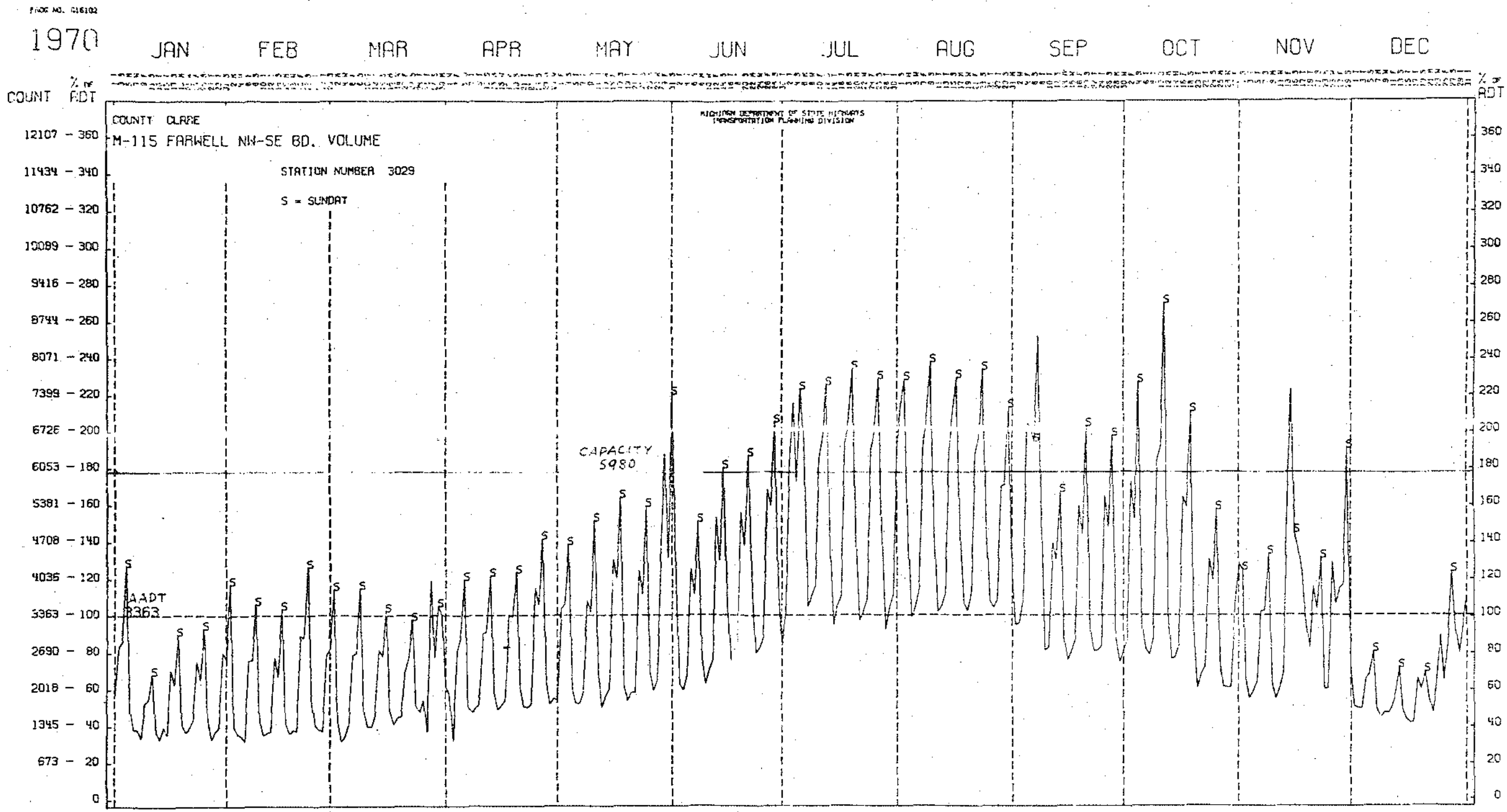
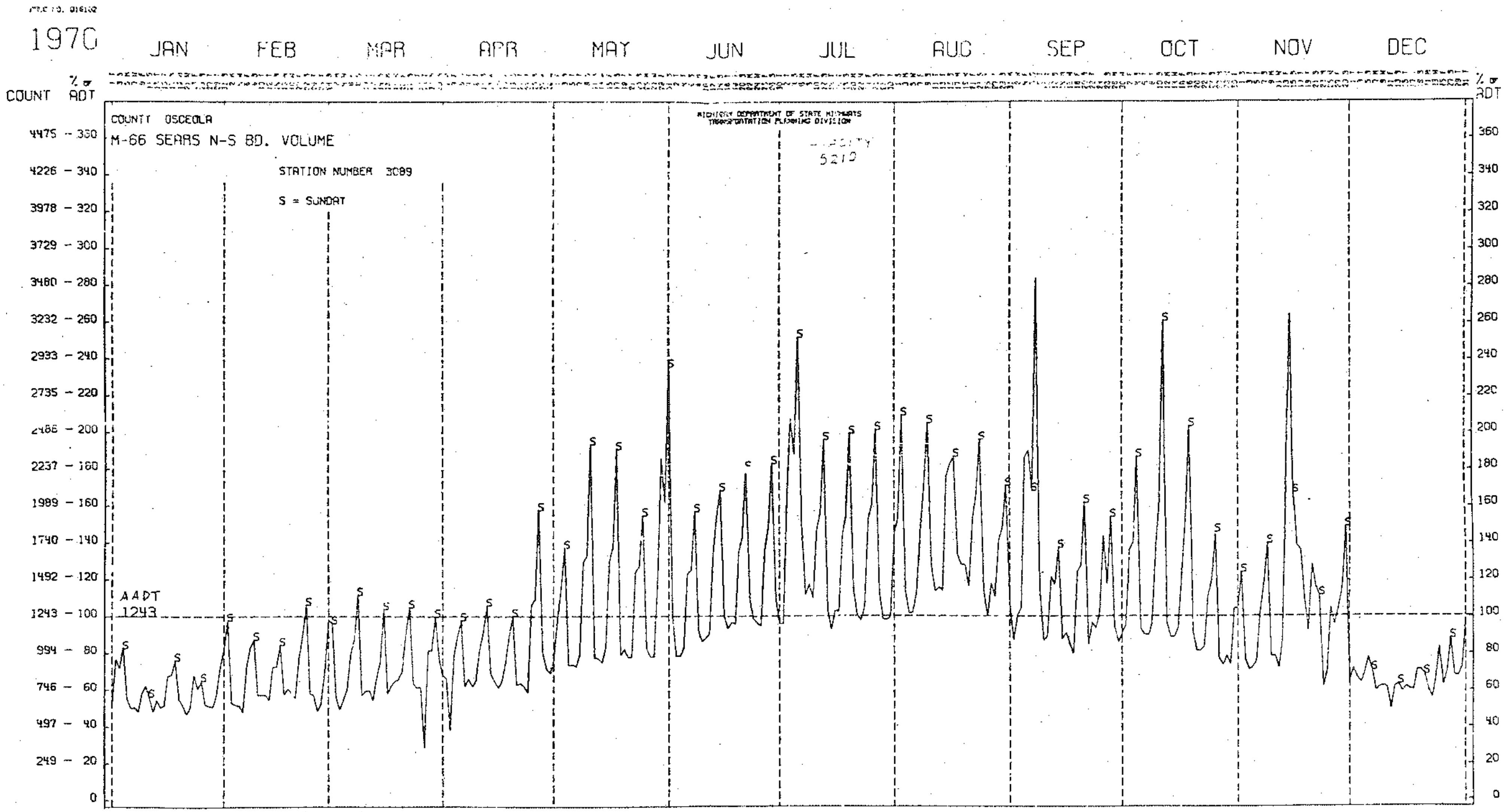

1970
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
COUNT
% OF ADT
COUNTY CLARE
M-115 FARWELL NW-SE BD. VOLUME
STATION NUMBER 3029
S = SUNDAY
MICHIGAN DEPARTMENT OF STATE HIGHWAYS
TRANSPORTATION PLANNING DIVISION
CAPACITY
5980
AADT
3363
12107 - 360
11434 - 340
10762 - 320
10089 - 300
9416 - 280
8744 - 260
8071 - 240
7399 - 220
6726 - 200
6053 - 180
5381 - 160
4708 - 140
4036 - 120
3363 - 100
2690 - 80
2018 - 60
1345 - 40
673 - 20
0
360 340 320 300 280 260 240 220 200 180 160 140 120 100 80 60 40 20 0

FIGURE 3


1970
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
COUNT
% of ADT
COUNTY OSCEOLA
M-66 SEARS N-S BD. VOLUME
STATION NUMBER 3089
S = SUNDAY
MICHIGAN DEPARTMENT OF STATE HIGHWAYS TRANSPORTATION PLANNING DIVISION
AADT 1243
4475 – 360
4226 – 340
3978 – 320
3729 – 300
3480 – 280
3232 – 260
2983 – 240
2735 – 220
2486 – 200
2237 – 180
1989 – 160
1740 – 140
1492 – 120
1243 – 100
994 – 80
746 – 60
497 – 40
249 – 20
0

At the first glance to these plot diagrams, variation in daily traffic with respect to the change of the seasons is the most striking fact. Roads with capacities accommodating traffic for the average day of the year may fail to carry traffic under prevailing conditions in some heavily travelled seasons. With a view to the seasonal variation, the mere use of capacity and predicted AADT (and hence the predicted v/c ratio) in the prediction of capacity breakdown is evidently insufficient and some additional traffic variable reflecting this variation in daily traffic is needed.

