Statewide Transportation Analysis & Research

MICHIGAN'S
STATEWIDE TRAFFIC FORECASTING
MODEL

VOLUME VII

DESIGN HOUR VOLUME MODEL DEVELOPMENT

NOVEMBER, 1972
STATEWIDE STUDIES UNIT

MICHIGAN DEPARTMENT OF STATE HIGHWAYS AND TRANSPORTATION

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NOVEMBER, 1972
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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

July 11, 1973

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

Dear Mr. Cryderman:

This report introduces our efforts in developing a Design Hour Factor (DHV Factor) forecasting model. Design Hour Volume is a highway design criterion which is normally defined as the thirtieth highest hourly volume of the year.

Design-hour volume factors and Annual Average Daily Traffic (AADT) volume collected at our permanent traffic recording stations are our data base. On the basis of the analysis results, two methods of forecasting design hour volume factors have been developed. These may be used to predict future design hour volumes on every link of the highway system. Some test samples of reliable data prove the validity of the model.

Michigan appears to be one of the first states to develop a statewide design hour volume model. This model could become a cornerstone in the building of more refined DHV models.

This report was prepared by Benjamin Pin-fan Chu of our 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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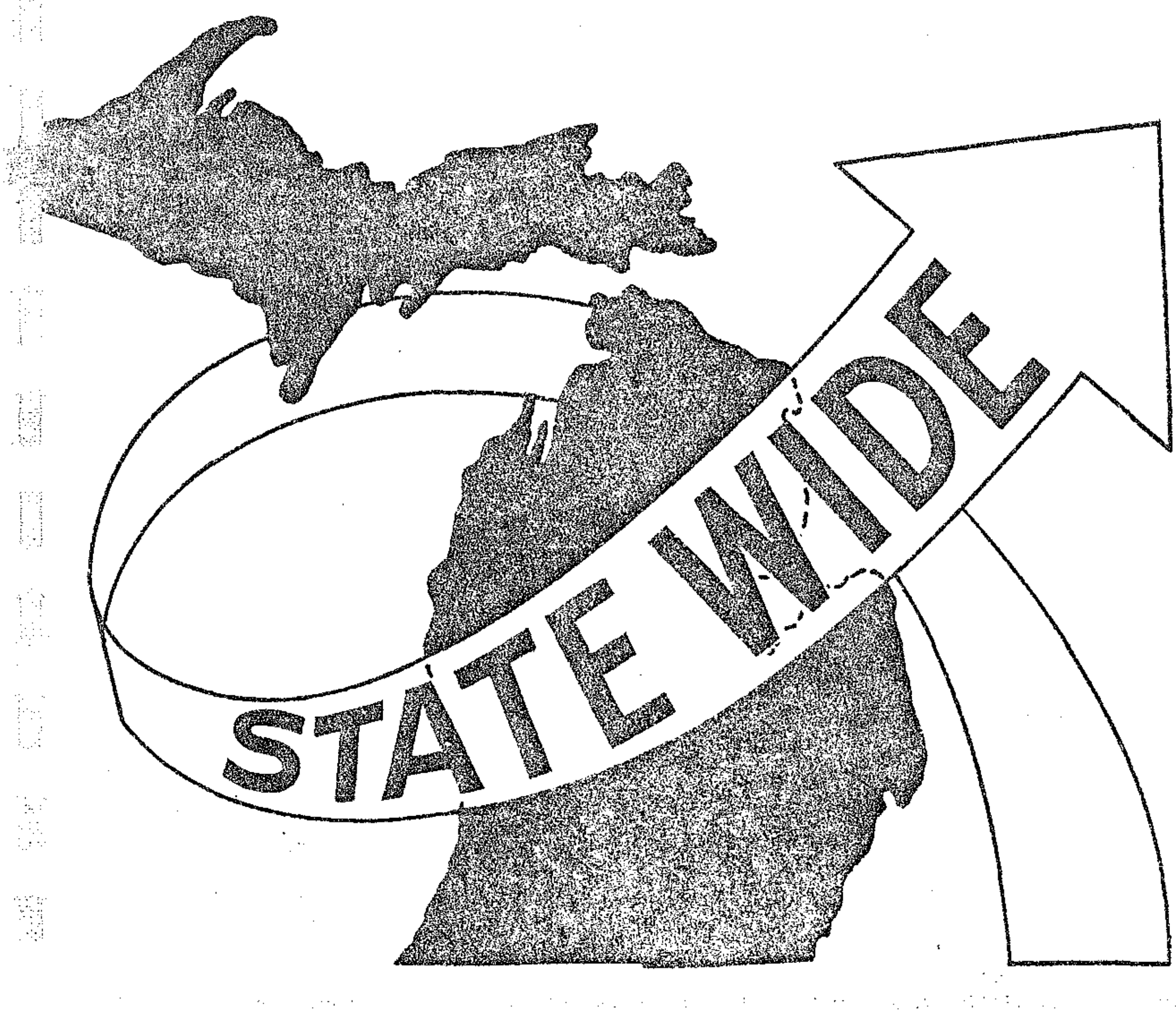

PREFACE

This is the seventh in a series of reports dealing with the development of a Statewide Traffic Forecasting model for the State of Michigan. This report will describe the efforts put into the development of a Design-Hour Volume (DHV) model. DHV data is a necessary travel input to route location analysis, environmental impact analysis and final route design. The model developed in this report in conjunction with the present Annual Average Daily Traffic (AADT) model will allow the Michigan Department of State Highways to supply both AADT and DHV by using a highly systematic forecasting process. Therefore, the development of the model should allow the department to shorten the total highway planning process because of the rapidity with which the model responds to planning analysis needs.

The initial approach taken in the development of the DHV model remained simple for the following reasons:

(1) Limited amount of data available for the analysis process,

(2) Learning process as few efforts of this type have been documented, and

(3) Size of Statewide model almost demands simplicity and generality in the final operation.

Vast testing using actual Statewide model networks during the next year may result in minor DHV model changes if operational difficulties develop. At this time, related tests indicate that the operation and reliability of the model appear very satisfactory.

Other reports in the State Model Development Series are listed below:

Volume	I	Objectives and Work Program
Volume	I-A	Workshop Topic Summaries
Volume	I-B	Traffic Forecasting Applications Single and Multiple Corridor Travel Analysis
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Volume	VI	Corridor Location Dynamics

INTRODUCTION
& DATA BASE

STATE WIDE

Introduction

It has long been recognized that Design-Hour Volume or the 30th-Hour Volume is essential but hard to predict in the traffic forecasting process. Few comprehensive reports on this subject have been completed compared with efforts related to the analysis and prediction of annual average daily traffic (AADT). The present traffic forecasting process used by both state and urban transportation planning studies handles AADT forecasting in a relatively reliable and efficient manner, but the wide variation in DHV from one year to another presents a more difficult situation.

Some trend analyses of DHV factors have been performed throughout the country with reasonable success. Two of the more widely circulated DHV analysis efforts are:

(1) Bureau of Public Roads DHV Analysis completed in 1957 using data from 26 states and 160 PTR's and

(2) State of New Jersey DHV Analysis using data from 69 PTR's

The first study resulted in a DHV prediction technique which is based on change in average annual DHV factor. The user is required to know the initial DHV factor and future AADT for each segment of road where forecasting DHV is required. New Jersey's analysis resulted in the development of a mathematical equation which represented the general change in the DHV factor over time. This technique demands the knowledge of the initial DHV factor and the length of time of the forecast. These two studies are the starting point for Michigan's effort in the area of Statewide DHV model development.

This report deals with a model constructed with data collected at Michigan's permanent traffic recording stations. The stations were located strategically on various types of rural highways, and the data used is based on eight years of DHV records, from 1963 to 1970, collected at each of forty eight stations.

The analyses are handled in two ways. One is to study trends by groups classified according to magnitude of DHV factors, and the other is to study trends by groups classified according to AADT volumes. On the basis of these results, two prediction procedures have been developed. A prediction curve is obtained which shows the general trend of the DHV factor in the long run regardless of the effect of AADT volume on the annual change of DHV factor. The second approach uses a table showing the average annual decreases at various AADT-DHV combinations. The results identify some striking differences and supplements to efforts obtained in papers previously mentioned.

The models, as developed, can provide the department with future DHV if existing DHV and an AADT forecasting model are available. Test results are also included in this report to substantiate the validity of the final models.

Data Base

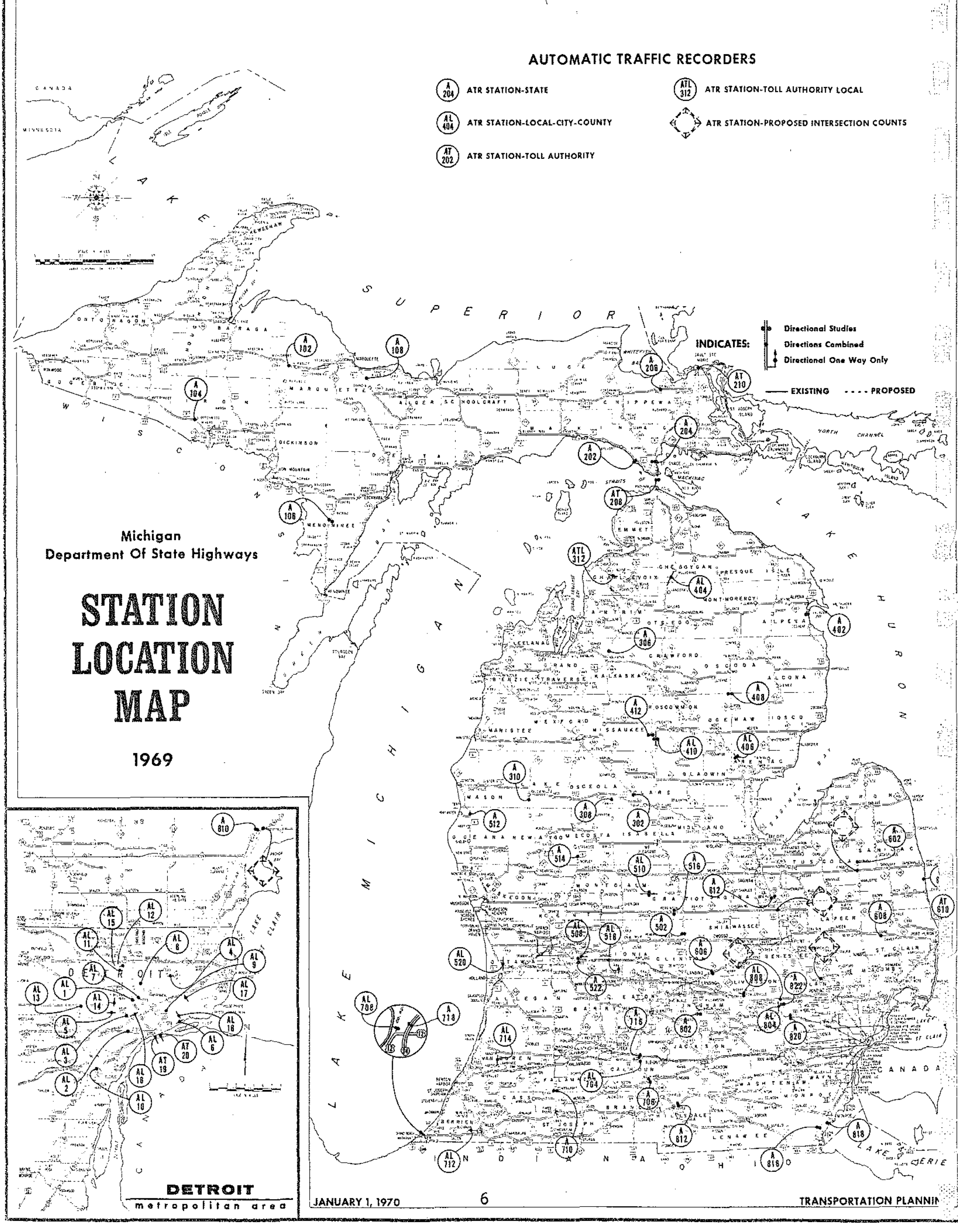
Since 1936 Michigan has installed and maintained a system of permanent traffic recorders or P.T.R.'s as commonly called. These electronically operated P.T.R.'s continuously perform the function of recording the number of vehicles passing through the various stations.

The locations were strategically chosen along selected county highways as well as state trunklines so that the maximum possible information about traffic flow could be available for those representative areas throughout the state. The locations of all P.T.R.'s appear in Figure 1. A more detailed description of the locations is listed in Appendix 1. Note that all of them were located on various types of rural highways, and therefore, the study in this report may be characterized to predict DHV factor for rural areas.

As of 1970, fifty-one stations had been installed. Not all stations were installed at the same time, and some of them had subsequently been removed. Additional traffic recorders have been installed on a lane basis at selected locations. However, in this report, we are interested in DHV obtained by the hourly, two-way totals, that is, the number of vehicles passing through on all lanes in both directions within an hour.

According to the analyses used in this report, the annual DHV records at each station should be arranged in a time-series so that we can keep track of the chronological variation.

FIGURE 1

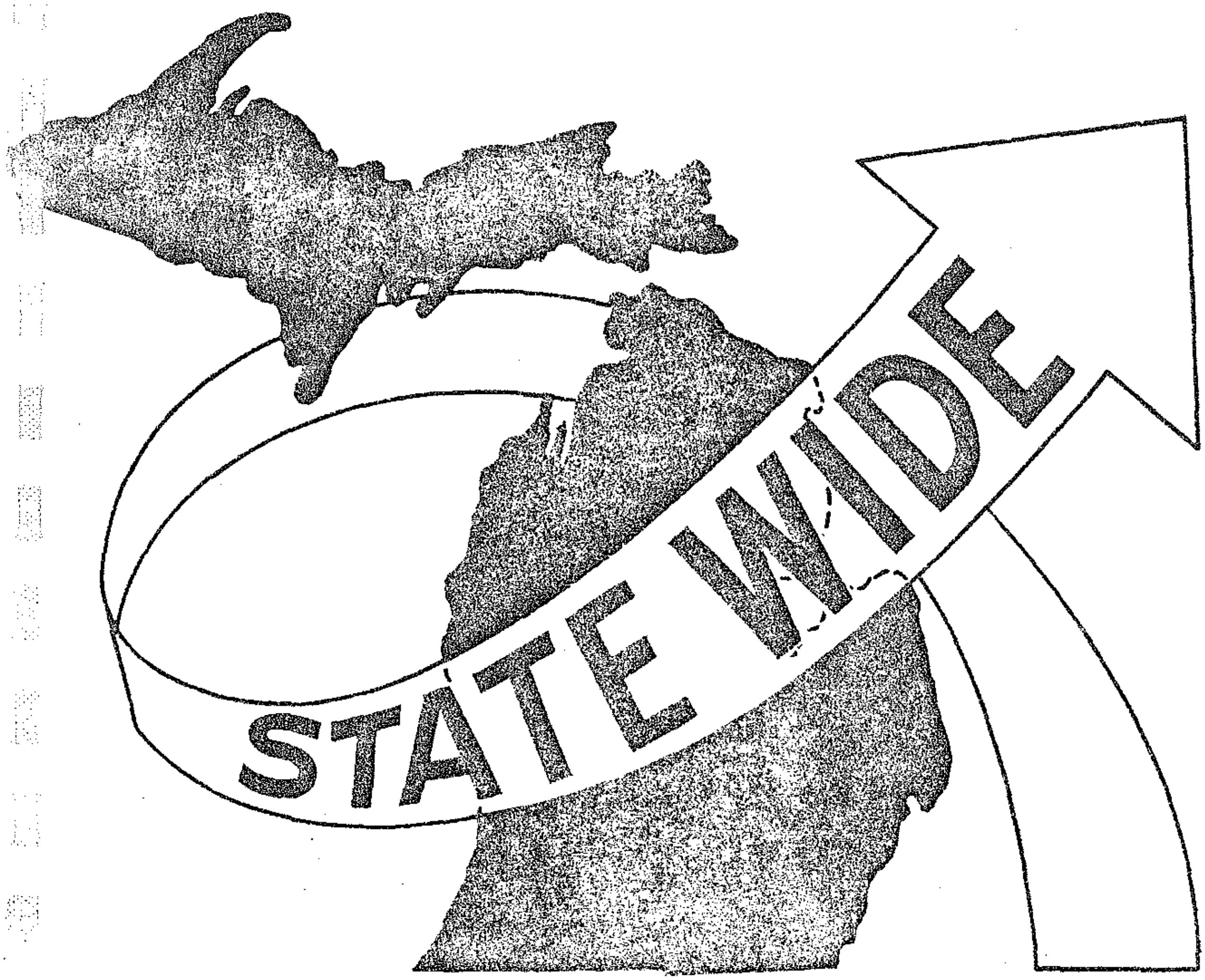

AUTOMATIC TRAFFIC RECORDERS
ATR STATION-STATE
ATR STATION-LOCAL-CITY-COUNTY
ATR STATION-TOLL AUTHORITY
ATR STATION-TOLL AUTHORITY LOCAL
ATR STATION-PROPOSED INTERSECTION COUNTS
INDICATES:
Directional Studies
Directions Combined
Directional One Way Only
EXISTING
PROPOSED
Michigan
Department Of State Highways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

Therefore, the stations of interest should be maintained in continuous operation for a long period of years. The reason for a long observation period is that, if it is too short, then the variation of DHV would be disturbed by so many irregular factors, which occurred casually, that the actual trend is concealed. Because all stations were not installed in the same year, if a longer observation period is preferred, then fewer stations can satisfy the above requirement.