The seasonal variation in daily traffic varies significantly among highways particularly in recreational states in this country*.

When a road had an AADT not close to the capacity, for instance, a v/c ratio of about 0.60, capacity breakdown could not occur in most cases if the road was relatively unaffected by seasonal variations. For example, Station 6089 was located on this type of road and had no capacity breakdown in 1970. On

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* Road with highly seasonal variation were mostly recreational routes; conversely, roads carrying significant proportions of recreation traffic were highly seasonal.

The former statement may well be explained by the fact that the high peaks in daily traffic usually occurred in the summer (especially in July and August) which is generally the traveling season.

The latter statement can be justified by extensive empirical studies. (The recreation trip data can be obtained from the Mississippi Valley Multiple Screen Line O-D Survey.)

Moreover, roads located near urban areas carry mostly work and shopping trips, and hence had relatively small proportions of recreation trips. These roads generally had high AADTs and high v/c ratios but had little seasonal flucations.

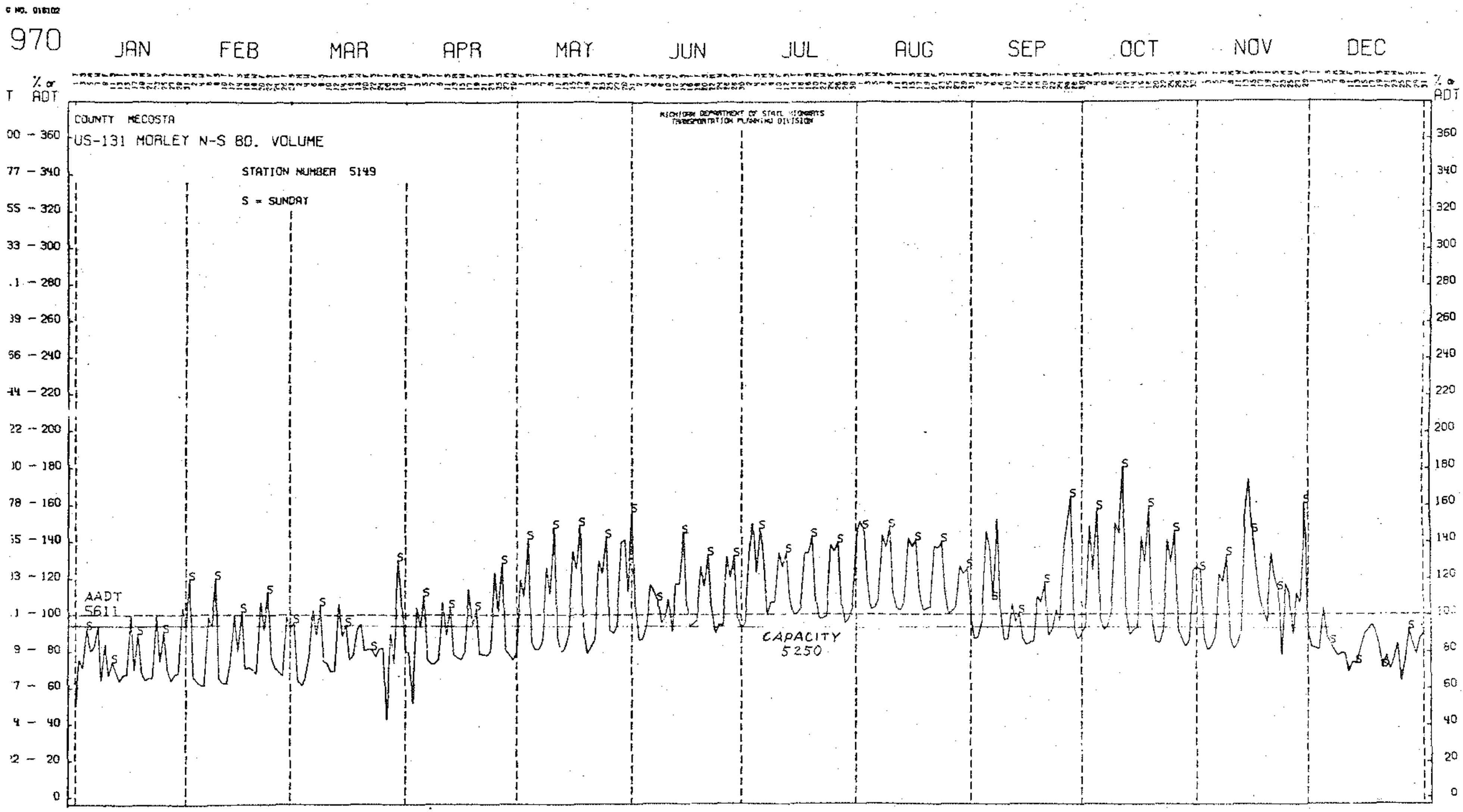
the other hand, when a road had low v/c ratio and was highly seasonal, capacity breakdown might occur frequently. For example, data of Station 3029 shown in Figure 2 seems to be of the case.

When the AADT of the road was very close to the capacity, say, the v/c ratio was close to or even greater than 1.00, capacity breakdown occurred frequently on the road experienced little seasonal variation. This is supported by the data of Station 5149 in Figure 4 in which 178 days of capacity breakdown were recorded. Roads having high v/c ratio and highly influenced by the seasons are not available in our data base. For such roads, the daily traffic in the traveling seasons would far exceed the capacities. Probably such cases rarely occur, if ever. Additional discussion will follow later in this section.

Therefore, we conclude that if the seasonal variations of two roads in the future are of distinct patterns, then probabilities of future capacity adequacy would be significantly different even though the magnitudes of their capacities and future AADTs are almost identical (and hence almost identical v/c ratios also).

In addition to the seasonal variation, attention must be given to the fact that for most daily traffic distributions under study, especially those highly seasonal, a few days of the year had unusually high traffic volumes. The unduly high peaks of the distributions generally occurred on summer weekends and holidays. Undoubtedly, these high peaks were brought about on roads mainly by recreation trips. Furthermore,

FIGURE 4


970
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
% or ADT
COUNTY MECOSTA
US-131 MORLEY N-S BD. VOLUME
STATION NUMBER 5149
S = SUNDAY
AADT 5611
CAPACITY 5250
0 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300 320 340 360

on some roads in Michigan (for example, I-2, M-28 and I-75 in Upper Peninsula and I-75 in Northern Lower Peninsula), some high peaks also occurred in November. Since the middle of November is the deer hunting season, the routes carrying deer hunters to and from deer hunting areas must be responsible for these peaks in November.

Therefore, the variation in daily traffic may be considered as being affected partly by the seasons and partly by occasions, and recreation traffic is essential to the variation.

Although the effect of the variation in daily traffic on capacity breakdown can in no way be denied, the variation must be measurable and predictable before being given scope to the construction of a practical model. In other words, a predictable measurement of the variation is required to serve as the variable mentioned before.

A widely used measurement of the hourly capacity requirement is based on DHV which, by definition, is the 30th highest hourly volume of the year. It has been observed that DHV occurred, in general, in the seasonal or occasional peaks of the daily traffic distribution. In other words, days on which the peak hourly volumes occurred were generally of the peaks of daily traffic distribution.

Furthermore, the gradually upwards shifts in the daily traffic distribution over years could be responded by gradual increase in DHV.* In case the daily traffic distribution had an abrupt change in the high peaks, it has been found that the change in DHV could reasonably reflect the change in daily traffic.**

Therefore, DHV has a close relationship to the peaks in daily traffic. High DHV indicates high peaks in daily traffic volumes.

The higher the peaks of the daily traffic distribution compared with the average, namely, AADT, the higher the DHV factor. The comparison of DHV with AADT should supply a relatively reliable measurement which indicates the probable variation in daily traffic.***

Furthermore, two roads with similar patterns of daily traffic distribution may have significantly different AADT. By using DHV factor, the dissimilarity in daily traffic distributions of the two roads may be reflected.

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* However, the DHV factor, the percentage of DHV divided by AADT, has a generally decreasing property. This may result from the less fluctuated traffic conditions over time.

** For example, station 7049, which was highly affected by the opening of I-94 on the 1st of July, 1960, had its AADT dropped 60 percent while, correspondingly, DHV also decreased 68 percent. (This caused DHV factor from 15.7 dropped to 12.7.) Examples like this are common in our P.T.R. data base.

*** Note that all the capacity, AADT and DHV data are all-lane totals. The use of ratio and percentage eliminates the necessity of using data on lane basis.

Therefore, DHV factor, instead of DHV, is used in the construction of a capacity adequacy forecasting model.

FURTHER INVESTIGATIONS

On the basis of the above investigations, two variables, v/c ratio and DHV factor, have been found to have a significant impact on the intricate variation in the daily traffic of any selected route. Now, the possible interaction of these two variables on the dependent variable (the number of days of capacity breakdown) as pointed out previously should be explored more explicity.

Among all the records in our data base, 49 records having capacity breakdown are drawn from 14 stations during the observation period. These records are listed on the next few pages. For each of the capacity breakdown record, the corresponding v/c ratio and the DHV factor are attached. The question arises as to whether or not some sort of relationship existed between the v/c ratios and the DHV factors among these records.

It is observed that the range of the v/c ratios of all the 49 records were running from 0.25 up to 1.13, and the range of the DHV factors from 9.3% up to 27.6%. On the basis of preliminary investigations on the frequency distributions of the v/c ratios and the DHV factors of the 49 records respectively, it seems reasonable to stratify the v/c ratios into four groups, namely, below 0.40, 0.40 to 0.60, 0.60 to 0.80, and over 0.80, and to stratify the DHV factors into three groups, namely, below 13.0%, 13.0% to 20.0%, and over 20.0%. Each record has been identified as belonging to one of the combinations of the two classifications. A table has been made in Figure 5 showing

P.T.R. STATION NO.	YR.	V/C RATIO	DHV FACTOR	NO. OF DAYS
2029	1966	0.26	25.2	1
	1967	0.25	26.3	1
	1968	0.28	23.6	1
	1971	0.34	24.3	2
3029	1968	0.48	22.2	24
	1969	0.49	21.6	28
	1970	0.56	21.2	44
	1971	0.56	20.8	39
3049	1966	0.62	14.3	33
	1968	0.93	13.3	112
3109	1966	0.41	21.3	15
	1967	0.42	20.7	11
	1968	0.48	20.1	19
	1969	0.49	19.5	21
	1970	0.53	19.3	22
	1971	0.55	17.9	25
4029	1971	0.63	11.7	1
4089	1966	0.25	27.6	1
	1967	0.25	27.5	1
	1968	0.32	25.7	2
	1969	0.38	24.6	6
	1970	0.43	22.9	15
	1971	0.45	22.3	21

P.T.R. STATION NO.	YR.	V/C RATIO	DHV FACTOR	NO. OF DAYS
5129	1967	0.44	17.7	1
	1968	0.53	18.2	20
	1969	0.55	17.9	23
	1970	0.58	16.5	28
	1971	0.65	16.7	39
5149	1966	0.70	15.7	41
	1967	0.73	15.5	49
	1968	1.00	14.6	157
	1969	1.03	14.6	167
	1970	1.07	14.3	178
	1971	1.13	14.2	217
6049	1966	0.40	25.1	13
6129	1966	0.53	15.8	10
	1967	0.53	16.3	18
	1968	0.55	15.5	21
	1969	0.63	14.5	38
	1970	0.65	14.3	46
	1971	0.68	14.2	52
6149	1971	0.52	14.2	4
8129	1968	0.71	9.7	2
	1969	0.75	9.3	3
	1970	0.79	9.6	10
	1971	0.82	9.5	20

P.T.R. STATION NO.	YR.	V/C RATIO	DHV FACTOR	NO. OF DAYS
8189	1971	0.65	9.6	5
8209	1969	0.50	13.5	1
	1971	0.56	12.7	1

the scatter of the data records (regardless of the number of days of capacity breakdown)

We wish to investigate, from the table, a dependence between these two classifications of the data records. If there existed a significant dependence between the classifications, then for those roads experiencing capacity breakdown, the magnitudes of their v/c ratios and the corresponding DHV factors were highly related.

By applying a statistical method concerning the dependence in the table in Figure 5, the data records seem to indicate that when the capacity was exceeded by the daily traffic on a road, the magnitudes of the v/c ratio and the DHV factor of the road were related.*

The relationship between the two variables can be shown by another approach.

In Figure 6, there is a correlation coefficient table in which the correlation coefficient of any two of the three variables, that is, the number of capacity breakdown days, the

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* In the statistical hypothesis testing method concerning the contingency table (in Figure 5), the null hypothesis of independence between the two classifications is rejected at confidence level $\alpha = 0.005$, since $\chi^2 = 31.82$ which is greater than $\chi^2_{\alpha,6} = 18.54$.

In Figure 5, we can combine row 2 and row 3, and thus at $\alpha = 0.005$, $\chi^2 = 26.02$ which is greater than $\chi^2_{\alpha,3} = 12.84$. Or, we can combine not only the last two rows but also combine columns 1 and 2, and columns 3 and 4. In this case, $\chi^2 = 16.51$ and $\chi^2_{\alpha,1} = 7.88$ at $\alpha = 0.005$.

Therefore, it seems no matter how the v/c ratios and the DHV factors are classified, the null hypothesis will be rejected.

Figure 5: Contingency Table According to Classifications in V/C Ratio and DHV Factor

V/C Ratio / DHV Factor	(1) Below 0.40	(2) 0.40 - 0.60	(3) 0.60 - 0.80	(4) Over 0.80	(5) Total
(1) Over 20%	9	9	0	0	18
(2) 13% - 20%	0	12	7	5	24
(3) Below 13%	0	1	5	1	7
(4) Total	9	22	12	6	49

FIGURE 6: Correlation Coefficient Table for the Ungrouped Data Records

	NO. OF DAYS	V/C RATIO	DHV FACTOR
NO. OF DAYS	1.00		
V/C RATIO	0.80	1.00	
DHV FACTOR	-0.27	-.075	1.00

v/c ratio, and the DHV factor, is included (regardless of the effect of the other variable). The correlation coefficient of the v/c ratios and the DHV factors of all the capacity breakdown records is -0.75 which may be considered to be high. Note the correlation coefficient of the number of capacity breakdown days and the v/c ratio, 0.80, is high while the correlation coefficient of the number of days and the DHV factor, -0.27, is quite low.* This means that the DHV factor was less sensitive to the number of capacity breakdown days,

In order to predict the number of capacity breakdown days by making use of v/c ratio and DHV factor, it seems reasonable to stratify all the records under consideration by the DHV factor groups, and then to study the relationship of the numbers of capacity breakdown days, the v/c ratios, and DHV factors within each group.

The correlation coefficient tables by the three DHV factor groups are displayed in Figure 7. Note that almost all of the correlation coefficients of the numbers of capacity breakdown days and

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* The significance of an observed correlation coefficient from zero can be tested by statistical hypothesis testing method with the use of the quantity T which is t distributed with n - 2 degrees of freedom where γ is the correlation coefficient, and n is the sample size.

$$T = \gamma \sqrt{(n - 2) / (1 - \gamma^2)}$$

The null hypothesis of no correlation is rejected when $\gamma = -0.75$ and $n = 49$, since $T = -7.87$, $t_{\alpha, 40} = -2.704$, and $t_{\alpha, 60} = 2.660$ at $\alpha = 0.01$, either one of the t values smaller than the absolute value of T.

The null hypothesis can not be rejected when $\gamma = 0.27$ evan at $\alpha = 0.05$, since $T = -1.92$ while $t_{\alpha, 40} = 2.021$ and $t_{\alpha, 60} = 2.00$ at $\alpha = 0.05$.

FIGURE 7: Correlation Coefficient Table for the Grouped Data Records

DHV Factor Group 1: DHV factor over 20%

	NO. OF DAYS	v/c RATIO	DHV FACTOR
NO. OF DAYS	1.00		
V/C RATIO	0.94	1.00	
DHV FACTOR	-0.74	-0.86	1.00

DHV Factor Group 2: DHV factor from 13% to 20%

	NO. OF DAYS	v/c RATIO	DHV FACTOR
NO. OF DAYS	1.00		
V/C RATIO	0.98	1.00	
DHV FACTOR	-0.45	-0.54	1.00

DHV Factor Group 3: DHV factor below 13%

	NO. OF DAYS	v/c RATIO	DHV FACTOR
NO. OF DAYS	1.00		
V/C RATIO	0.76	1.00	
DHV FACTOR	-0.48	-0.82	1.00

the v/c ratios have been highly improved (0.90, 0.98 and 0.76 vs. 0.80), and most other correlation coefficients are better than the ungrouped counterparts.*

Therefore, the data records seem to provide sufficient evidence indicating the relationship among the three variables.

For a more detailed investigation on the relationship of all three variables, a closer look should be taken at the scatter diagram shown in Figure 8 in which all the chosen records are plotted as data points. Now, the question turns out to be how and why were the variables related.

The observations and postulates are stated as follows:

(1) Note that, in Figure 8, for the group of records having highest DHV factors (over 20%), their v/c ratios had never gone over 0.60 and the numbers of capacity breakdown days in most cases were not large.

In further discussion, this fact can be separated into two arguments.

(A) If v/c ratio is high (for instance, 1.00), then DHV factor will probably be low (that is, below 20%).

If the assertian in (A) is true, then for DHV factor over 20% the corresponding v/c ratio cannot be high.