Nevertheless, from a statistical point of view, the more stations used in the analyses the more likely the maximum amount of information could be drawn from the data provided. This is due to the fact that with more stations involved, more irregular and local disturbances can be removed.

According to these criteria, forty-eight stations with their DHV data collected during a period from 1963 to 1970 are chosen to serve as the data base.

TREND ANALYSES



The General Trend in DHV Factor

DHV factor, or DHV percentages, is the ratio of DHV to AADT volume represented in terms of percentage.

The DHV factors ranged in magnitude from 10.1 to 32.3 in 1963, which is taken as the initial year, while factors ranged from 9.4 to 25.4 in 1970, which is taken as the ending year. Since in 1970 the factors were remarkably lower and the range smaller, it is apparent that DHV factors, on the average, are declining over the study period of eight years.

For a more detailed investigation, DHV factors are first stratified into groups ranging 9.1 - 10.0, 10.1 - 11.0, . . ., up to 32.1 - 33.0. For each of these groups the number of P.T.R. stations having their DHV factors lying within the range of the group is then totaled as shown in Table 1. These totals are calculated for 1963 and 1970 and listed in column 2 and 4 respectively in the table.

The fact that DHV factors, are declining over time can be revealed by referring to Figures 2 and 3. In Figure 2, two curves of frequency distributions are plotted for the years 1963 and 1970. Similarly, in Figure 3, two curves of cumulative frequency distributions are also plotted for the same years.

Note that in Figure 3 the curves look similar in their shape with the one for 1970 lying to the left of the one for 1963. This means that for each value of DHV factor the number of stations having DHV factors less than or equal to the

Table 1

DHV Factor Group	1963 Frequency Distribution	1963 Cumulative Distribution	1970 Frequency Distribution	1970 Cumulative Distribution
9.1 - 10.0	0	0	4	4
10.1 - 11.0	5	5	5	9
11.1 - 12.0	5	10	9	18
12.1 - 13.0	7	17	4	22
13.1 - 14.0	4	21	4	26
14.1 - 15.0	1	22	5	31
15.1 - 16.0	6	28	0	31
16.1 - 17.0	3	31	3	34
17.1 - 18.0	3	34	1	35
18.1 - 19.0	1	35	2	37
19.1 - 20.0	1	36	1	38
20.1 - 21.0	0	36	2	40
21.1 - 22.0	2	38	3	43
22.1 - 23.0	1	39	2	45
23.1 - 24.0	2	41	0	45
24.1 - 25.0	0	41	2	47
25.1 - 26.0	3	44	1	48
26.1 - 27.0	1	45		
27.1 - 28.0	0	45		
28.1 - 29.0	0	45		
29.1 - 30.0	0	45		
30.1 - 31.0	2	47		
31.1 - 32.0	0	47		
32.1 - 33.0	1	48		

Figure 2

DISTRIBUTION OF DHV FACTORS

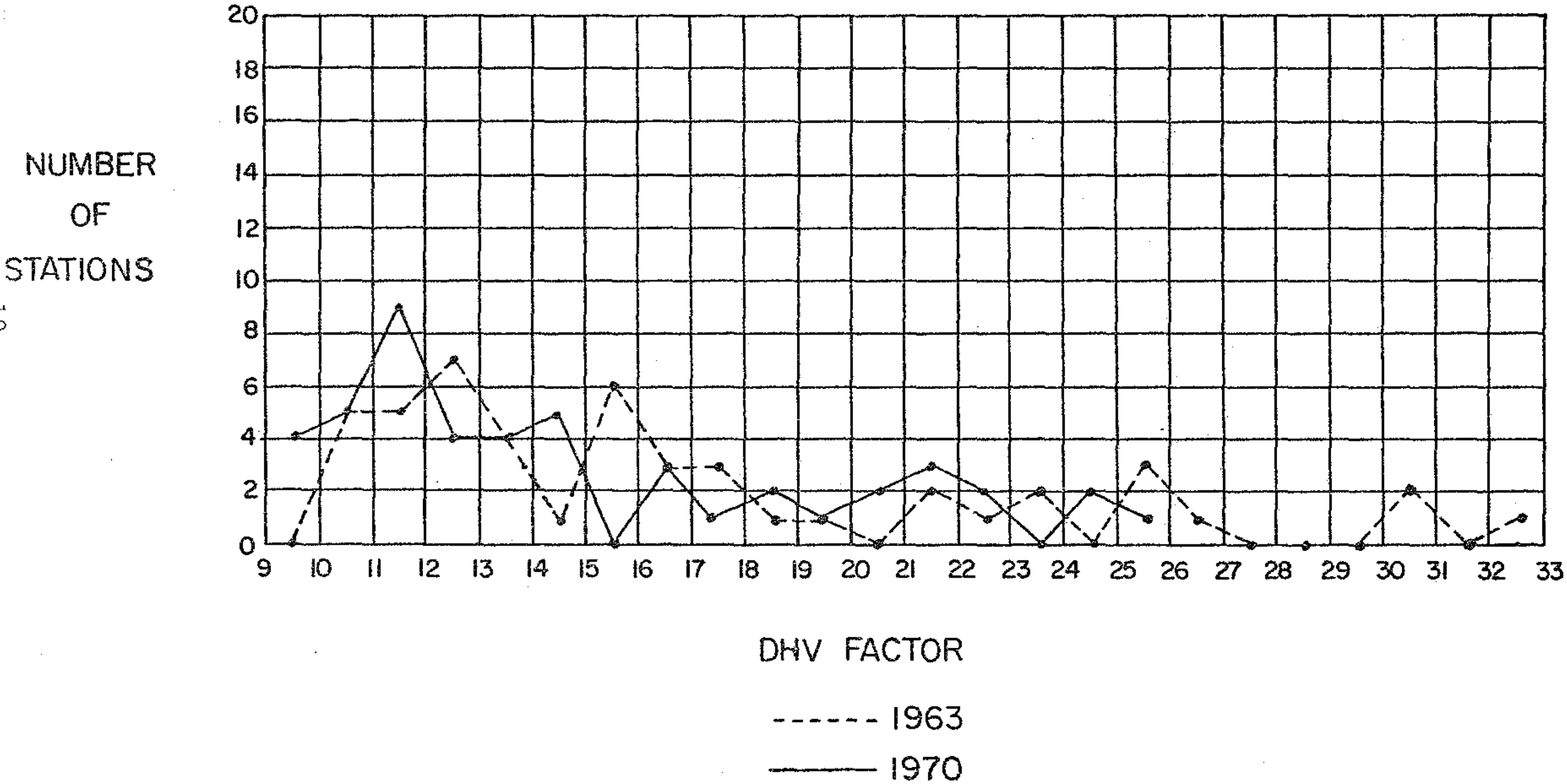
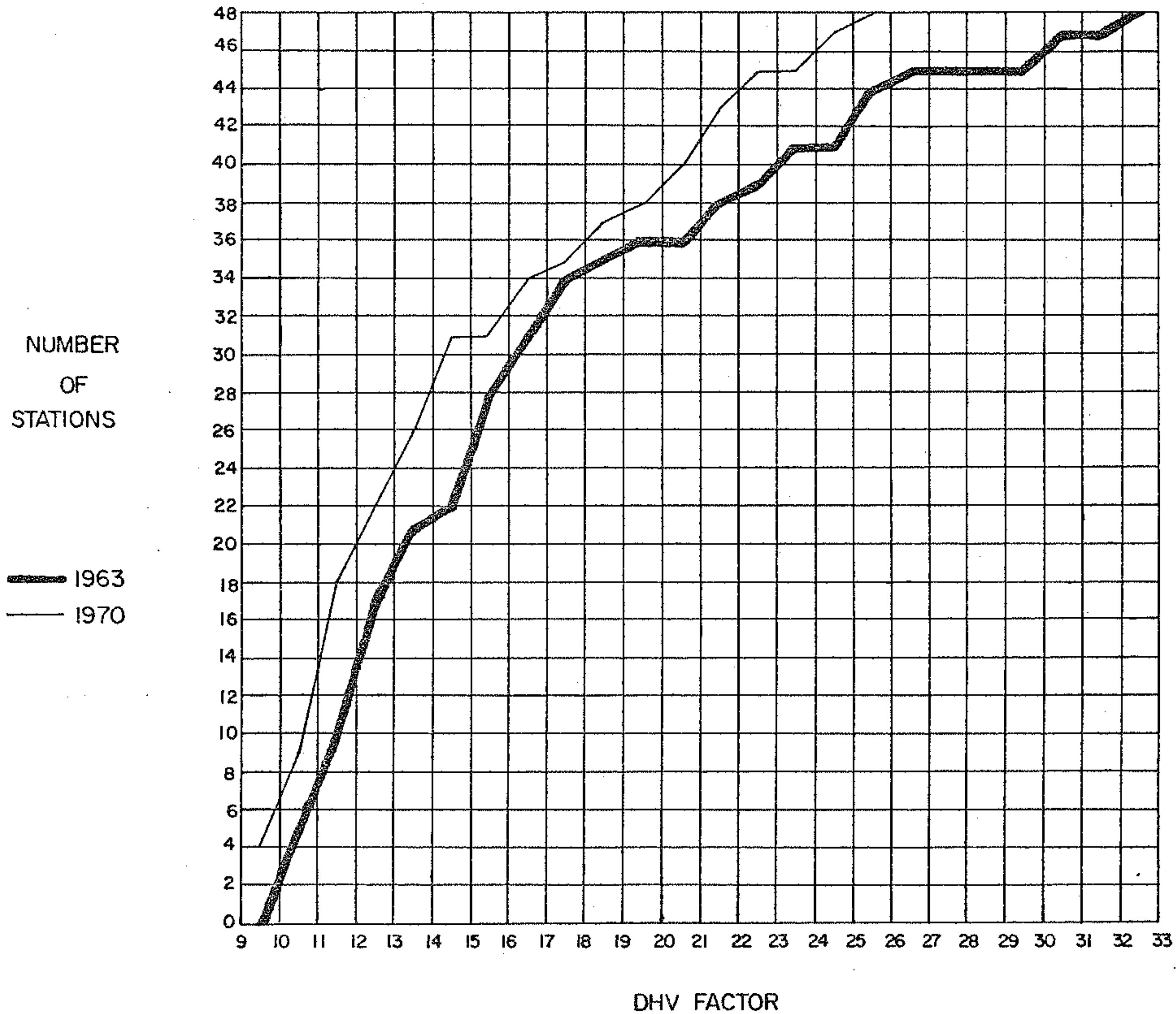


FIGURE 3

CUMULATIVE DISTRIBUTIONS OF DHV FACTORS



specified value was more in 1970 than that in 1963. And this, in turn, indicates that the general DHV trend was declining over the eight year study period.

Additional analysis has been carried out and the result also supports the previous conclusion.

Nineteen stations are found to have been maintained for twenty-eight years of continuous operation. Information summarized in the same way as previously described are listed in Tables 2 and 3. In Figure 4, the curve for 1970 is also located to the left of those curves for previous years, and the curve for 1942 to the right of those curves for later years. This does strengthen the conclusion just claimed. The curves for 1952 and 1962 do not look so obvious with regard to justifying the conclusion. However, roughly speaking, the curve for 1962 is still located to the left of the curve for 1952.

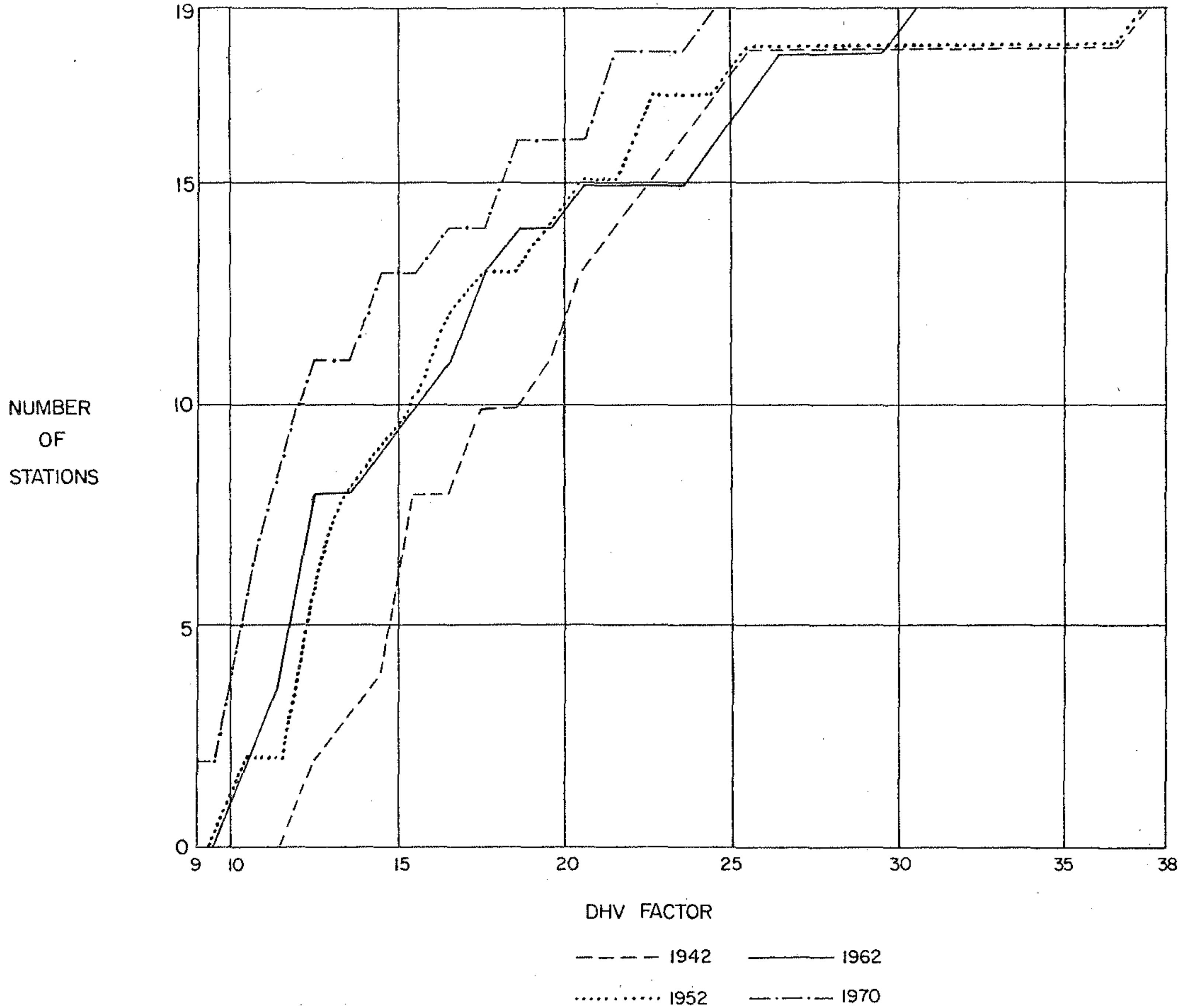
Table 2

DHV Factor Group	1942		1952	
	Frequency Distribution	Cumulative Distribution	Frequency Distribution	Cumulative Distribution
9.1 - 10.0	0	0	0	0
10.1 - 11.0	0	0	2	2
11.1 - 12.0	0	0	0	2
12.1 - 13.0	2	2	4	6
13.1 - 14.0	1	3	2	8
14.1 - 15.0	1	4	1	9
15.1 - 16.0	4	8	1	10
16.1 - 17.0	0	8	2	12
17.1 - 18.0	2	10	1	13
18.1 - 19.0	0	10	0	13
19.1 - 20.0	1	11	1	14
20.1 - 21.0	2	13	1	15
21.1 - 22.0	1	14	0	15
22.1 - 23.0	1	15	2	17
23.1 - 24.0	1	16	0	17
24.1 - 25.0	1	17	0	17
25.1 - 26.0	1	18	1	18
26.1 - 27.0	0	18	0	18
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.
36.1 - 37.0	0	18	0	18
37.1 - 38.0	1	19	1	19