The phenomenon, which appeared in the Michigan data and identified in the discussion on P. 15 , is probably not due to lack of a complete data base.

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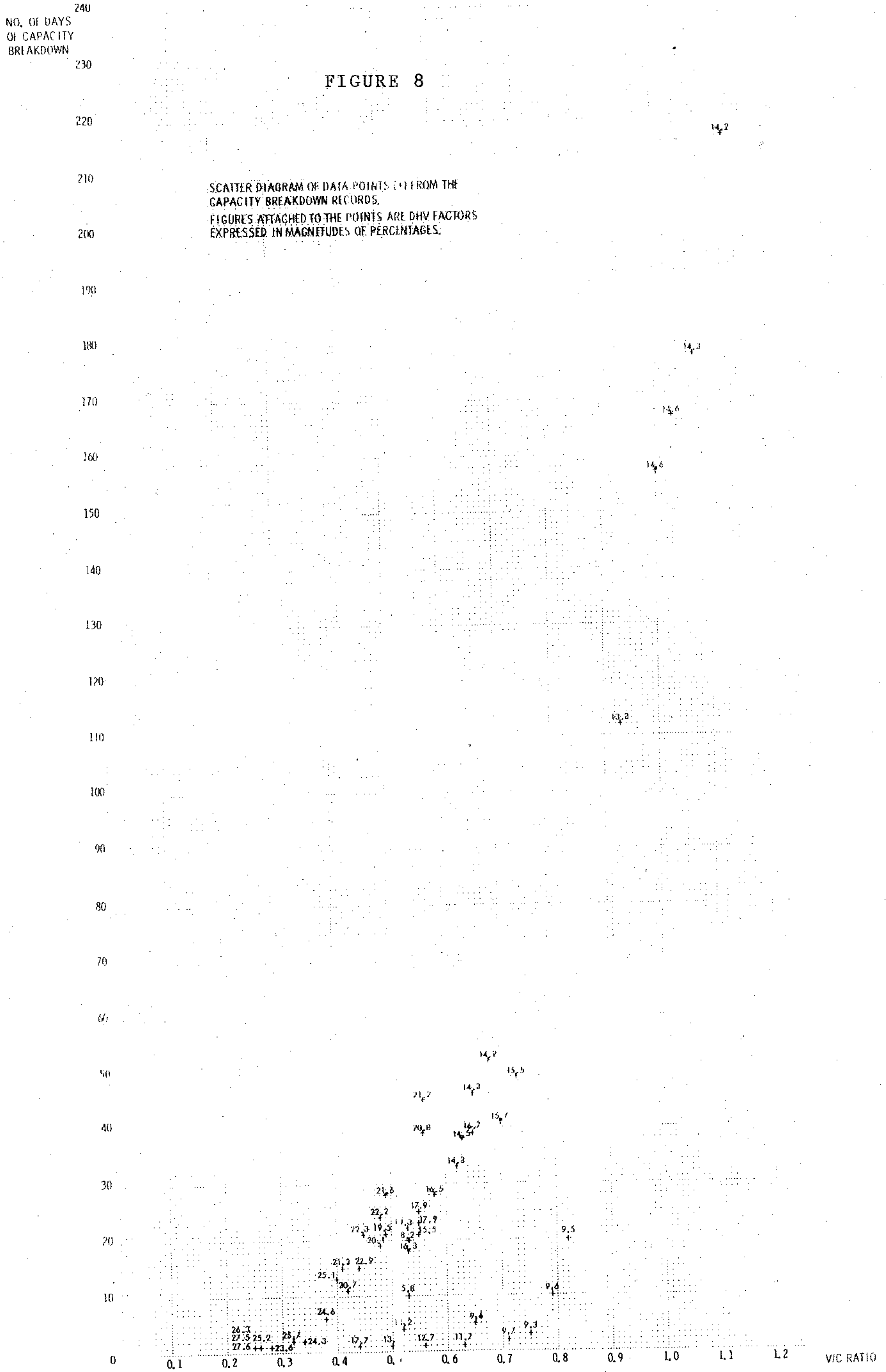
* The null hypothesis of no correlation of any two of the three variables for any DHV factor group are rejected by the T test.

FIGURE 8


NO. OF DAYS OF CAPACITY BREAKDOWN
V/C RATIO
SCATTER DIAGRAM OF DATA POINTS (+) FROM THE CAPACITY BREAKDOWN RECORDS.
FIGURES ATTACHED TO THE POINTS ARE DHV FACTORS EXPRESSED IN MAGNITUDES OF PERCENTAGES.

Should the v/c ratio have been high on a road with high traffic variations, then the drivers, most for recreational purposes, would have suffered from excessive traffic congestion most frequently during the heavily travelled seasons and holidays. This situation would be particularly true in the peak hours of the year.*

Therefore, some travellers confronted with this travel situation would have been forced to divert to the alternative routes or to change their driving schedules. The reduction in traffic volume in the peak hours of the year caused by a change in driving habits would reduce the DHV factor on the road.

(b) If DHV factor is high but v/c ratio is low, then the number of capacity breakdown days will probably not be large (for instance, below 50 days).

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* By definition, Daily Capacity = 10 Hourly Capacity, and v/c Ratio = AADT/ Daily Capacity, so Hourly Capacity =

$$\frac{1}{10\ (v/c\ \text{Ratio})}\ \text{AADT}$$

For a v/c ratio of 1.00, the hourly capacity is equivalent to 0.10 AADT, or, 10% of AADT. If the DHV factor equals to 20%, or, the DHV equals to 20% AADT, then the DHV is twice as high as the hourly capacity can accommodate.

For a v/c ratio of 0.90, the hourly capacity is equivalent to about 11% of AADT. In this case, a DHV of 16.5% of AADT will exceed 50% of the capacity.

Therefore, if the v/c ratio were high along with a high DHV factor, then traffic in the peak hours of the year would be incredibly congested.

From the daily traffic distribution, this assertian seems to be intuitively plausible.

(2) Note that, in Figure 8, for the group of data points having lowest DHV factors (below 13%), in most cases the v/c ratios were neither low (for instance, over 0.50) nor high (for instance, below 1.00) and the numbers of capacity breakdown were relatively small.

Since if DHV factor is low then the daily traffic distribution looks flat with respect to AADT, the fact stated in (2) seems to stand to reason. To make the point clearer, two assertions follow:

(A) If DHV factor and v/c ratio are quite low, the likelihood of capacity breakdown is little.

(B) If DHV factor is low but v/c ratio is very high (for instance, about 1.00), there will be many days on which capacity is exceeded by traffic.*

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*

From the hourly capacity conversion formula, a v/c ratio of 1.00 together with a low DHV factor of 13.0% or less, the hourly capacity is 10.0% of AADT.

However, it has been observed from the P.T.R. that when DHV factor is about 13.0% of below, the percentage of the highest 200 hourly volume to AADT is very close to 10.0%. This implies that there are at least 200 hours of the year with hourly traffic volume very close to the hourly capacity if the v/c ratio is about 1.00

It has also been observed that there is a close relationship between the number of hours in which the hourly traffic volume exceeding the hourly capacity and the number of days on which the daily traffic volume exceeding the daily capacity.

Therefore, all these facts help justify the assertion that when DHV factor is low but v/c ratio is high, there are many days daily traffic exceeding the daily capacity.

(3) Note that, in Figure 7, for the group of data points having DHV factors neither low nor high (ranging from 13% to 20%), the correlation coefficient of the v/c ratios and the DHV factors is quite small (- 0.54).

As a matter of fact, in this group of records, the v/c ratios had a range from 0.44 up to 1.13. The relationship between the v/c ratio and the DHV factors is quite loose.

However, the correlation coefficient of the v/c ratio and the numbers of capacity breakdown days is very high (0.98). This means that the prediction of the number of capacity breakdown days on a road with DHV factor falling in this group is possible to make.

(4) Note that, in Figure 8, for all the data points having DHV factors at the same level as classified in foregoing discussion, the higher the v/c ratio, the more the number of days of capacity breakdown.

In a graphical presentation, this means that within each groups of data points in the DHV factor group, the trend of points was curved running from S-W towards N-E. This characteristic was particularly true for the highest and the lowest DHV factor groups.

(5) There are some other interesting characteristics in the data points in Figure 8. These are in agreement with the facts stated above.

(A) Note that, in general, for all the data points having the same number of capacity breakdown days, the higher the DHV factor, the lower the v/c ratio.

For example, for all the data points having one capacity breakdown day, dHV factors went from 27.6% down to 11.7%, while the v/c ratios from 0.25 up to 0.63 with data points in the same order as that of DHV factors.

(B) Note that, in general, for all the data points having the same v/c ratios, the higher the DHV factor, the more the number of capacity breakdown days.

For example, for all the data points having a v/c ratio of 0.53, DHV factors went from 11.3% down to 15.8%, while the numbers of capacity breakdown days went from 22 down to 10 with data points in the same order as that of DHV factors.