Table 3

DHV Factor Group	1962 Frequency Distribution	1962 Cumulative Distribution	1970 Frequency Distribution	1970 Cumulative Distribution
9.1 - 10.0	0	0	2	2
10.1 - 11.0	2	2	4	6
11.1 - 12.0	2	4	3	9
12.1 - 13.0	4	8	2	11
13.1 - 14.0	0	8	0	11
14.1 - 15.0	1	9	2	13
15.1 - 16.0	1	10	0	13
16.1 - 17.0	1	11	1	14
17.1 - 18.0	2	13	0	14
18.1 - 19.0	1	14	2	16
19.1 - 20.0	0	14	0	16
20.1 - 21.0	1	15	0	16
21.1 - 22.0	0	15	2	18
22.1 - 23.0	0	15	0	18
23.1 - 24.0	0	15	0	18
24.1 - 25.0	0	15	1	19
25.1 - 26.0	2	17		
26.1 - 27.0	1	18		
27.1 - 28.0	0	18		
28.1 - 29.0	0	18		
29.1 - 30.0	0	18		
30.1 - 31.0	1	19		

CUMULATIVE DISTRIBUTIONS OF DHV FACTORS



Diversity in Trends at Various Locations

Although the general trend in DHV factors is declining over time, there was a significant variation among trends for the selected individual stations; and this DHV variation makes development of a dynamic DHV model extremely difficult.

The DHV factors of all selected stations during the observation period along with their corresponding trend slopes and correlation coefficients are listed in Appendix 2. In the appendix, the average annual changes for some stations, expressed by the slopes of linear trends, were increases rather than decreases. Therefore, although most of the stations displayed typical decreasing trends, some individual stations actually experienced increasing trends. Examples of both an increasing and decreasing trend in DHV factors are shown in Figures 5 and 6.

The average annual changes were often far from uniform even when they were all decreases.

Variation also exists among correlation coefficients, which are used to measure the degree of deviation between observed and trend values, for various stations. High correlation coefficient means a good linear fit and, in turn, indicates a stable trend.

In order to investigate such variations, stations should be classified into groups so that more detailed analysis can be handled on a group basis.

FIGURE 5

TRAFFIC VARIATION AT STATION 520

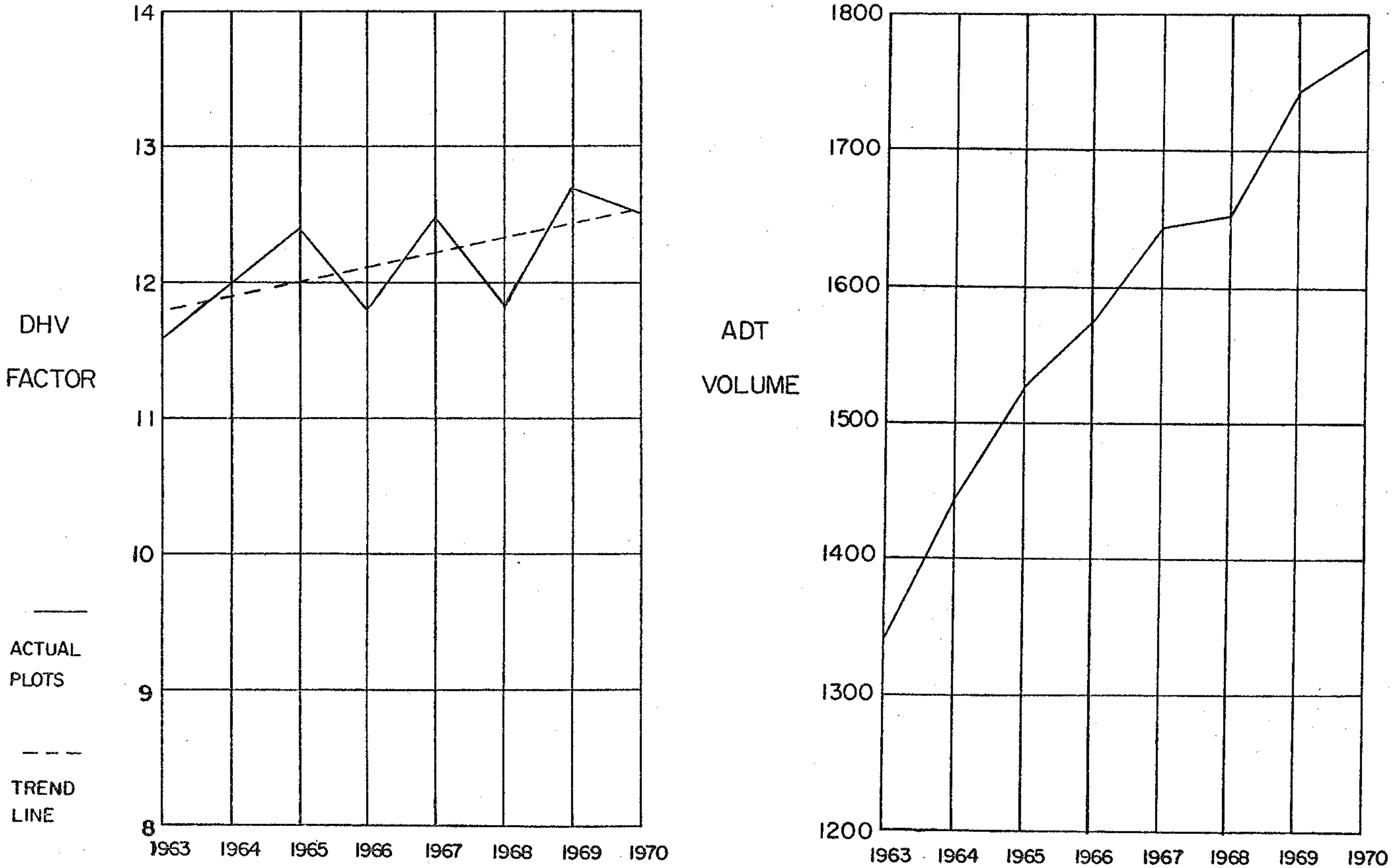
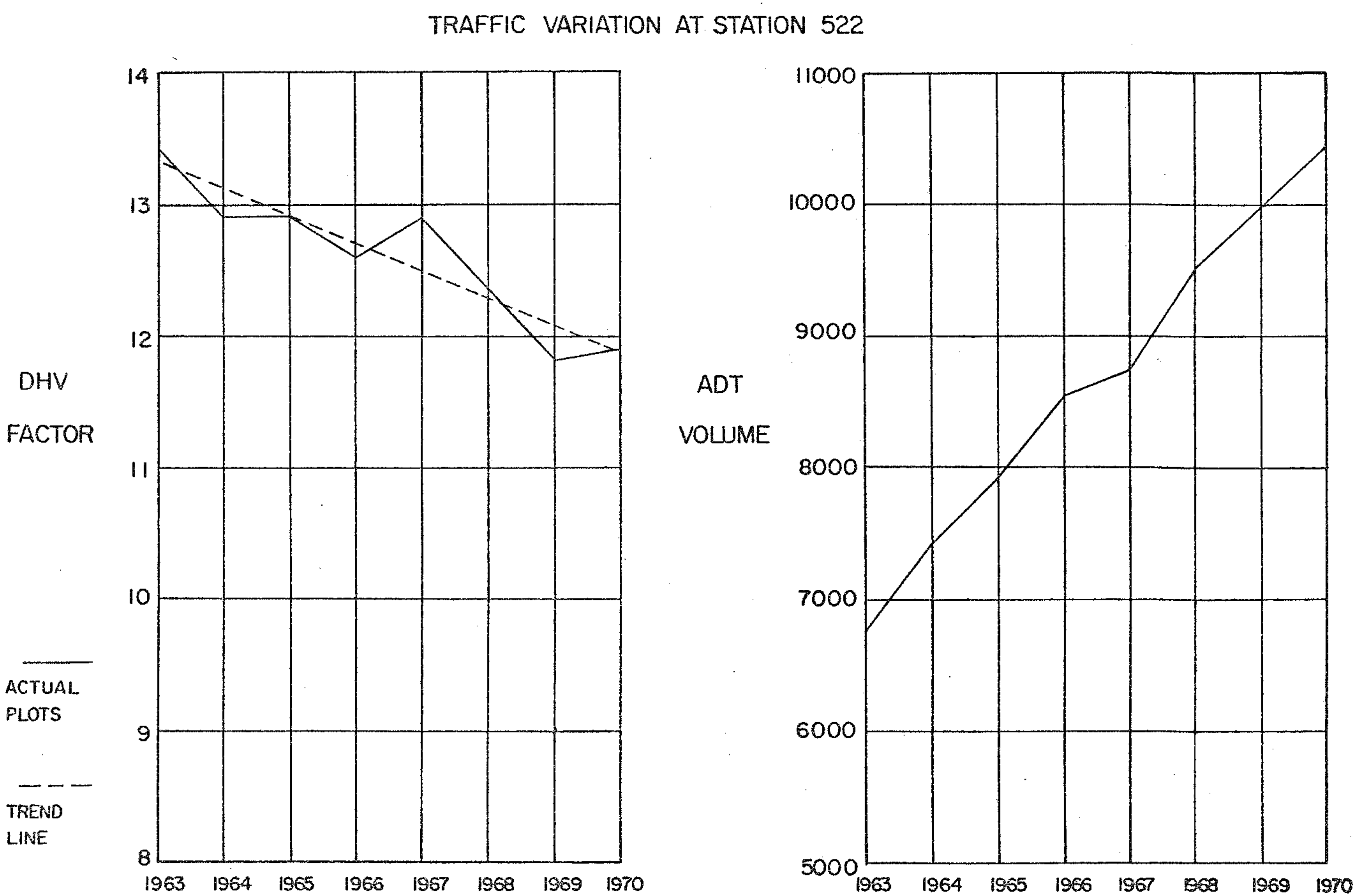


FIGURE 6


TRAFFIC VARIATION AT STATION 522
DHV
FACTOR
14
13
12
11
10
9
8
1963
1964
1965
1966
1967
1968
1969
1970
ACTUAL
PLOTS
TREND
LINE
ADT
VOLUME
11000
10000
9000
8000
7000
6000
5000

As suggested by the distribution curve in Figure 2, the forty-eight stations are broken down according to magnitude of 1963 DHV factors into four groups ranging 9.1 - 15.0, 15.1 - 20.0, 20.1 - 25.0 and over 25.1. Stations are not only classified by these DHV factor groups but also by magnitudes of correlation of coefficient. The number of stations have been summarized and listed in Table 4.

Only six or 12.5% of all forty-eight stations experienced increasing trends. The distinguishing features of this group of stations are:

(1) low DHV factor,

(2) small magnitude of trend slope, and

(3) low correlation coefficient.

More specifically, refer to Table 5, stations possessing increasing average annual change were all of the lower groups, 10.1 - 15.0 and 15.1 - 20.0. Small magnitude of trend slope reflects the fact that the average annual increase is insignificant and low correlation coefficient gives evidence of unstable annual change. Therefore, for those stations with a low DHV factor the chance of having an increasing but unstable, insignificant average annual change is about one fifth.

Thirty, or 62.5 percent of all forty-eight stations had decreasing trends with correlation coefficients 0.70 or more. Nineteen of them even possessed correlation coefficients 0.85 or more. This indicates that about half of the stations with decreasing trends had a very stable trend.

Table 4

NUMBER OF STATIONS WITH INCREASING TRENDS

DHV Factor Range	Correlation Coefficient Range 1.00-0.70	0.70-0.40	0.40-0.00	TOTAL
10.1 - 15.0	0	4	0	4
15.1 - 20.0	1	0	1	2
20.1 - 25.0	0	0	0	0
Over 25.1	0	0	0	0
Total	1	4	1	6

NUMBER OF STATIONS WITH DECREASING TRENDS

DHV Factor Range	Correlation Coefficient Range 1.00-0.85	0.85-0.70	0.70-0.00	TOTAL
10.1 - 15.0	7	5	6	18
15.1 - 20.0	5	4	3	12
20.1 - 25.0	2	1	2	5
Over 25.1	5	1	1	7
Total	19	11	12	42

Table 5

	8089	5209	7049	7129	7189	1049
1963 DHV FACTOR	10.5	11.6	11.8	12.5	15.8	16.5
1963 AADT VOLUME	2894	1347	1375	3902	9744	908
CORRELATION COEFFICIENT	0.632	0.618	0.427	0.475	0.360	0.721
ACTUAL AVERAGE ANNUAL CHANGE	+0.06	+0.10	+0.05	+0.10	+0.08	+0.23
PREDICTED AVERAGE ANNUAL CHANGE	-0.063	-0.090	-0.090	-0.135	-0.190	-0.291
DIFFERENCE BETWEEN THE ACTUAL & PREDICTED	0.123	0.190	0.140	0.235	0.270	0.521

Trends with Respect to DHV Factor Grouping

Since the chance of having an increasing trend in DHV factor over a period of eight years is quite small for a particular segment of road (at most one fifth), and there is no valid way so far in telling whether or not the trend is increasing, for all practical purposes, a general (or composite) trend line should be established for each of the DHV factor groups. The general trend is expected to be decreasing, according to the conclusion obtained in the previous section.

There are three methods to figure out the general annual average change for each of the DHV factor groups. Each method is used to reduce the diversity in the linear trends of individual stations within the group.

The first method is for each of the DHV factor groups to find the slope of trend in the group average DHV factors.

The actual plots and trend lines are shown in Figures 7 and 8 for each of the DHV factor groups. As shown in Table 6, about 74.0 percent of the stations had DHV factors ranging from 10.1 to 20.0 Next, note that the lower the magnitude of the DHV factor of a station was in the initial year, the smaller its average annual decrease. The variation in the average annual decreases for four groups was wide-- from 0.115 of the lowest group to 0.810 of the highest group. The correlation coefficients are high.

The second is for each of the DHV factor groups to find the weighted average of trend slopes of individual

Figure 7

TRENDS IN THE GROUP AVERAGES OF DHV FACTORS

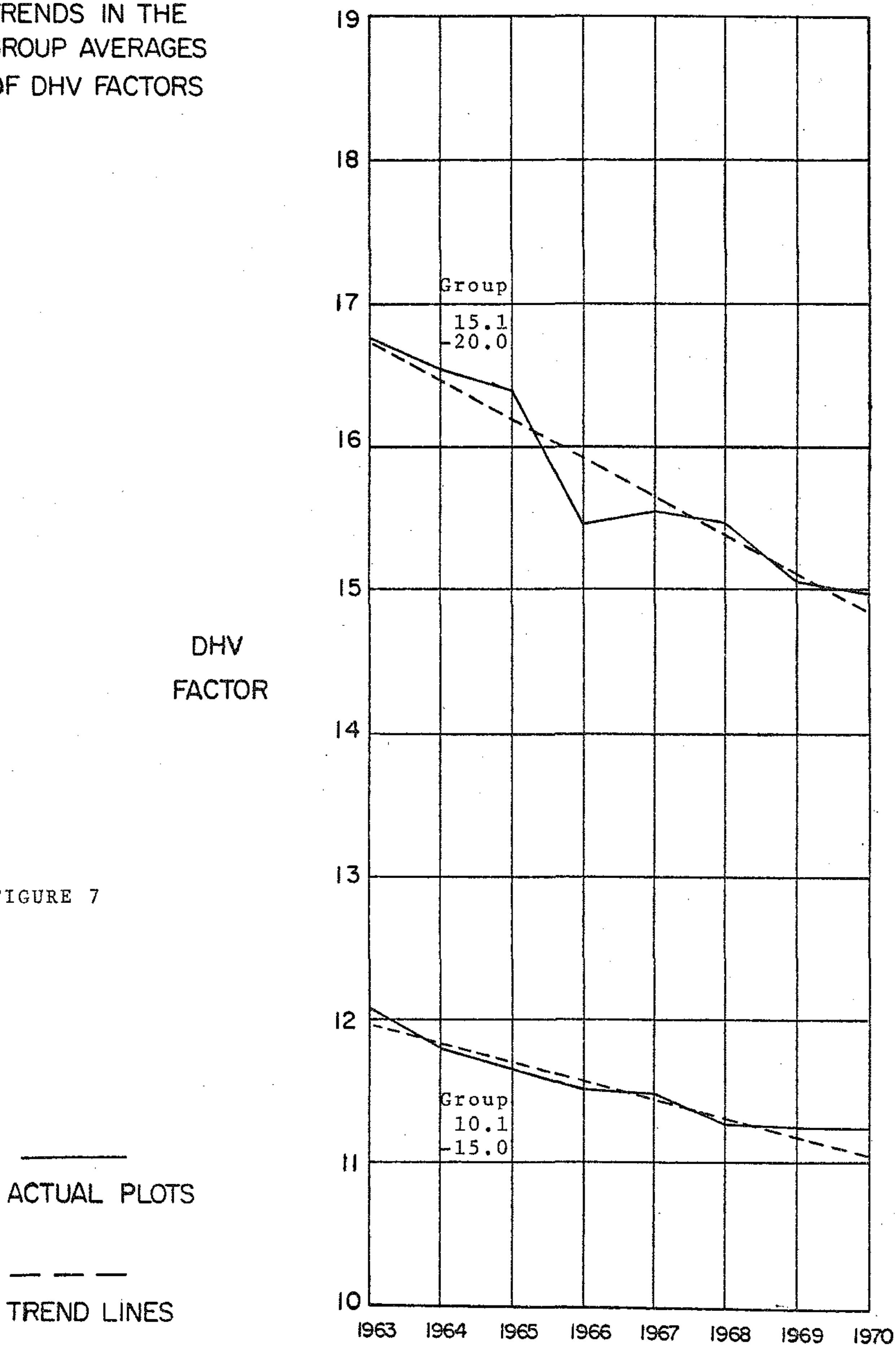
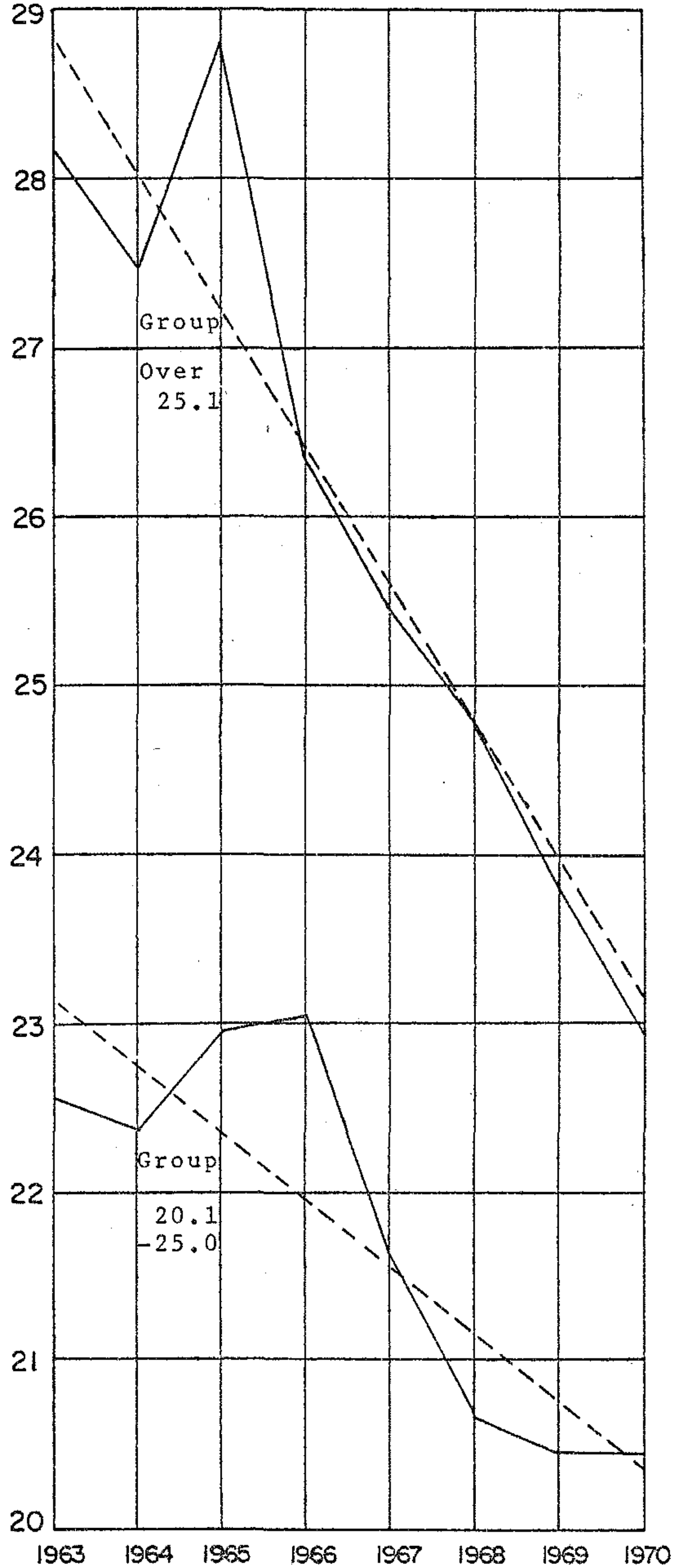


FIGURE 7

TRENDS IN THE GROUP AVERAGES OF DHV FACTORS

Figure 8



DHV FACTOR

FIGURE 8

ACTUAL PLOTS

TREND LINES

Table 6

DHV Factor Range	Number of Stations	Average of DHV Factors	Annual Decreasing Rate	Correlation Coefficient
10.1 - 15.0	22	11.535	-0.115	0.960
15.1 - 20.0	14	15.778	-0.265	0.951
20.1 - 25.0	5	21.750	-0.390	0.853
Over 25.1	7	25.975	-0.810	0.942
Overall	48	15.942	-0.289	0.980

stations included in the group, where the weights are the corresponding correlation coefficients of trends such that unstable elements in the trends can be reduced in the general trend. The results are listed in column (3) of Table 7. As can be seen in the table the weighted averages were about 0.03 greater in magnitude than the slopes of the averages in column (2).

The method used so far is simple regression. For a third way, a linear model may also be fitted to the averaged data.

The Model is

$$Y = B_0+B_1X_1+B_2X_2+B_3X_3+B_4X_4+B_5X_1X_4+B_6X_2X_4+B_7X_3X_4+e^*.$$

The main interest is not only to find out the prediction function but also to test whether or not the average annual changes are significant.

It is found that:

$$Y = 11.53500 + 4.24250X_1 + 10.21500X_2 + 14.44000X_3 - 0.11500X_4 - 0.26546X_1X_4 - 0.39094X_2X_4 - 0.81070X_3X_4.$$

From the statistical hypothesis testing results, the data do present evidence to indicate the obvious existence of a general decreasing trend in DHV factors. However, the analysis indicates that annual average decreases of lower DHV factor groups are much smaller. This is partly due to the fact as observed that decreasing trends are influenced by some increasing trends in these groups.

*For the derivation of the model refer to Appendix 3.

Table 7

DHV Factor Group \ Trend Slope	Weighted Average of Trend Slopes	Trend Slope of Averaged Factors by Simple Linear Model	Trend Slope of Averaged Factors by General Linear Model
10.1 - 15.0	-0.145	-0.115	-0.115
15.1 - 20.0	-0.299	-0.265	-0.265
20.1 - 25.0	-0.428	-0.390	-0.391
Over 25.1	-0.826	-0.810	-0.811

The average annual changes of various DHV factor groups obtained for the general linear model are listed in column (4) of Table 7. Surprisingly, the differences between the average annual decreases (that is, the trend slopes) obtained for each of the groups by the simple linear model and by the general linear model are almost nil. Therefore, the general linear model along with the statistical analysis gives us confidence in what we have found by simple linear model.

Trends with Respect to AADT Volume Grouping

It is of interest to study trends in DHV factors by grouping according to AADT volumes. The range of AADT volumes for all stations in 1963 was from 405 to 29,534. This range is wide enough so that stations could be grouped according to 1963 AADT volume as shown in Table 8. The partitions in AADT volume are largely made up with an inspection on the distribution of 1963 AADT volumes of all stations.

Twenty-one, or 43.75 percent, of all stations composed the first group having AADT volume 2,000 or less. DHV factors in this group had a range of 11.6 to 32.3 with an average of about 17.8. The average annual decrease in the DHV factor over the eight years was found to be 0.367 which was the greatest among all three groups. The goodness of fit of the linear trend was expressed by a high correlation coefficient of 0.9532.

Sixteen, or 33.33 percent, of all stations made up the second group having AADT volume ranging from 2,000 to 6,000. DHV factors in this group had a range from 10.2 to 30.7 with an average of 15.3. The average annual decrease was 0.233 and the correlation coefficient was 0.9683.

Eleven, or 22.91 percent, of all stations constituted the third group with an AADT volume over 6,000. The range of DHV factors in this group was 10.4 to 17.8, which was the smallest. The average DHV factor, 12.9, suggests that DHV

Table 8

AADT VOLUME GROUP	NUMBER OF STATIONS	AVERAGE OF DHV FACTORS	AVERAGE ANNUAL DECREASE	CORRELATION COEFFICIENT
0 - 2,000	21	17.8355	-0.3667	0.9532
2,000 - 6,000	16	15.2983	-0.2329	0.9683
OVER 6,000	11	12.7393	-0.1400	0.6657
OVERALL	48	15.9421	-0.2891	0.9801

factors in this group, on the whole, could be lower than those of other groups. The average annual decrease was 0.140 which was also the smallest. The correlation coefficient of 0.6657 reveals a wide variation of the trend from observations. This may be explained by the possibility that eleven stations do not provide sufficient information to predict the actual trend, or the possibility that the actual trend is not linear at all.

The average annual decrease of all stations was 0.289 with a surprisingly good fit.

The actual plots and trends for each of the AADT groups are shown in Figure 9. Note that for each of the AADT groups the range of variation for the trend line, as well as data plots, was not overlapping with that for any other AADT group.

The actual plots and trend for all stations is shown in Figure 10. The trend had a slope similar to that of the middle AADT group, ranging from 2,000 to 6,000 AADT volume, but was slightly higher.

Among the six stations with increasing trends, three had their AADT volumes below 2,000, two below 6,000 and one over 6,000. From Table 5, no effect of AADT volume to the occurrence of an increasing trend can be visualized.

Figure 9

TRENDS IN THE GROUP AVERAGES OF ADT VOLUMES

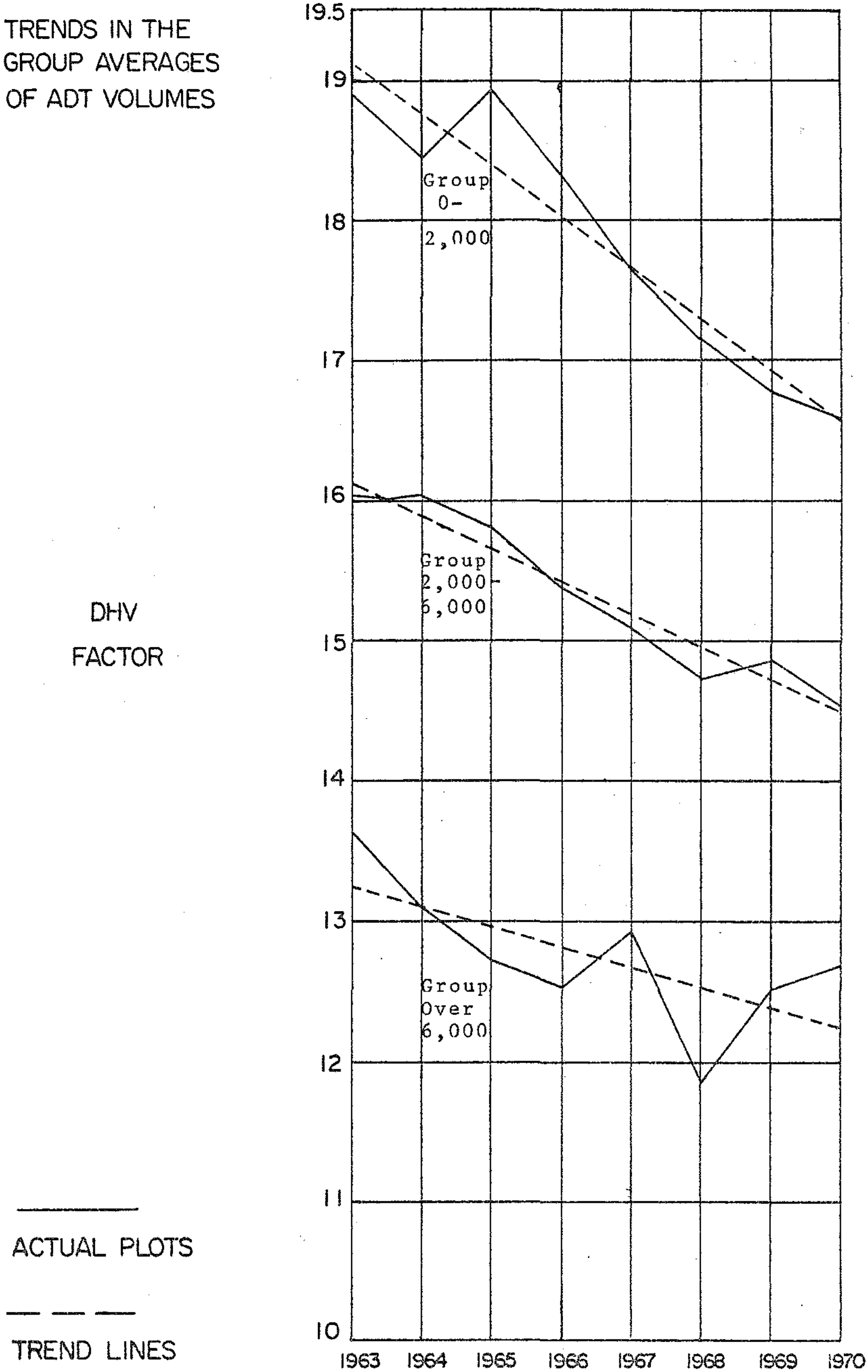
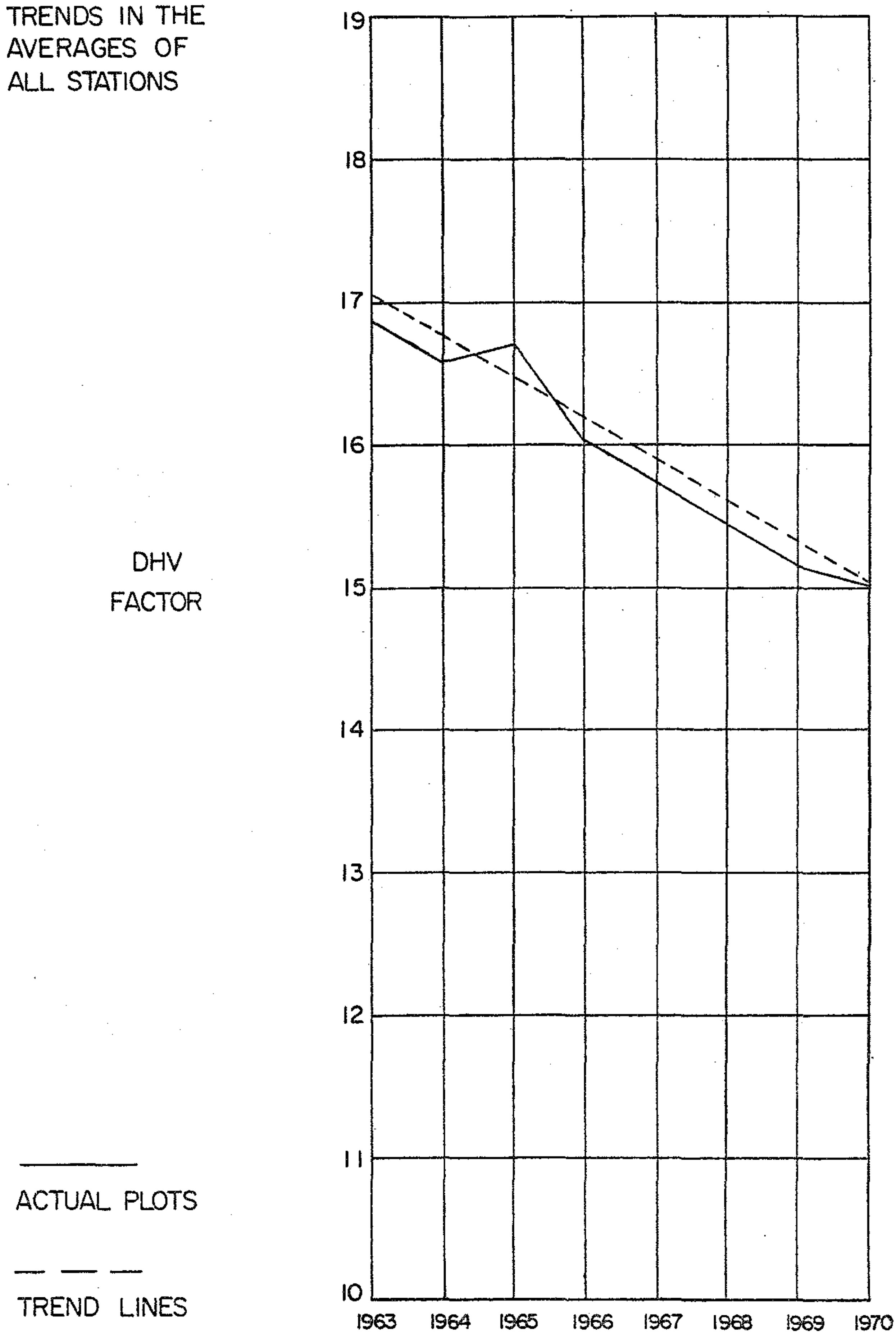