From the above observations and postulates, it can be seen exactly how the two explanatory variables had effects on the number of capacity breakdown days. It seems that the relationship is so solid that a forecasting model of the number of capacity breakdown days can be established for a given predicted v/c ratio and DHV factor.

PREDICTION

Statistical regression model is used to set up the relationship under consideration.

Once the relationship has been set up, forecasts can be made on the basis of the predicted information of future v/c ratio and future DHV factor. The closer the relationship, the greater the confidence can be put in the forecast.

Several types of curves have been fitted to the grouped (by the DHV factor groups) and the ungrouped data points. The resulting prediction equations were derived by fitting to the appropriately transformed grouped and ungrouped data points, if necessary, with linear regression method. Here are some good prediction equations:

$$Yc = 25.5561 - 203.5789\, X_1 + 415.3361\, X_1^2 \quad (1\text{-}1)$$

$$Yc = 27.8549 - 184.4127\, X_1 + 307.8920\, X_1^2 \quad (1\text{-}2)$$

$$Yc = 191.2452 - 602.7018\, X_1 + 475.5439\, X_1^2 \quad (1\text{-}3)$$

$$Yc = \mathrm{EXP}\ (-3.984 + 13.5056\, X_1) \quad (2\text{-}1)$$

$$Yc = \mathrm{EXP}\ (-0.3990 + 5.5617\, X_1) \quad (2\text{-}2)$$

$$Yc = \mathrm{EXP}\ (-5.9712 + 10.2846\, X_1) \quad (2\text{-}3)$$

$$Yc = 53.5060 - 14.4510/X_1 \quad (3\text{-}1)$$

$$Yc = 288.8818 - 146.1958/X_1 \quad (3\text{-}2)$$

$$Yc = 41.3539 - 24.4094/X_1 \quad (3\text{-}3)$$

$$Yc = -287.5369 + 325.0500\, X_1 + 753.6524\, X_2 \quad (\ 4\ )$$

$$Yc = -184.4581 + 106.9612\, X_1 + 578.5473\, X_2 + 142.5876\, X_1^2 \quad (\ 5\ )$$

$$Yc = 9.1578 - 182.3915 X_1 + 45.4969 X_2 + 399.6268 X_1^2 \quad (6\text{-}1)$$

$$Yc = -32.2658 - 123.9896 X_1 + 222.5068 X_2 + 276.2039 X_1^2 \quad (6\text{-}2)$$

$$Yc = 327.6504 - 900.5406 X_1 - 239.0974 X_2 + 670.0296 X_1^2 \quad (6\text{-}3)$$

Eqs. 1-1, 1-2 and 1-3 are parbolic functions in v/c ratio (X_1) fitted respectively to data points of the DHV factor groups. It can be seen that eq. 1-2 has quite large residuals for low v/c ratios. However, all three equations have relatively small residuals.

Eqs. 2-1, 2-2 and 2-3 are exponential functions (in X_1) fitted respectively to data points of the DHV factor groups. Eq. 2-2 has predictions too low for v/c ratios between 0.53 and 0.73. All three equations have predictions too high for high v/c ratios in the respective DHV factor groups.

Eqs. 3-1, 3-2 and 3-3 are reciprocal functions (in X_1) fitted to data points for the DHV factor groups. Eq. 3-2 has predictions overestimated for v/c ratios between 0.62 and 0.93. All three equations have predictions underestimated for high v/c ratios in the respective DHV factor groups.

Eq. 4 is a linear function of two variables, that is, v/c ratio (X_1) and DHV factor (X_2). This prediction equation has large residuals for v/c ratios around 0.38 and 0.75.

Eq. 5 has, in addition to the two variables in Eq. 4, a term of second degree in X_1. This prediction equation has better predictions than those of eq. 4 for many v/c ratios.

Until now, Eqs. 1-1, 1-2 and 1-3 are the best among all the prediction equations under consideration. By adding a variable, DHV factor (X_2), to the original parabolic functions eqs. 1-1, 1-2 and 1-3 respectively, eqs. 6-1, 6-2 and 6-3 are obtained. The resulting equations have improved predictions. This is not

DHV FACTOR GROUP1: DHV FACTOR OVER 20%

X_1 v/c RATIO	Y ACTUAL DAYS	RESIDUAL = Yc - Yc RESIDUAL = ACTUAL DAYS - PREDICTED DAYS Eq. 1-1	Eq.2-1	Eq.3-1	Eq. 4	Eq. 5	Eq. 6-1
0.25	1.00	0.38	1.00	1.00	- 0.73	- 9.87	- 0.09
0.25	1.00	0.38	1.00	1.00	0.02	- 9.29	- 0.05
0.25	1.00	0.38	1.00	1.00	1.00	- 2.35	0.50
0.26	1.00	0.30	-0.12	1.00	1.00	1.00	0.78
0.28	1.00	-0.12	-0.50	-0.90	1.00	1.00	0.84
0.32	2.00	-0.94	-0.50	-6.35	-8.17	-11.06	-1.41
0.34	2.00	-2.35	-1.30	-9.00	-4.12	-6.98	-2.40
0.38	6.00	-2.17	0.30	-9.48	-15.38	-13.10	-2.75
0.40	13.00	2.42	5.60	-4.38	-18.65	-13.36	1.44
0.41	15.00	3.09	6.50	-3.26	8.74	8.40	3.75
0.42	11.00	-2.32	1.30	-8.10	6.01	5.62	-1.47
0.43	15.00	0.19	4.00	-4.90	-9.82	-5.39	-0.04
0.45	21.00	2.95	6.40	-0.39	-5.80	-0.56	2.85
0.48	19.00	-4.53	-2.90	-4.40	-0.97	2.98	-3.83
0.48	24.00	0.47	2.10	0.60	-11.80	-4.17	0.22
0.49	28.00	2.48	3.00	3.99	-6.53	0.85	2.44
0.56	39.00	-2.80	-25.00	11.30	-12.25	-1.49	-2.80
0.56	44.00	2.20	-20.30	16.30	-10.27	1.19	2.01
(MULTIPLE) CORR. COEF.		0.987	0.975	-0.851			0.988
STAND. ERR. OF. EST.		2.32		7.31			2.33
ABS. MAX. RESIDUAL		4.53	25.00	16.30	18.65	13.36	3.83

DHV FACTOR GROUP 2: DHV FACTOR FROM 13% to 20%

X_1 v/c RATIO	Y ACTUAL DAYS	RESIDUAL = $Y_c - Y_c$ RESIDUAL = ACTUAL DAYS - PREDICTED DAYS Eq. 1-2	Eq. 2-2	Eq. 3-2	Eq. 4	Eq. 5	Eq. 6-2
0.44	1.00	- 5.32	- 6.80	1.00	1.00	1.00	- 5.04
0.49	21.00	9.58	10.80	21.00	2.30	6.00	4.32
0.50	1.00	- 11.62	- 9.80	1.00	1.00	1.00	- 3.83
0.52	4.00	- 11.21	- 8.10	- 3.74	4.00	4.00	- 5.54
0.53	10.00	- 6.60	- 2.80	- 3.04	6.18	6.31	- 4.76
0.53	18.00	1.40	5.20	4.96	10.42	11.41	2.13
0.53	20.00	3.40	7.20	6.96	- 1.90	2.42	- 0.10
0.53	22.00	5.40	9.20	8.96	- 8.19	- 1.94	- 0.55
0.55	21.00	1.43	6.70	-2.07	12.94	13.82	3.42
0.55	23.00	3.43	8.70	-0.07	- 3.14	1.94	0.08
0.55	25.00	5.43	10.70	1.93	- 1.14	3.94	2.08
0.58	28.00	3.53	11.10	-8.82	2.66	6.99	2.55
0.62	33.00	1.13	11.90	-20.08	11.23	13.60	4.15
0.63	38.00	4.12	15.70	-18.82	11.48	14.59	6.49
0.65	39.00	0.93	14.10	-24.97	-10.61	- 2.93	-2.00
0.65	46.00	7.93	21.10	-17.97	14.48	17.96	10.34
0.68	52.00	7.18	22.50	-21.89	11.48	15.64	9.27
0.70	41.00	-8.63	8.10	-39.03	-17.32	-10.11	-10.21
0.73	49.00	-8.31	10.10	-39.61	-17.57	-10.28	- 9.90
0.93	112.00	-10.65	- 6.30	-19.68	- 3.00	- 3.29	-8.91
1.00	157.00	5.67	-17.60	14.31	9.45	7.44	4.57
1.03	167.00	2.45	-39.30	20.06	9.70	5.55	1.46
1.07	178.00	- 5.04	-79.80	25.75	9.96	2.03	-5.11

DHV FACTOR GROUP 2: DHV FACTOR FROM 13% to 20% (continued)

X_1 v/c RATIO	Y ACTUAL DAYS	RESIDUAL = Y - Yc / RESIDUAL = ACTUAL DAYS - PREDICTED DAYS Eq. 1-2	Eq. 2-2	Eq. 3-2	Eq. 4	Eq. 5	Eq. 6-2
1.13	217.00	4.38	- 142.90	57.50	30.21	16.37	5.09
(MULTIPLE) CORR. COEF		0.994	0.813	- 0.921			0.996
STAND. ERR. OF EST.		6.89	24.70				6.13
ABS. MAX. RESIDUAL		11.62	142.90	57.50	30.21	17.96	10.34