Figure 10


TRENDS IN THE
AVERAGES OF
ALL STATIONS
DHV
FACTOR
19
18
17
16
15
14
13
12
11
10
1963
1964
1965
1966
1967
1968
1969
1970
ACTUAL PLOTS
TREND LINES

Joint Effect on Average Annual Decrease

Now, attention is given to a study of the joint effect (or interaction) of DHV factor and AADT volume in the initial year on the average annual change. Combining the effects caused by DHV factor and AADT volume groupings, their joint effect on the average annual decrease is apparent as the following analysis will indicate.

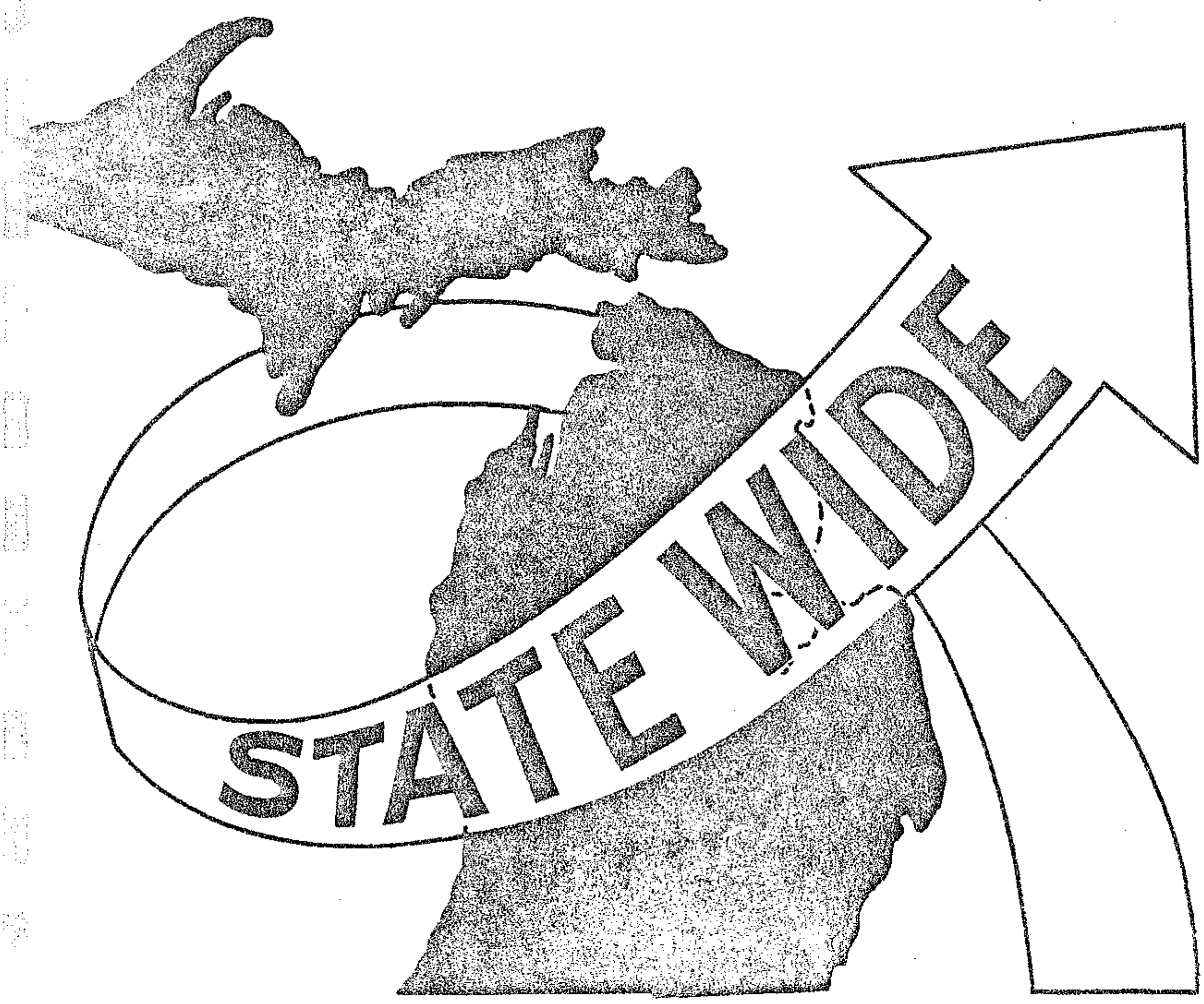
If DHV factor of magnitude over 20.1 and AADT volume over 6,000 are considered to be high, and DHV factor in magnitude under 15.0 and AADT volume under 2,000 are considered to be low, then the previous results suggest possibly that many sections of roads carrying low AADT volumes often possess high DHV factors, while those carrying high AADT volumes often possess low DHV factors. Thus, on any heavily traveled highway the DHV factor may often not be too high, while lightly traveled highways will actually experience the higher DHV factors.

As shown in Table 9, the seven stations having ADT volumes over 6,000 and DHV factors of magnitude below 15.0 had an average annual decrease of 0.097 which is the least among those for all combinations. Eight stations having AADT volumes below 2,000 and DHV factors of magnitude over 20.1 had the greatest average annual decrease. Moreover, what is shown in the table for any one of the combinations seems, on the whole, to offer convincing evidence of what just concluded as far as the joint effect on the average annual decrease is concerned.

Table 9

AADT VOLUME GROUP	DHV FACTOR GROUP	NUMBER OF STATIONS	DHV AVERAGE IN THE INITIAL YEAR	ANNUAL DECREASING RATE	CORRELATION COEFFICIENT
0 - 2,000	10.1 - 15.0	7	12.60	-0.1287	0.9659
	15.1 - 20.0	6	16.73	-0.2489	0.9187
	Over 20.1	8	26.03	-0.6532	0.9362
2,000 - 6,000	10.1 - 15.0	8	11.54	-0.0985	0.8749
	15.1 - 20.0	4	16.38	-0.2786	0.9101
	Over 20.1	4	25.45	-0.6006	0.9372
Over 6,000	10.1 - 15.0	7	12.05	-0.0969	0.8339
	15.1 - 20.0	4	16.78	-0.2129	0.8025

FORECASTING
PROCESSES



There is only one exception. The average annual decrease for the combination of the lowest AADT group had the middle DHV factor group in the table seems doubtful. The doubt arises from the fact that the average annual decrease for this group of stations is 0.294 which is greater than expected. In order to reach more accurate estimated average annual decrease for this combination, more data must be included in the data base. If the 1962 average DHV factor of this group is used, then the estimated average annual decrease turns out to be smaller, that is 0.249, with higher correlation coefficient.

The logical distribution of data in Table 9 is quite surprising and that is the basis of the DHV forecasting model developed in a later section.

METHOD I: A general Average Annual Rate of Decrease

The original grouping with respect to DHV factor is satisfactory for an initial analysis, but since 75.0 percent of stations had DHV factors in the range from 10.1 to 20.0, a finer grouping will be used to develop the DHV forecasting model. The new grouping appears in Table 10 at the top of the chart.

By a careful inspection of data listed in Table 10, some interesting points can be observed.

(1) Yearly changes was decreasing with the passing of years for each of the DHV factor groups.

(2) DHV factor in the last year of any group was close to the factor in the initial year of adjacent lower group.

(3) The average annual decrease was decreasing from any group to adjacent lower group.

From (1), assume for each of the groups, DHV factor was decreasing over years at approximately a constant annual rate of change. From (2), a new series of DHV factors is developed which is arranged in an order from high DHV factor group to low DHV factor group as well as in chronological order within each of the groups. From (3), we assume all of the constant rates were the same. In other words, the new series had a constant annual rate of decrease.

This general rate may be uniquely determined if a non-linear model

$$Y_x = A\ (1 + r)^x V_x \ *$$

is fitted which is called a constant growth function.

*Refer to Appendix 4.

Table 10

DHV % Range / Year	Over 30.1	25.1 - 30.0	20.1 - 25.0	17.6 - 20.0	15.1 - 17.5	12.6 - 15.0	10.1 - 12.5
1963	31.200	25.925	22.540	18.500	16.254	13.471	11.413
1964	29.666	25.825	22.360	18.700	15.982	13.143	11.173
1965	31.400	26.900	22.940	17.833	15.990	12.857	11.086
1966	28.333	24.850	23.040	16.000	15.300	12.514	11.000
1967	27.533	23.850	21.620	15.966	15.436	12.514	10.993
1968	27.533	22.750	20.660	16.466	15.209	12.243	10.813
1969	25.933	22.200	20.440	16.266	14.745	12.343	10.746
1970	24.366	21.875	20.400	15.933	14.727	11.900	10.946
Slope	-0.939	-0.713	-0.391	-0.408	-0.227	-0.200	-0.074
Average	28.245	24.272	21.750	16.958	15.455	12.623	11.021
C.Coef.	0.938	0.926	0.853	0.842	0.966	0.965	0.868

One important point that should be made clear is that the predicted DHV factor in the model converges to zero as the number of years X tends to infinity, while the actual irreducible minimal DHV factor is 4.1666.* Thus some modifications must

* If a large number of hours carry traffic lower than the average hourly traffic volume of the year, then some hours must carry traffic greater than the average, and hence the DHV factor may be greater. The irreducible minimal DHV factor is derived by theoretically assuming constant traffic volume during all hours of the year, that is, the hourly traffic volumes of the year are all the same. Therefore, daily traffic volumes equal AADT volume and all of the hourly volumes equal 1/24 AADT volume. Obviously DHV factor under this circumstance is, in terms of percentage of AADT volume, $\frac{100}{24}$ or 4.1666.

Strictly speaking, DHV factor could be in magnitude lower than 4.1666. However, if this were the case, the 30th high hour volume could not be assumed as a DHV criterion since traffic in peak hours would be incredibly heavier than usual. This may be revealed by the following calculation. If DHV factor were in magnitude anywhere less than 4.1666, say, 4.0000, then there would be 8731 hours (all but the 29 peak hours of the year) having their DHV factors of magnitude less than or equal to 4.0000. Thus, traffic volumes in these hours would build up to at most 349.24 AADT volume, and 15.76 AADT volume would be left over for the remaining 29 peak hours so as to arrive at a yearly total of 365 AADT volume. DHV factors in these peak hours would be, in the average, at least 54.34 in magnitude. Therefore, it is obvious that the variation in the hourly traffic is fantastically large.

The actual lowest DHV factor of all P.T.R. stations during the eight years was 9.3 which was also the lowest of all P.T.R. records. Information listed in the appendices of Highway Capacity Manual published in 1964 shows the lowest was 8.2 which was also the lowest reported in paper (1) mentioned previously. The fact that 8.2 is 100 divided by 12.2 rather than 24 coincides with the seasonal and the daily fluctuations of the traffic volume. The actual daily traffic distributions and the hourly traffic distributions by the months of the year and by the days of the week, which may be found in Michigan's "Automatic Traffic Recorder Analysis", reveal the fact.

be made in the process of fitting the curve to satisfy the requirement of a new asymptotic minimum.

The analysis indicates that

$$Y_x = 13.2115\ (0.97389)^x + 4.166$$

From this the average annual decreasing rate is found to be 0.02611, that is, 2.611 percent.

The actual plots and the steady decreasing curve are shown in Figure 11. By making use of this curve, Method I of the DHV forecasting model is thus obtained.

Similar compound reduction rates have been found by New Jersey -- 2.3 percent for New Jersey State, and 1.4 percent for Pennsylvania State.*

From the derivation of the forecasting curve, it seems that an important characteristic of the average annual decreasing rate is in the magnitude of minimal DHV factor to which the curve approaches. Since the actual minimal DHV factor ever reached on Michigan highways in most cases has never gone below 9.0, it seems reasonable to assume 8.1666 as an actual minimal DHV factor for a statewide curve rather than the theoretical 4.1666. The new curve obtained appears to be similar to the original one but slightly lower in the middle part. However, the tail part should be emphasized, and a composite curve may be used (Figure 11).