DHV FACTOR GROUP 3: DHV FACTOR BELOW 13%

X_1 v/c RATIO	Y ACTUAL DAYS	RESIDUAL = Y - Yc / RESIDUAL = ACTUAL DAYS - PREDICTED DAYS Eq. 1-3	Eq. 2-3	Eq. 3-3	Eq. 4	Eq. 5	Eq. 6-3
0.56	1.00	- 1.86	1.00	1.00	1.00	1.00	- 2.10
0.63	1.00	0.71	- 0.70	- 1.61	- 4.42	- 6.21	1.00
0.65	5.00	4.59	3.00	1.20	5.00	4.15	2.57
0.71	2.00	- 1.05	-1.80	-4.97	-14.35	-17.48	- 0.84
0.75	3.00	- 3.71	-2.70	-5.81	-23.34	-26.77	- 3.90
0.79	10.00	- 1.90	1.40	-0.46	-31.60	-34.57	- 1.44
0.82	20.00	3.21	8.30	8.41	-30.60	-34.09	2.98
(MULTIPLE) CORR. COEF		0.902	0.844	- 0.707	0.961*	0.969*	0.918
STAND. ERR. OF EST.		3.67		5.37	13.85	12.47	3.89
ABS. MAX. RESIDUAL		4.59	8.30	8.41	31.60	34.57	3.90

* The multiple correlation coefficients and the standard errors of estimates listed are ungrouped.

surprising because, as shown in the observation (5/A) in the previous section, DHV factor is highly responsive to the number of capacity breakdown days for any assigned v/c ratio.

Since eqs. 6-1. 6-2 and 6-3 cannot be presented graphically, eqs. 1-1, 1-2 and 1-3, having predictions not much different from those of eqs. 6-1, 6-2 and 6-3, are plotted in Figure 9 to display the accuracy of the predictions achieved by these equations.

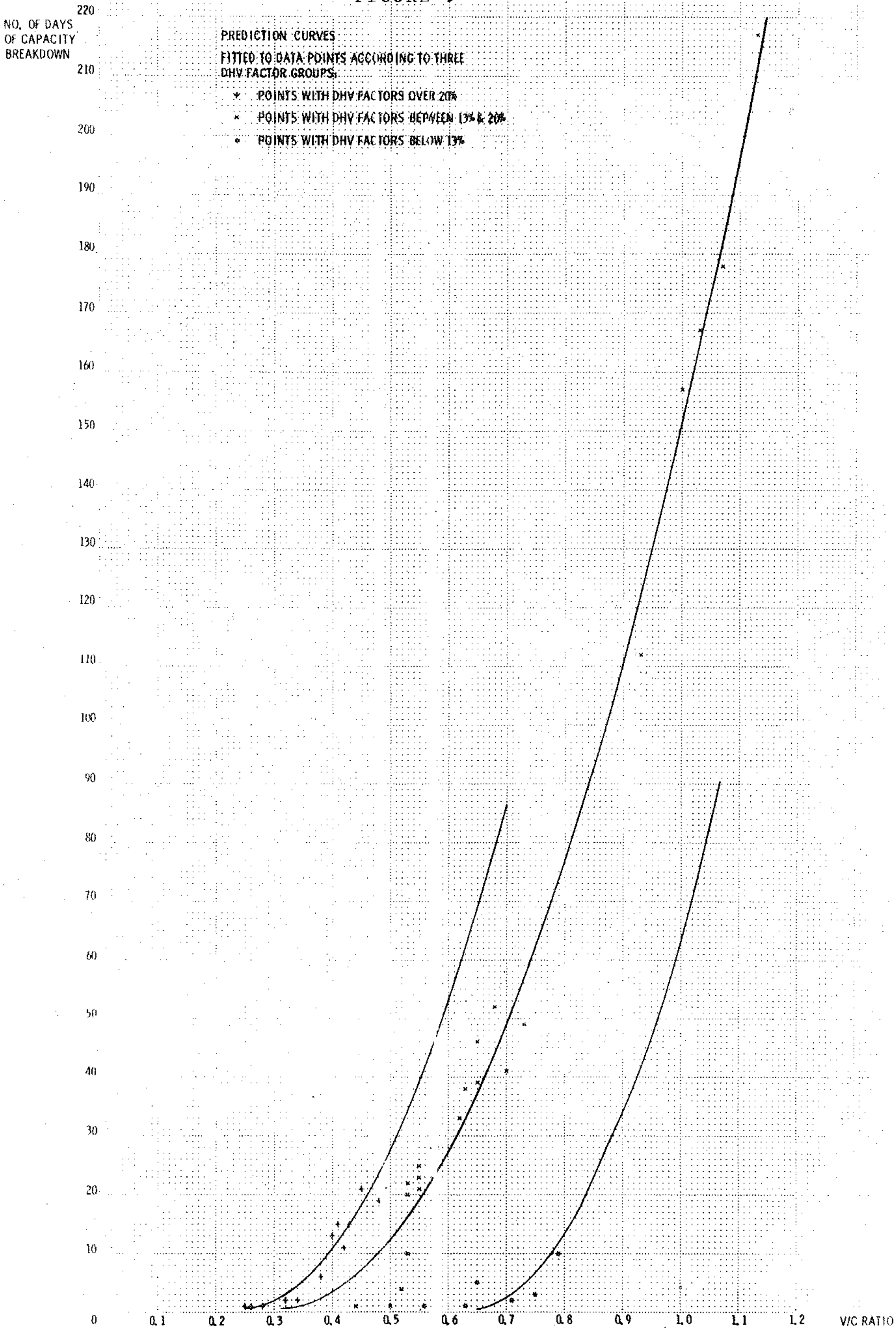
Note that, in Figure 9, those parts of the prediction curves left to the lowest points of the curves and/or lying below the horizontal axis are discarded. Predictions on these parts of the curves are assigned a value of zero. This rule applies to the rest of the prediction equations when applicable.

The predictions obtained from eqs. 6-1, 6-2 and 6-3 for ALL the data records available to this study are listed in column (7) in the appendix. The predicted number of capacity breakdown days are rounded to the nearest integar.

Note that the predictions will vary greatly for data records having a v/c ratio somewhere between 0.35 and 0.65, and DHV factor near the critical cut-off value 13.0%. It seems that a curve corresponding to the group of data points having DHV factors ranging from 10.0% to 14.0% should exist. However, in our data base which is used to derive the equations, there are only four points falling in this group, and with these four points it seems difficult to establish a good prediction equation.

Although small deviation of the model prediction from the actual situation may possibly be found, the model prediction should

FIGURE 9


NO. OF DAYS OF CAPACITY BREAKDOWN
PREDICTION CURVES
FITTED TO DATA POINTS ACCORDING TO THREE DHV FACTOR GROUPS:
+ POINTS WITH DHV FACTORS OVER 20%
× POINTS WITH DHV FACTORS BETWEEN 13% & 20%
• POINTS WITH DHV FACTORS BELOW 13%
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
V/C RATIO

be closer to the actual situation than any other prediction which is made in the absence of such empirical analysis.

If the daily capacity of a section of road will be exceeded by traffic volume once or twice a year versus 110 to 120 times a year, our model prediction will certainly indicate the real difference between these two extreme situations. An evaluation of the model prediction on the actual highway network may identify the merits of this forecasting process.

As more data will be available in coming years, the model can be expected to be refined.

CONCLUSION

To summarize the analysis and the model prediction of this report, the following are some new findings:

(1) Congestion has been expressed, in this report, in terms of capacity breakdown, or, capacity exceeded by traffic volume. Here, capacity is defined, theoretically (and practically also, hopefully), as the maximal traffic volume with implication of traffic condition in a good level of service. In this sense, congestion occurs when traffic condition is in level of service D, E, or F.

When the DHV factor on a road was over 20%, a v/c ratio of 0.5 of the road would cause, according to the model, at least 20 or 30 days on which traffic conditions were most frequently in unfavorable level of service, although traffic conditions on the rest of the days of the year were quite satisfactory. On the other hand, when the DHV factor on the road was 10%, a v/c ratio of 0.5 would evidently suffice to provide a good level of service on the road.

Therefore, two roads having the same v/c ratio may not always possess similar traffic conditions during the year. From this respect, v/c ratio alone can only reflect the traffic condition on the average day but do not guarantee a good level of service all the year round.

(2) There is another possible way to illuminate the effect of DHV factor of the road on the occurrence of an unfavorable traffic condition on the road.

Because AADT generally is increasing on a road with passage of time, so that v/c ratio is also increasing if the capacity of the road will not be significantly improved. However, the number of capacity breakdown days in the future year depends not only on the magnitude of increase of the v/c ratio but also on the decreasing characteristic of DHV factor of the road.

Two roads have similar v/c ratios and DHV factors may end up in several years with different numbers of capacity breakdown days if the DHV factors decrease with distinct rate. Unfortunately, our data base is so limited that no example can be drawn in support of this assertion.