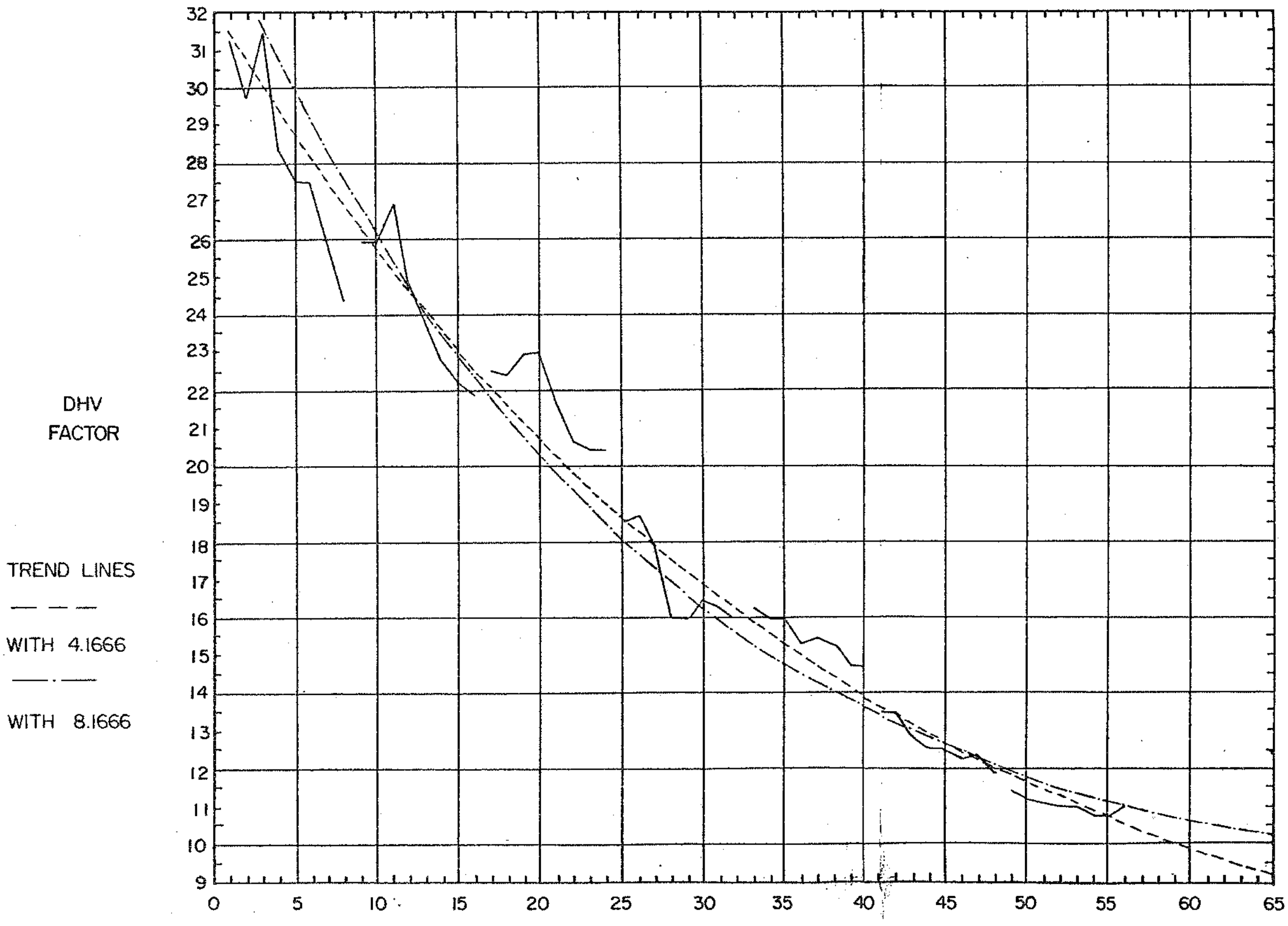
As a result of investigating the closeness of the model prediction to the P.T.R. data, it has been found that for areas or routes with distinct characteristic

* Refer to HRR Bulletin 199, 1963.

(for instance, recreational) individual minimal DHV factor should be separately determined so that the actual traffic situations can be accommodated. Some efforts have been made to fit curves to data of distinct DHV factor levels (for instance, 20 percent or more). The study in this area is still in its preliminary stage.

FIGURE 11

GENERAL TREND IN DHV FACTOR
AT CONSTANT DECREASING RATE



METHOD II: Forecasting with Respect to Joint Effect

The results obtained in the preliminary analysis dealing with the joint effect of the DHV factor and AADT volume on the average annual decrease provide a possible pattern for forecasting DHV factor. Specifically, stations classified in the same combination of DHV factor and AADT volume are largely characterized to possess similar average annual decreases. Therefore, the average annual decrease should be determined for each of the DHV factor and AADT volume combinations, and hence grouping of stations by the combinations is utilized as a means to construct a DHV forecasting model.

If this model is to be useful, more break-downs in DHV factor or AADT volume are required to be included in the model so that change in DHV factor or AADT volume can be sensitive to change in average annual decrease.

The effect of the DHV factor seems to be more sensitive to the annual change than the effect of AADT volume is. It is actually the basis on which the model is developed in the previous section. With this in mind, the forecasting model is constructed with more breakdowns in DHV factor.

However, the data used in the analysis can not afford further breakdowns since the number of stations for each of the combinations would be too small. Thus, only estimated average annual decreases are obtainable for some of the combinations which lack actual PTR data.

Since it is observed that the higher the DHV factor was, the greater was its average annual decrease. Thus, a linear relationship between the magnitude of DHV factor and its average annual average may be assumed for each of the AADT groups. In other words, for each AADT group, the estimated average annual decrease for each DHV factor group (as shown in Column (1) of Table 11) may be obtained on a linear regression line which is fitted to data points for that AADT group. Table 9 is a list of average annual decreases for some DHV factor and AADT volume combinations which are used as data points to be fitted by regression lines. The corresponding "DHV averages in the initial year" are taken to locate these data points in the refined grouping system in Table 11. Moreover, instead of the DHV magnitudes, the ranks of the magnitudes are used to simplify the computation involved in fitting the regression lines.

Estimated average annual decreases for all combinations of DHV factor group and AADT volume is thus summarized in Table 11, and this is Method II of the DHV forecasting model.

Table 11

AADT VOLUME GROUP DHV FACTOR GROUP	2,000	2,001 - 6,000	6,000
Below 10.0	-0.010	-0.028	-0.051
10.0 - 10.9	-0.050	-0.063	-0.074
11.0 - 11.9	-0.090	-0.099	-0.097
12.0 - 12.9	-0.131	-0.135	-0.120
13.0 - 13.9	-0.171	-0.171	-0.143
14.0 - 14.9	-0.211	-0.207	-0.167
15.0 - 15.9	-0.251	-0.242	-0.190
16.0 - 16.9	-0.291	-0.278	-0.213
17.0 - 17.9	-0.332	-0.314	-0.236
18.0 - 18.9	-0.372	-0.350	-0.259
19.0 - 19.9	-0.412	-0.386	-0.283
20.0 - 20.9	-0.452	-0.421	-0.306
21.0 - 21.9	-0.492	-0.457	-0.329
22.0 - 22.9	-0.533	-0.493	-0.352
23.0 - 23.9	-0.573	-0.529	-0.375
24.0 - 24.9	-0.613	-0.565	-0.399
25.0 - 25.9	-0.653	-0.600	
26.0 - 26.9	-0.693	-0.636	
27.0 - 27.9	-0.734	-0.672	
28.0 - 28.9	-0.774	-0.708	
29.0 - 29.9	-0.814	-0.744	
30.0 - 30.9	-0.854	-0.779	
31.0 - 31.9	-0.894	-0.815	
32.0 - 32.9	-0.935	-0.851	
33.0 - 33.9	-0.975	-0.887	
34.0 - 34.9	-1.015	-0.923	

The Estimated Average Annual Decrease For Each DHV Factor Group

Application of the Forecasting Processes

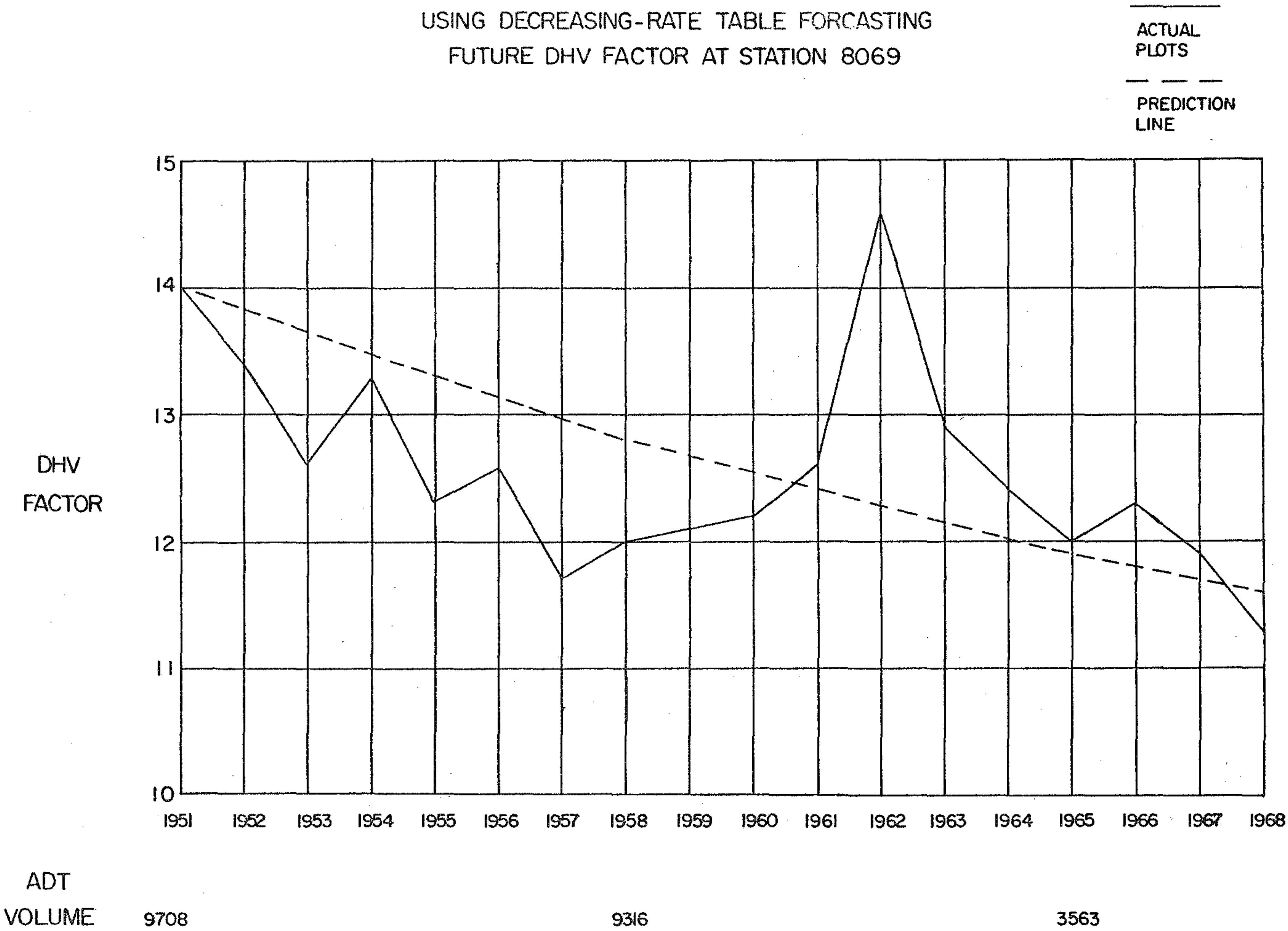
Under the condition that existing DHV volume (or DHV factor) is known and that AADT volume is available for any year in the future, one is now able to predict future DHV by making use of either of the forecasting methods developed so far.

It should be mentioned that when applying the result of any trend analysis, it is meaningless to predict for a relatively short period of time, especially when the trend has been disturbed significantly by some unexpected factors (discussed later). Since this analysis is based on eight years of study period, it is suggested to predict DHV factor over a span of at least eight years.

The use of the processes can be clearly illustrated by an example. Since P.T.R. station 806 was removed in 1969 and hence was not used as data base in the analysis, suppose in 1951 the department was required to predict the 1968 DHV factor on a county road parallel to I-75 near Pontiac where the station was located.

If the joint effect of AADT volume and magnitude of DHV factor on average annual decrease is taken into account in the prediction, then Method II and Table 11 can be applied. In Figure 12, AADT volume and DHV factor in 1951, which is taken as the initial year, was 9,708 and 14.0 respectively. Thus, by consulting Table 11 the estimated average annual decrease

Figure 12


USING DECREASING-RATE TABLE FORCASTING
FUTURE DHV FACTOR AT STATION 8069
ACTUAL PLOTS
PREDICTION LINE
DHV FACTOR
15
14
13
12
11
10
1951
1952
1953
1954
1955
1956
1957
1958
1959
1960
1961
1962
1963
1964
1965
1966
1967
1968
ADT VOLUME
9708
9316
3563

in the subsequent years was 0.167. The estimated DHV factor in 1958 was hence 12.8 together with an AADT volume of 9,316. Then in turn, the estimated average annual decrease in the subsequent years was 0.120 and resulted in a 1965 DHV factor 11.9. In exactly the same way we get 11.6 as the predicted 1968 DHV factor.

By using Method I which neglects the effect of AADT volume on the average annual decrease, the 1958 DHV factor should decline along the curve shown in Figure 11, and it would reach a predicted 1968 DHV factor of 10.4.

The actual DHV factor in 1968 was 11.3. The deviation between the actual and the predicted values are small for both processes in the example.

Stations 3049, and 8149 are not used as a data source either so serve as additional tests. It can be seen in Figure 13 how good the result of prediction is for station 8199 while Figure 14 shows the prediction for station 3049 is not so good. A detailed evaluation of both models follows.