(3) In addition, note the fact that when the DHV factor on a road was over 20%, the v/c ratio of the road could not exceed 0.6. In other words, when v/c ratio was very high (for instance, over 0.9), DHV factor could not be high (that is, over 20%). In this sense, a high v/c ratio of over 0.6 may be a restraint to the occurrence of a high DHV factor of over 20%, and a high DHV factor can reflect a low v/c ratio on the road.

Therefore, for a recreational road with predicted DHV factor of over 20% for some future year, the capacity of the road should built to accommodate the future traffic volume so that the future v/c ratio can not exceed 0.6. In this case, if the future v/c ratio exceeds 0.6, then there will be many days of the year on which travellers of the road will suffer from excessive congestion on the road and a good number of the travellers will be forced to change their travel route or schedule, and hence the highway user's benefits will diminish due to lack of driving comfort, convenience, rapidity and safety.

Note also the fact that when the DHV factor on a road was lower than 20%, capacity breakdown could occur only with higher v/c ratio. When DHV factor was below 11%, capacity breakdown occurred along with considerable high v/c ratio.

Also, when DHV factor was below 11%, v/c ratio seems rarely over 1.0. This fact gives us the indication of a capacity restraint of the road, expressed in terms of a high v/c ratio, to the traffic. However, when DHV factor was higher, this restraint seems to be slackened.

(4) The usefulness of this model lies in the fact that for any road a capacity without the occurrence of excessive traffic congestion can be confidently determined for some future year, if the predicted AADT and DHV of the road in the future year are obtainable with reliability. In this sense, the model produces a valid joint application for AADT and DHV without the involvement of other important traffic variables. And also, the model is a direct offshoot of the existing statewide traffic forecasting model.

Furthermore, the model prediction may be applied to all the existing as well as planned highways.

In the case that funds are inadequate to construct all the roads that should be built according to some other standards, the model should be able to provide some information concerning the future capacity adequacy.

Or, in the case of scheduling priorities for highway improvements on the existing highway network, this model should be helpful in determining the magnitude of future capacity adequacy.

In words, the model, which deals with predicting the frequencies of occurrences of unfavorable traffic conditions, is pertinently applicable in handling the problem of forecasting highway capacity adequacy.

APPENDIX

(1) YEAR	(2) AADT	(3) CAPA-CITY	(4) V/C RATIO	(5) DHV FACTOR	(6) NO. OF DAYS	(7) PRED. NO. OF DAYS
P.T.R. STATION 1029, ROUTE US-41, M-28						
1966	2540	7620	0.33	14.8	0	0
1967	2626	7710	0.34	15.0	0	0
1968	2702	6970	0.39	15.1	0	0
1969	2787	6970	0.40	14.5	0	0
1970	2877	6970	0.41	14.5	0	0
1971	3047	6550	0.47	14.6	0	3
P.T.R. STATION 1049, ROUTE US-2						
1966	929	7390	0.13	17.2	0	0
1967	946	7390	0.13	17.1	0	0
1968	981	5330	0.18	18.7	0	0
1969	956	5330	0.18	17.6	0	0
1970	973	5330	0.18	17.6	0	0
1971	989	5330	0.19	19.8	0	0
P.T.R. STATION 1069, ROUTE US-41						
*1966	—	—	—	—	—	
1967	1121	7400	0.15	12.0	0	0
1968	1170	5170	0.23	11.5	0	0
1969	1256	5170	0.24	11.4	0	0
1970	1319	5170	0.26	11.2	0	0
1971	1375	5170	0.27	11.3	0	0

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* The mark (-) is used to indicate the lack of data.

YEAR	AADT	CAPA- CITY	V/C RATIO	DHV FACTOR	NO. OF DAYS	PRED. NO OF DAYS
P.T.R. STATION 1089, ROUTE US-41						
1966	2648	7460	0.35	13.1	0	0
1967	2503	7460	0.34	11.9	0	0
1968	2514	5880	0.43	11.7	0	0
1969	2659	5880	0.45	11.7	0	0
1970	2789	5880	0.47	11.4	0	0
1971	2997	5880	0.51	11.5	0	0
P.T.R. STATION 2029, ROUTE US-2						
1966	2117	8200	0.26	25.2	1	0
1967	2079	8200	0.25	26.3	1	1
1968	2259	8110	0.28	23.6	1	0
1969	2417	8110	0.30	23.7	0	1
1970	2521	8110	0.31	24.8	0	2
1971	2770	8110	0.34	24.3	2	4
P.T.R. STATION 2049, ROUTE I-75						
1966	2921	37220	0.08	23.9	0	0
1967	2897	37220	0.08	22.7	0	0
1968	3142	37600	0.08	22.6	0	0
1969	3503	37600	0.09	22.9	0	0
1970	3659	37600	0.10	22.1	0	0
1971	3933	37600	0.10	22.0	0	0

YEAR	AADT	CAPACITY	V/C RATIO	DHV FACTOR	NO. OF DAYS	PRED. NO. OF DAYS
P.T.R. STATION 2069, ROUTE M-28						
1966	1158	7460	0.16	20.8	0	0
1967	1224	7460	0.16	20.5	0	0
1968	1221	6890	0.18	21.0	0	0
1969	1292	6890	0.19	21.4	0	0
1970	1353	6890	0.20	20.8	0	0
1971	1299	6890	0.19	20.2	0	0
P.T.R. STATION 3029, ROUTE M-115						
1966	2525	7710	0.33	23.1	0	3
1967	2657	7710	0.34	23.0	0	4
1968	2853	5980	0.48	22.2	24	24
1969	2924	5980	0.49	21.6	28	26
1970	3364	5980	0.56	21.2	44	42
1971	3367	5980	0.56	20.8	39	42
P.T.R. STATION 3049, ROUTE US-31						
1966	4855	7790	0.62	14.3	33	29
1967	4457	7710	0.58	15.6	—	—
1968	5813	6270	0.93	13.3	112	121
1969	—	6420	—	—	—	—
1970	—	6270	—	—	—	—
1971	—	6140	—	—	—	—

YEAR	AADT	CAPA-CITY	V/C RATIO	DHV FACTOR	NO. OF DAYS	PRED. NO. OF DAYS
P.T.R. STATION 3069, ROUTE US-131, M-66						
1966	1816	___	___	16.5	0	___
1967	1893	6820	0.28	15.4	0	0
1968	1999	6110	0.33	15.5	0	0
1969	2071	6180	0.34	15.4	0	0
1970	2261	6180	0.37	14.9	0	0
1971	2404	6180	0.39	15.0	0	0
P.T.R. STATION 3089, ROUTE M-66						
1966	1073	6810	0.16	29.4	0	0
1967	1051	6890	0.15	22.4	0	0
1968	1113	5210	0.21	22.5	0	0
1969	1183	5210	0.23	23.1	0	0
1970	1243	5210	0.24	21.4	0	0
1971	1287	5060	0.25	22.0	0	0
P.T.R. STATION 3109, ROUTE M-37						
1966	3287	8040	0.41	21.3	15	11
1967	3407	8040	0.42	20.7	11	12
1968	3703	7780	0.48	20.1	19	23
1969	3820	7870	0.49	19.5	21	17
1970	4102	7780	0.53	19.3	22	23
1971	4297	7870	0.55	17.9	25	23

YEAR	AADT	CAPA-CITY	C/C RATIO	DHV FACTOR	NO. OF DAYS	PRED. NO. OF DAYS
P.T.R. STATION 4029, ROUTE US-23						
1966	3294	7620	0.43	11.3	0	0
1967	3375	7620	0.44	11.5	0	0
1968	3565	7040	0.51	11.9	0	0
1969	3907	7040	0.55	13.1	0	12
1970	4228	7040	0.60	11.3	0	2
1971	4448	7040	0.63	11.7	1	0
P.T.R. STATION 4089, ROUTE M-33						
1966	2041	8200	0.25	27.6	1	1
1967	2035	8200	0.25	27.5	1	1
1968	2219	6880	0.32	25.7	2	3
1969	2630	6880	0.38	24.6	6	9
1970	2953	6880	0.43	22.9	15	15
1971	3070	6810	0.45	22.3	21	18
P.T.R. STATION 4129, ROUTE US-27						
1966	7008	30100	0.23	26.8	0	1
1967	7305	37620	0.19	26.2	0	0
1968	8116	38000	0.21	26.7	0	1
1969	8446	38000	0.22	25.1	0	0
1970	9345	38000	0.25	24.8	0	0
1971	9776	38000	0.26	25.2	0	0