Figure 13

USING DECREASING-RATE TABLE FORCASTING
FUTURE DHV FACTOR AT STATION 8149

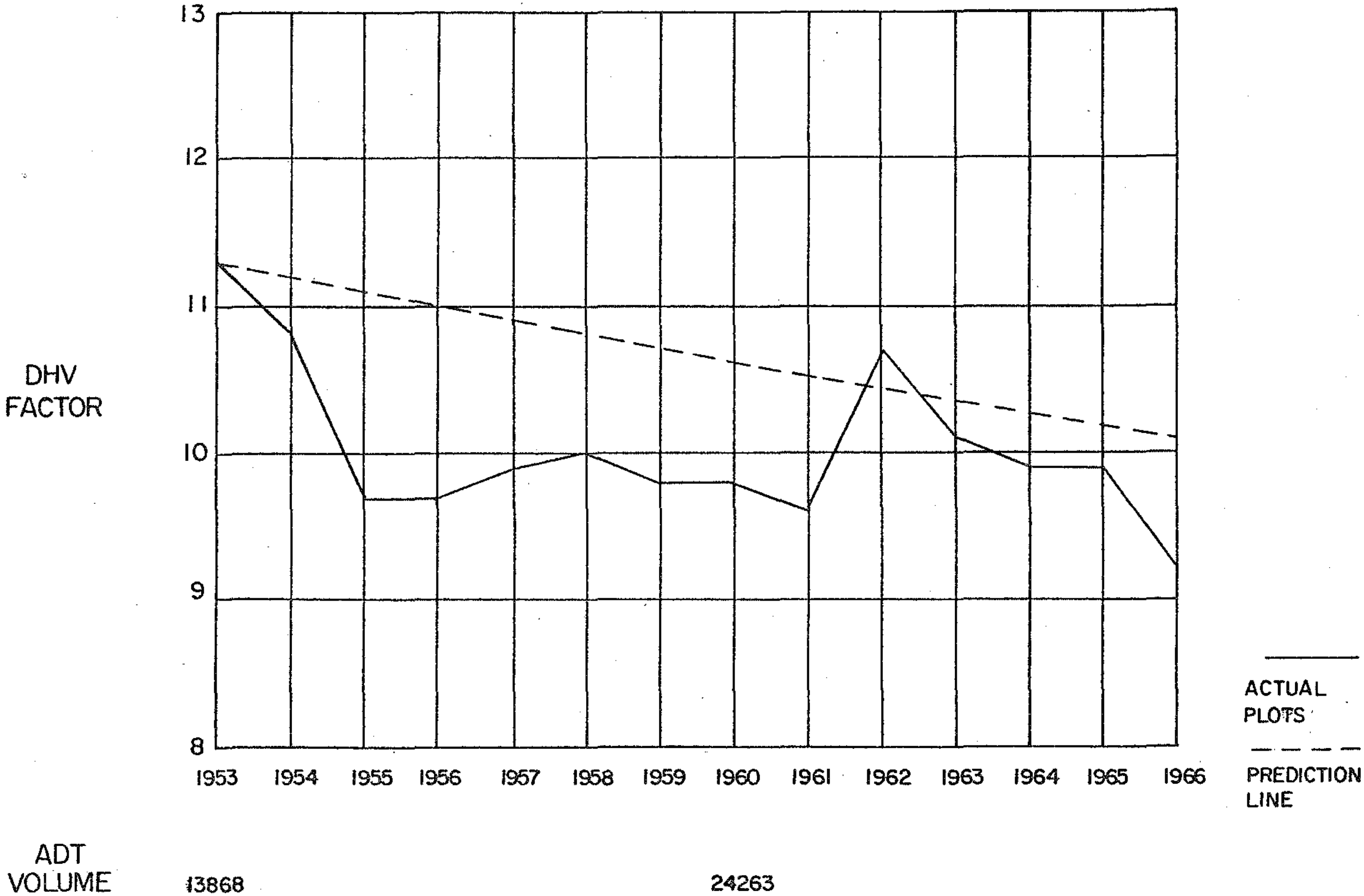
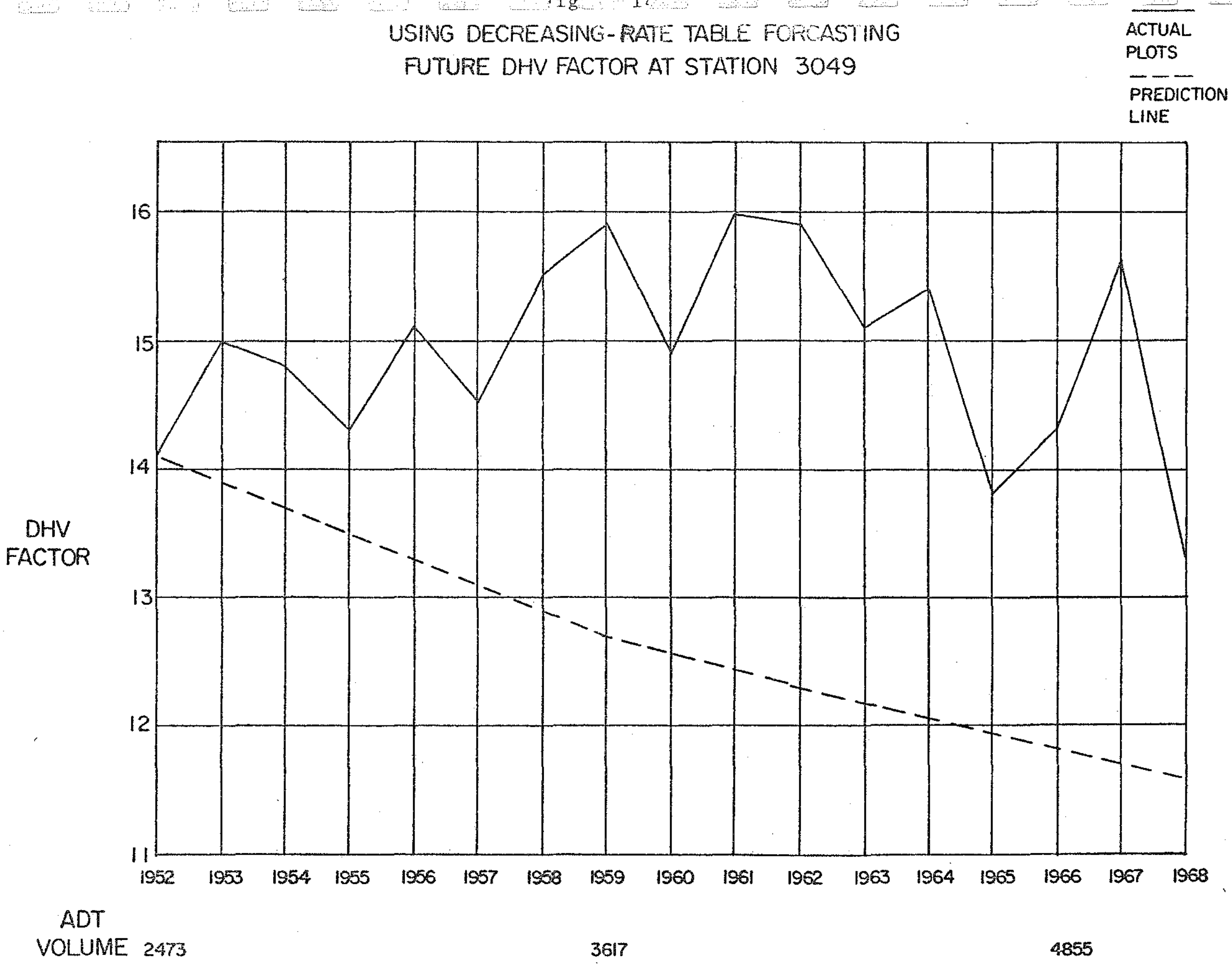


Fig. 14

USING DECREASING-RATE TABLE FORCASTING
FUTURE DHV FACTOR AT STATION 3049



Evaluation of the Forecasting Processes

Two forecasting processes have been developed on the basis of the observation that normally most highways, particularly those with high AADT volumes, have decreasing trends over a long period of several years. Accordingly, most of the data used in the analysis are chosen to conform to this assumption. A small error in prediction lies naturally in the existence of a stable decreasing trend in the future.

As a matter of fact, fluctuations occurred in DHV factor with the passing of time. It is observed that in some cases the trend in DHV factor declined in a stable way, while in some other cases the entire trend shifted upwards after an ascending jump.

The fluctuations were caused by some factors other than those which normally and constantly had an effect on the decline of DHV factor in the long run. Therefore, these factors should be considered as irregular factors in contrast with those determining the trend.

Among the irregular factors, the most noticeable is highway constructions which greatly improved the accessibility of various areas in the state. In this case, a change in traffic volume took place on highways in the vicinity. Another element is the change in the attraction of major recreational areas which have generated more long distance trips than normally expected during the last ten years. This appears to have had a great influence on the formation of DHV factor trends on major recreational roads. The influence of these factors may well explain why and when abrupt changes occurred in recent DHV factor trends.

Since the application of both forecasting processes demand an assumption of ever-decreasing trend it seems reasonbale to apply the technique to highways which are not influenced by such irregular factors. How to handle the forecasting under the influence of irregular factors which occurred casually is important in the development of a dynamic DHV forecasting model. This is not discussed in any detail in this report, but the preliminary analysis completed up to this point will serve as a basis for the development of a more dynamic DHV forecasting model(s).

As can be seen in the application of Method II, that is the forecasting process developed with respect to the joint effect, the forecasting scheme depends heavily on the starting condition. Since the DHV factor sometimes fluctuates, if it is extraordinarily higher in the starting year than those in the subsequent years, and this is common in the abnormal cases, then the consultant table will offer a greater average annual decrease and accordingly the entire predicted trend will be lower. In other words, in this case the forecasting process possesses the property of a built-in adjustment. However, it is unfavorable to the prediction when DHV factor jumps up in the initial year and shifts the entire trend upwards in the whole prediction period, or DHV factor jumps up in some intermediate year and shifts the trend upwards thereafter.

As far as this model is concerned the three groups of AADT volumes identified in the table might imply a lack of sensitivity with respect to AADT change. However, it provides a guideline in forecasting even when only rough estimates of future AADT volume is obtainable.

Method I, the forecasting process developed with regard only to the magnitude of DHV factor, is at large highly applicable. It depends also on the starting level of DHV factor but it faces the difficult situations almost contrary to the intricacy confronted to the other forecasting technique: The prediction is unfavorable when DHV factor is remarkably high in the starting year and the trend drops down significantly in the subsequent years. By Method I better estimate of future DHV factor can be obtained if DHV factor shifts upwards slightly in the intermediate year and thereafter.

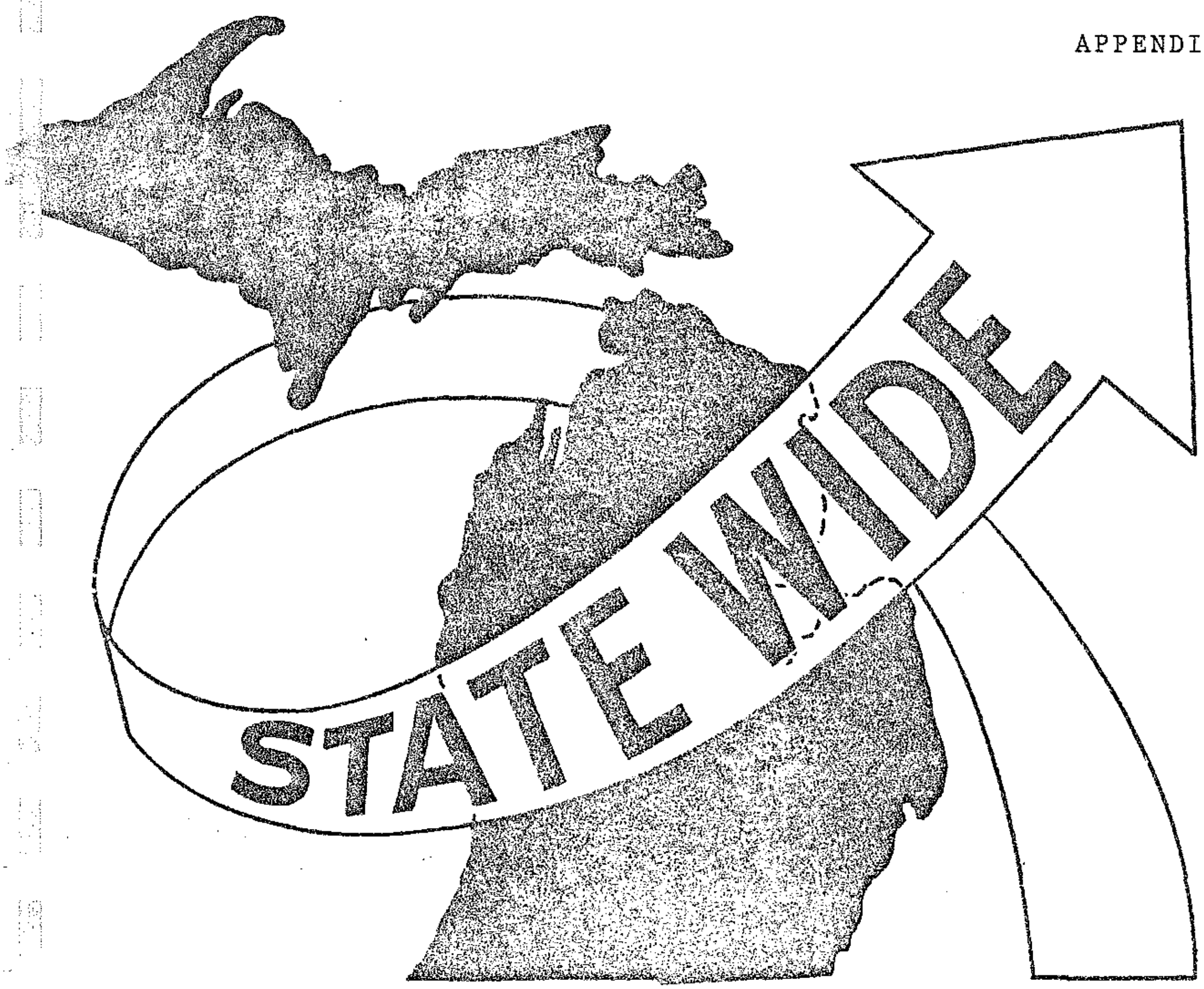
A good number of additional test examples have been made and listed as Appendix 5 to justify the validity of the use of both of the forecasting processes. The data used in the tests are based on some P.T.R. records of years different from those used in the analysis. The test result is therefore pretty convincing. Furthermore, records obviously influenced by highway constructions are excluded from the test data with the intention of exposing the normal decreasing trends, and making the application valid.

In Appendix 5, column (1) of the predicted DHV factor is the result of Method II forecasting by making use of the process dealing with the joint effect, and column (2) by Method I.

The difference between the predicted and actual DHV factors (or DHV volumes) can easily be calculated.

There are more cases in which the magnitudes of predicted DHV factors in column (2) are lower than those in column (1). In many cases, the predicted DHV factors of both processes had downward (or underestimate) bias. The reason has been mentioned earlier in this section and therefore the prediction seems to be better if the higher one of the two predicted value in columns (1) and (2) is chosen as the predicted DHV factor.

APPENDICES



APPENDIX 1
MICHIGAN DEPARTMENT OF STATE HIGHWAYS
P.T.R. STATION LOCATIONS

STATION	ROUTE	VICINITY	COUNTY
1029	US-41, M-28 E-W BD.	CHAMPION	MARQUETTE
1049	US-2, E-W BD.	IRON RIVER	IRON
1069	US-41, N-S BD.	POWERS	MENOMINEE
1089	US-41, NW-SE BD.	SKANDIA	MARQUETTE
2029	US-2, E-W BD.	BREVORT	MACKINAC
2049	I-75, N-S BD.	ST. IGNACE	MACKINAC
2069	M-28, E-W BD.	RACO	CHIPPEWA
3029	M-115, NW-SE BD.	FARWELL	CLARE
3069	US-131, M-66 N-S BD.	KALKASKA	KALKASKA
3089	M-66, N-S BD.	SEARS	OSCEOLA
3109	M-37, N-S BD.	BALDWIN	LAKE
4029	US-23, N-S BD.	ALPENA	ALPENA
4049	OLD US-27, N-S BD.	WOLVERINE	CHEBOYGAN
4069	OLD M-76, NW-SE BD.	STERLING	ARENAC
4089	M-33, N-S BD.	ROSE CITY	OGEMAW
4109	HOU-HIGG DR. N-S BD.	HOUGHTON HEIGHTS	ROSCOMMON
4129	US-27, N-S BD.	HOUGHTON LAKE	ROSCOMMON
5029	US-27, N-S BD.	ST. JOHNS	CLINTON
5089	CASCASE RD. E-W BD.	CASCADE	KENT

STATION	ROUTE	VICINITY	COUNTY
5109	WASHINGTON RD. E-W BD.	ITHACA	GRATIOT
5129	US-31, N-S BD.	PENTWATER	OCEANA
5149	US-131, N-S BD.	MORLEY	MECOSTA
5169	M-57, E-W BD.	PERRINTON	GRATIOT
5189	JORDAN LAKE RD. N-S BD.	LAKE ODESSA	IONIA
5209	96TH AVE., N-S BD.	ZEELAND	OTTAWA
5229	I-96, E-W BD.	GRAND RAPIDS	KENT
6029	M-53, N-S BD.	MARLETTE	SANILAC
6049	US-25, N-S BD.	PORT SANILAC	SANILAC
6069	M-78, NE-SW BD.	LANSING	SHIAWASSEE
6089	M-21, E-W BD.	CAPAC	ST. CLAIR
6129	I-75, US-10, N-S BD.	BIRCH RUN	SAGINAW
7049	RED ARROW HWY., E-W BD.	MARSHALL	CALHOUN
7069	M-60, E-W BD.	HOMER	CALHOUN
7089	RED ARROW HWY., NE-SW BD.	UNION PIER	BERRIEN
7109	US-131, N-S BD.	SCHOOLCRAFT	KALAMAZOO
7129	NILES-BUCHA. RD. E-W BD.	BUCHANAN	BERRIEN
7149	CO. RD. 215, 54 ST., N-S BD.	LAWRENCE	VAN BUREN
7169	I-94, E-W BD.	JACKSON	CALHOUN
7189	I-94, N-S BD.	NEW BUFFALO	BERRIEN

STATION	ROUTE	VICINITY	COUNTY
8029	US-27, N-S BD.	MASON	INGHAM
8049	OLD US-23, N-S BD.	BRIGHTON	LIVINGSTON
8089	GRAND RIVER, E-W BD.	FOWLERVILLE	LIVINGSTON
8109	US-25, NE-SW BD.	MT. CLEMENS	MACOMB
8129	US-12, E-W BD.	JONESVILLE	HILLSDALE
8169	US-24, N-S BD.	ERIE	MONROE
8189	I-75, N-S BD.	MONROE	MONROE
8209	I-96, E-W BD.	NEW HUDSON	OAKLAND
8229	US-23, N-S BD.	HARTLAND	LIVINGSTON

THE FOLLOWING STATIONS WERE REMOVED BEFORE 1969 AND WERE NOT INCLUDED IN THE DATA BASE.