YEAR	AADT	CAPA-CITY	V/C RATIO	DHV FACTOR	NO. OF DAYS	PRED. NO OF DAYS
P.T.R. STATION 5029, ROUTE US-27						
1966	9441	27100	0.35	15.9	0	0
1967	10307	27400	0.38	16.0	0	0
1968	10894	28860	0.38	15.4	0	0
1969	11938	28860	0.41	15.6	0	0
1970	12405	28860	0.43	16.7	0	3
1971	13130	28860	0.45	16.6	0	5
P.T.R. STATION 5129, ROUTE US-31						
1966	3046	7540	0.40	18.3	0	3
1967	3332	7540	0.44	17.7	1	6
1968	3603	6820	0.53	18.2	20	20
1969	3719	6820	0.55	17.9	23	23
1970	3975	6820	0.58	16.5	28	25
1971	4468	6900	0.65	16.7	39	41
P.T.R. STATION 5149, ROUTE US-131						
1966	4678	6700	0.70	15.7	41	51
1967	4876	6700	0.73	15.5	49	59
1968	5136	5120	1.00	14.6	157	152
1969	5399	5250	1.03	14.6	167	166
1970	5612	5250	1.07	14.3	178	183
1971	5915	5250	1.13	14.2	217	212

YEAR	AADT	CAPA-CITY	V/C RATIO	DHV FACTOR	NO. OF DAYS	PRED. NO OF DAYS
P.T.R. STATION 5169, ROUTE M-57						
1966	1671	7460	0.22	12.6	0	0
1967	1976	7540	0.26	13.7	0	0
1968	2245	6890	0.33	12.6	0	0
1969	2502	6970	0.36	12.5	0	0
1970	2611	6970	0.37	13.1	0	0
1971	2831	6970	0.41	12.9	0	0
P.T.R. STATION 5229, ROUTE I-96						
1966	8553	35640	0.24	12.6	0	0
1967	8735	36040	0.24	12.9	0	0
1968	9514	36400	0.26	12.3	0	0
1969	9981	36400	0.27	11.8	0	0
1970	10466	36800	0.28	11.9	0	0
1971	11284	36800	0.31	11.6	0	0
P.T.R. STATION 6029, ROUTE M-53						
1966	2140	8020	0.27	16.9	0	0
1967	1978	8020	0.25	18.2	0	0
1968	2013	7930	0.25	17.6	0	0
1969	2149	7930	0.27	17.4	0	0
1970	2240	7930	0.28	18.1	0	0
1971	2426	7750	0.31	17.9	0	0

YEAR	AADT	CAPA-CITY	V/C RATIO	DHV FACTOR	NO. OF DAYS	PRED. NO OF DAYS
P.T.R. STATION 6049, ROUTE US-25						
1966	1756	___	___	25.1	13	___
1967	2079	8290	0.25	21.8	0	0
1968	2174	8100	0.27	22.6	0	0
1969	2283	8100	0.28	21.5	0	0
1970	2381	8100	0.29	21.4	0	0
1971	2494	8100	0.31	20.7	0	0
P.T.R. STATION 6069, ROUTE M-78						
1966	9199	28520	0.32	11.4	0	0
1967	9173	28520	0.32	10.7	0	0
1968	9959	24640	0.40	10.4	0	0
1969	10627	24640	0.43	10.5	0	0
1970	11713	24640	0.48	10.9	0	0
1971	13406	24640	0.54	10.7	0	0
P.T.R. STATION 6089, ROUTE M-21						
1966	3417	7370	0.46	12.1	0	0
1967	3245	7460	0.43	12.4	0	0
1968	3140	6580	0.48	12.1	0	0
1969	3180	6580	0.48	12.4	0	0
1970	3298	6580	0.50	11.8	0	0
1971	3639	6580	0.55	11.3	0	0

YEAR	AADT	CAPA-CITY	V/C RATIO	DHV FACTOR	NO. OF DAYS	PRED. NO. OF DAYS
P.T.R. STATION 6129, ROUTE I-75, US-10						
1966	19334	36820	0.53	15.8	10	15
1967	19569	37220	0.53	16.3	18	16
1968	20566	37600	0.55	15.5	21	18
1969	23515	37600	0.63	14.5	38	32
1970	24295	37200	0.65	14.3	46	36
1971	25346	37200	0.68	14.2	52	43
P.T.R. STATION 6149, ROUTE I-75, US-10, US-23						
1966	—	28120	—	—	—	—
1967	—	37220	—	—	—	—
1968	—	37600	—	—	—	—
1969	—	37600	—	—	—	—
1970	27074	37600	0.72	12.8	—	—
1971	28879	56000	0.52	14.2	4	10
P.T.R. STATION 7069, ROUTE M-60						
1966	3188	7400	0.43	9.7	0	0
1967	3182	7570	0.42	9.6	0	0
1968	3232	7130	0.45	9.7	0	0
1969	3221	7130	0.45	9.3	0	0
1970	3136	6860	0.46	10.0	0	0
1971	3195	7260	0.44	10.4	0	0

YEAR	AADT	CAPA-CITY	V/C RATIO	DHV FACTOR	NO. OF DAYS	PRED. NO. OF DAYS
P.T.R. STATION 7109, ROUTE US-131						
1966	7375	26520	0.28	10.7	0	0
1967	7547	26820	0.28	11.1	0	0
1968	7693	28560	0.27	10.2	0	0
1969	7811	28860	0.27	10.5	0	0
1970	8102	28560	0.28	10.5	0	0
1971	8274	28560	0.29	10.1	0	0
P.T.R. STATION 7169, ROUTE I-94						
1966	12608	35240	0.36	11.9	0	0
1967	12902	35640	0.36	12.3	0	0
1968	13997	35600	0.39	12.2	0	0
1969	15466	36400	0.42	11.8	0	0
1970	16010	36400	0.44	11.7	0	0
1971	16184	35600	0.45	11.1	0	0
P.T.R. STATION 7189, ROUTE I-94						
1966	12400	51080	0.24	14.8	0	0
1967	13088	51080	0.26	16.5	0	0
1968	13678	61600	0.22	16.5	0	0
1969	14643	61600	0.24	16.1	0	0
1970	15015	61600	0.24	16.1	0	0
1971	15869	62480	0.25	16.0	0	0

YEAR	AADT	CAPA-CITY	V/C RATIO	DHV FACTORS	NO. OF DAYS	PRED. NO. OF DAYS
P.T.R. STATION 8029, ROUTE US-127						
1966	6978	26220	0.27	11.3	0	0
1967	7035	26520	0.27	11.6	0	0
1968	7406	27620	0.27	11.5	0	0
1969	7769	28240	0.28	11.1	0	0
1970	7991	35300	0.23	11.7	0	0
1971	8608	34540	0.25	11.6	0	0
P.T.R. STATION 8109, ROUTE US-25						
1966	9023	26810	0.34	10.8	0	0
1967	8644	26810	0.32	10.6	0	0
1968	8984	28420	0.32	10.5	0	0
1968	10040	28420	0.35	10.2	0	0
1970	10459	28420	0.37	10.4	0	0
1971	10848	27080	0.40	9.8	0	0
P.T.R. STATION 8129, ROUTE US-12						
1966	3125	6410	0.49	9.5	0	0
1967	3034	6480	0.47	9.7	0	0
1968	3144	4410	0.71	9.7	2	3
1969	3320	4410	0.75	9.3	3	7
1970	3464	4410	0.79	9.6	10	11
1971	3551	4310	0.82	9.5	20	17

YEAR	AADT	CAPA-CITY	V/C RATIO	DHV FACTOR	NO. OF DAYS	PRED. NO OF DAYS
P.T.R. STATION 8149, ROUTE I-94						
1966	35667	36040	0.99	9.2	—	—
1967	—	—	—	—	—	—
1968	—	61380	—	—	—	—
1969	—	61380	—	—	—	—
1970	—	61380	—	—	—	—
P.T.R. STATION 8169, ROUTE US-24						
1966	4093	32570	0.13	11.6	0	0
1967	4073	32220	0.13	9.4	0	0
1968	4223	34000	0.12	9.4	0	0
1969	4485	34000	0.13	9.4	0	0
1970	4591	34000	0.14	9.4	0	0
1971	5023	38880	0.13	9.3	0	0
P.T.R. STATION 8189, ROUTE I-75						
1966	19308	33660	0.57	9.9	0	0
1967	19325	34060	0.57	9.9	0	0
1968	20348	35200	0.58	9.9	0	0
1969	22044	35200	0.63	9.5	0	0
1970	21995	35200	0.62	9.7	0	0
1971	22782	35200	0.65	9.6	5	0

YEAR	AADT	CAPA-CITY	V/C RATIO	DHV-FACTOR	NO. OF DAYS	PRED. NO. OF DAYS
P.T.R. STATION 8209, ROUTE I-96						
1966	22623	___	___	12.8	0	_
1967	21739	55240	0.39	12.0	0	0
1968	24712	65100	0.38	13.6	0	0
1969	32605	65100	0.50	13.5	1	5
1970	34618	65100	0.53	13.2	0	9
1971	36259	65100	0.56	12.7	1	0
P.T.R. STATION 8229, ROUTE US-23						
1966	12639	28820	0.44	13.8	0	0
1967	13143	29140	0.45	13.5	0	0
1968	14375	29760	0.48	13.5	0	2
1969	15480	29760	0.52	12.9	0	0
1970	16066	37200	0.43	12.9	0	0
1971	17468	37200	0.47	12.6	0	0