3049	US-3L, M-37 N-S BD.	TRAVERSE CITY	GRAND TRAVERSE
8069	OLD US-10 NW-SE BD.	PONTIAC	OAKLAND
8149	I-94, E-W BD.	ROMULUS	WAYNE

APPENDIX 2

DHV FACTOR DATA AND LINEAR TRENDS
AT DHV-GROUPED P.T.R. STATIONS

1) 9.1 - 15.0

	8129	7069	8189	8089	8169	7109
1963	10.2	10.2	10.4	10.5	10.7	11.2
1964	10.6	9.9	10.0	10.6	11.2	11.1
1965	9.9	9.6	10.2	10.6	10.1	10.9
1966	9.5	9.7	9.9	10.6	11.6	10.7
1967	9.7	9.6	9.9	10.9	9.4	11.1
1968	9.7	9.7	9.9	10.4	9.4	10.2
1969	9.3	9.3	9.5	10.9	9.4	10.5
1970	9.6	10.0	9.7	11.0	9.4	10.5
SLOPE	-0.13	-0.05	-0.10	+0.06	-0.27	-0.11
CORR. COEF.	0.778	0.440	0.872	0.632	0.720	0.783

	6069	5209	8029	7049	8109	1069
1963	11.3	11.6	11.7	11.8	12.2	12.2
1964	10.9	12.0	11.3	11.2	12.1	11.1
1965	11.1	12.4	11.6	11.8	11.3	11.7
1966	11.4	11.8	11.3	11.8	10.8	*
1967	10.7	12.5	11.6	11.4	10.6	12.0
1968	10.4	11.8	11.5	12.1	10.5	11.5
1969	10.5	12.7	11.1	11.8	10.2	11.4
1970	10.9	12.5	11.7	11.9	10.4	11.2
SLOPE	-0.09	+0.10	-0.01	+0.05	-0.29	-0.07
CORR. COEF.	0.618	0.618	0.133	0.427	0.931	0.447

	8049	7169	7129	4029	1089	6089
1963	12.3	12.4	12.5	12.6	12.7	13.1
1964	11.6	12.0	12.0	11.9	13.3	12.9
1965	11.6	12.1	11.4	11.8	12.4	12.8
1966	11.2	11.9	11.8	11.3	1.31	12.1
1967	11.1	12.3	12.1	11.5	11.9	12.4
1968	10.9	12.2	12.0	11.9	11.7	12.1
1969	10.4	11.8	12.4	13.1	11.7	12.4
1970	10.6	11.7	13.1	11.3	11.4	11.8
SLOPE	-0.24	-0.06	+0.10	-0.03	-0.24	-0.16
CORR. COEF.	0.956	0.619	0.475	0.119	0.842	0.868

	5229	5189	5089	8229
1963	13.4	13.8	13.8	14.9
1964	12.9	13.4	13.3	14.3
1965	12.9	13.2	13.2	13.7
1966	12.6	12.0	12.7	13.8
1967	12.9	13.2	12.2	13.5
1968	12.3	12.5	11.7	13.5
1969	11.8	12.1	12.4	12.9
1970	11.9	11.8	12.2	12.9
SLOPE	-0.21	-0.25	-0.25	-0.26
CORR. COEF.	0.925	0.838	0.865	0.949

2) 15.1 - 20.0

	7149	5109	1029	5149	7189	5169
1963	15.3	15.6	15.8	15.8	15.8	16.0
1964	14.5	17.4	15.5	16.0	15.9	15.0
1965	14.9	16.7	15.9	15.8	*	14.2
1966	14.2	14.6	14.8	15.7	14.8	12.6
1967	14.8	14.2	15.0	15.5	16.5	13.7
1968	14.8	13.6	15.1	14.6	16.5	12.6
1969	13.7	13.7	14.5	14.6	16.1	12.5
1970	13.8	12.6	14.5	14.3	16.1	13.1
SLOPE	-0.17	-0.59	-0.19	-0.25	+0.08	-0.43
CORR. COEF.	0.739	0.873	0.868	0.923	0.360	0.832

	1049	6129	5029	7089	3069	8209
1963	16.5	16.7	16.8	17.1	17.4	17.8
1964	16.1	15.5	16.0	17.6	16.3	16.3
1965	17.3	15.2	16.4	16.8	16.7	15.5
1966	17.2	15.8	15.9	16.2	16.5	12.8
1967	17.1	16.3	16.0	15.3	15.4	12.0
1968	18.7	15.5	15.4	15.0	15.5	13.6
1969	17.6	14.5	15.6	14.0	15.4	13.5
1970	17.6	14.3	16.7	14.1	14.9	13.2
SLOPE	+0.23	-0.24	-0.07	-0.54	-0.32	-0.63
CORR. COEF.	0.721	0.726	0.327	0.966	0.924	0.774

	5129	6029
1963	18.1	19.6
1964	21.4	18.4
1965	18.9	19.1
1966	18.3	16.9
1967	17.7	18.2
1968	18.2	17.6
1969	17.9	17.4
1970	16.5	18.1
SLOPE	-0.37	-0.22
CORR. COEF.	0.654	0.615

3) 20.1 - 25.0

	3109	4049	2069	3089	2049
1963	21.7	21.8	22.1	23.1	24.0
1964	21.4	21.1	22.2	22.3	24.8
1965	22.6	21.7	23.6	23.3	23.5
1966	21.3	19.8	20.8	29.4	23.9
1967	20.7	21.8	20.5	22.4	22.7
1968	20.1	17.1	21.0	22.5	22.6
1969	19.5	15.3	21.4	23.1	22.9
1970	19.3	18.4	20.8	21.4	22.1
SLOPE	-0.41	-0.77	-0.25	-0.21	-0.32
CORR. COEF.	0.880	0.764	0.598	0.203	0.871

4) 25.1 AND OVER

	4069	3029	2029	6049	4089	4129
1963	25.4	25.5	25.9	26.9	30.6	30.7
1964	25.3	25.5	26.1	26.4	28.9	28.6
1965	28.9	24.7	26.2	27.8	31.0	29.1
1966	26.0	23.1	25.2	25.1	27.6	26.8
1967	24.3	23.0	26.3	21.8	27.5	26.2
1968	22.6	22.2	23.6	22.6	25.7	26.7
1969	22.0	21.6	23.7	21.5	24.6	25.1
1970	20.1	21.2	24.8	21.4	22.9	24.8
SLOPE	-0.88	-0.68	-0.31	-0.98	-1.09	-0.80
CORR. COEF.	0.793	0.980	0.700	0.899	0.938	0.948

	4109
1963	32.3
1964	31.5
1965	34.1
1966	30.6
1967	28.9
1968	30.2
1969	28.1
1970	25.4
SLOPE	-0.94
CORR. COEF.	0.854

*EXACT DATA NOT AVAILABLE DUE TO HIGHWAY CONSTRUCTION IN THE YEAR. WHEN AVERAGING DHV FACTORS OF SOME YEAR WITHIN THE GROUP, STATIONS WITH MISSING DATA ARE NOT TAKEN INTO ACCOUNT FOR THAT YEAR.

APPENDIX 3

A FUNCTION WITH A CONSTANT RATE OF CHANGE IS

$$Y_x = A(1 + \gamma)^x V_x ,$$

WHERE THE PARAMETERS

A = DHV FACTOR IN THE INITIAL YEAR,

γ = THE CONSTANT AVERAGE ANNUAL RATE OF CHANGE,

X = NUMBER OF YEARS PASSING BY FROM THE INITIAL YEAR WHEN THE OBSERVATION WAS MADE,

Y_x = OBSERVED DHV FACTOR IN THE X YEARS, AND V_x = DISTURBANCE IN THE X YEARS.

THE DISTURBANCE TERM IS MULTIPLICATIVE TOGETHER WITH THE DHV FACTOR OBSERVED, THAT IS, ASSUMING DISTURBANCE IS PROPORTIONAL TO THE TREND VALUE Y_x.

BY TAKING LOGARITHMS, AND DEFINE

$$y_x = \text{LOG } Y_x ,$$

$$a = \text{LOG } A ,$$

$$b = \text{LOG } (1 + \gamma) ,$$

$$v_x = \text{LOG } V_x ,$$

THE ORIGINAL FUNCTION TURNS OUT TO BE A TYPICAL FORM. NORMALITY IS ALSO ASSUMED IN v_x.

NOTE THAT THE ORIGINAL FUNCTION APPROACHES ZERO AS x TENDS TO INFINITY, SINCE $1 + \gamma < 1$. THEORETICALLY, DHV FACTOR HAS AN IRREDUCIBLE MINIMUM EQUAL TO 4.1666. IN OTHER WORDS, WE WANT

$$\hat{Y}_x = \hat{A} (1 + \hat{\gamma})^x$$

SUCH THAT

$$\hat{Y}_x \to 4.1666 \qquad \text{AS } x \to \infty .$$

WE SHOULD FIT THE FUNCTION TO A NEW SERIES OF DHV FACTOR RATHER THAN THE ORIGINAL.

LET $z_x = Y_x - 4.1666$, AND FIT THE FUNCTION TO z_x.

NOW $\hat{Y}_x = \hat{z}_x + 4.1666$ SINCE $Y_x = z_x + 4.1666$.

THEREFORE, $Y_x \to 4.1666$ AS $X \to \infty$, SINCE $\hat{z}_x \to 0$ AS $X \to \infty$.

FROM THE LOGARITHMIC LINEAR FUNCTION $\hat{z}_x = 1.120951750 - 0.005747092\, X$

WHERE X = ..., -3,-1,1,3, ...AND X UNIT = HALF YEAR, WHICH HAS A CORRELATION COEFFICIENT -0.9917, WE GET

$$\hat{z}_x = 13.2115\ (0.97389)^x .$$

$$\hat{Y}_x = 13.2115\ (0.97389)^x + 4.1666.$$

THE AVERAGE ANNUAL RATE OF DECREASE IN THE LOGARITHMIC FUNCTION IS -0.0114954184 WHICH IS THE LOGARITHM OF 0.97389. THEREFORE, $\gamma = -0.02611$.

APPENDIX 4

FOR SIMPLICITY IN PRESENTATION, DEFINE

A = STATIONS HAVING 1963 DHV FACTOR OF MAGNITUDE LESS THAN 15,

B = STATIONS HAVING 1963 DHV FACTOR OF MAGNITUDE LESS THAN 20 BUT GREATER THAN OR EQUAL TO 15.

C = STATIONS HAVING 1963 DHV FACTOR OF MAGNITUDE LESS THAN 25 BUT GREATER THAN OR EQUAL TO 20.

AND

D = STATIONS HAVING 1963 DHV FACTOR OF MAGNITUDE GREATER THAN OR EQUAL TO 25.

THE MULTIPARAMETER LINEAR MODEL CONSTRUCTED IS

$$Y = B_0 + B_1 X_1 + B_2 X_2 + B_3 X_3 + B_4 X_4 + B_5 X_1 X_4 + B_6 X_2 X_4 + B_7 X_3 X_4 + e$$

WHERE THE PARAMETERS

B_0 = AVERAGE DHV FACTOR OF ALL TYPE A STATIONS,

B_1 = DIFFERENCE IN THE AVERAGE DHV FACTORS, BETWEEN ALL TYPE B AND ALL TYPE A STATIONS,

B_2 = DIFFERENCE IN THE AVERAGE DHV FACTORS, BETWEEN ALL TYPE C AND ALL TYPE A STATIONS,

B_3 = DIFFERENCE IN THE AVERAGE DHV FACTORS, BETWEEN ALL TYPE D AND ALL TYPE A STATIONS,

B_4 = AVERAGE ANNUAL CHANGE OF ALL TYPE A STATIONS,

B_5 = DIFFERENCE IN THE AVERAGE ANNUAL CHANGES BETWEEN ALL TYPE B AND ALL TYPE A STATIONS,

B_6 = DIFFERENCE IN THE AVERAGE ANNUAL CHANGES BETWEEN ALL TYPE C AND ALL TYPE A STATIONS,

B_7 = DIFFERENCE IN THE AVERAGE ANNUAL CHANGES BETWEEN ALL TYPE D AND ALL TYPE A STATIONS,

WHERE THE VARIABLES

Y = OBSERVED DHV FACTOR,

$$X_1 = \begin{cases} 1, & \text{IF THE OBSERVED DHV FACTOR BELONGED TO A TYPE B STATION,} \\ 0, & \text{IF NOT,} \end{cases}$$

$$X_2 = \begin{cases} 1, & \text{IF THE OBSERVED DHV FACTOR BELONGED TO A TYPE C STATION,} \\ 0, & \text{IF NOT,} \end{cases}$$

$$X_3 = \begin{cases} 1, & \text{IF THE OBSERVED DHV FACTOR BELONGED TO A TYPE D STATION,} \\ 0, & \text{IF NOT,} \end{cases}$$

X_4 = NUMBER OF YEARS PASSING BY FROM THE INITIAL YEAR (1963) WHEN THE OBSERVATION TAKEN,

AND

e = DISTURBANCE CAUSED BY CASUAL FACTORS.

IT IS WORTH MENTIONING THAT AN ASSUMPTION OF NORMALITY IS MADE ON THE DISTRIBUTION OF RANDOM DISTURBANCE WHEN APPLYING THE PARAMETRIC LINEAR MODEL.

FITTING THE MODEL TO DATA IN TABLE , WE FIND

$$\hat{B} = \begin{vmatrix} 11.53500 \\ 4.24250 \\ 10.21500 \\ 14.44000 \\ -\ 0.05750 \\ -\ 0.07523 \\ -\ 0.13797 \\ -\ 0.34785 \end{vmatrix}$$

AND

$$s^2 = 0.25841 .$$

SINCE WE SET X_4 UNIT AS HALF YEAR IN THE X MATRIX AS TO SIMPLIFY THE COMPUTATION INVOLVED, $\hat{B}_4$, $\hat{B}_5$, $\hat{B}_6$, AND $\hat{B}_7$ SHOULD BE TWICE AS LARGE AS THOSE SHOWN IN THE VECTOR ABOVE.

TO ACHIEVE THE OTHER GOAL, WE TEST THE HYPOTHESES

$$H_0 : B_i = 0 \quad \text{vs.} \quad H_1 : B_i \neq 0$$

WHERE $i = 1, \ldots, 7$.

THE GENERAL TEST STATISTIC IS

$$t = \frac{B_i}{s \sqrt{C_{ii}}}$$

WHERE C_{ii} IS THE COEFFICIENT IN THE $(X'X)^{-1}$ MATRIX AND $i = 1, \ldots, 7$.

THE CORRESPONDING t VALUES ARE

$$
\begin{aligned}
t_1 &= 16.69158 \\
t_2 &= 40.18963 \\
t_3 &= 56.81236 \\
t_4 &= -1.46620 \\
t_5 &= -1.35696 \\
t_6 &= -2.48863
\end{aligned}
$$

AND $t_7 = -6.27434$

ALL OF THEM HAVE THE SAME t DISTRIBUTION WITH 24 DEGREES OF FREEDOM.

THE REJECTION REGION FOR THESE TESTS IS

$$|t| \geq 2.064 \text{ AND } |t| \geq 2.797$$

FOR CONFIDENCE COEFFICIENTS $\alpha = 0.05$ AND $\alpha = 0.01$ RESPECTIVELY.

AT SIGNIFICANCE LEVEL 5 PERCENT, REJECT THE HYPOTHESIS THAT $B_1 = 0$, $B_2 = 0$, $B_3 = 0$, $B_6 = 0$ AND $B_7 = 0$, BUT IT SEEMS THAT THE DATA DOES NOT PRESENT SUFFICIENT EVIDENCE TO REJECT $B_4 = 0$ AND $B_5 = 0$.

WE MAY ALSO TEST THE HYPOTHESIS THAT B_5, B_6 AND B_7 SIMULTANEOUSLY EQUAL TO ZERO. SPECIFICALLY,

$$H_0 : B_5 = B_6 = B_7 = 0 \text{ vs. } H_1 : H_0 \text{ NOT TRUE.}$$

TO DO THIS, WE HAVE TO WORK WITH THE REDUCED MODEL

$$Y = B_0 + B_1 X_1 + B_2 X_2 + B_3 X_3 + B_4 X_4 + e,$$

WHERE THE PARAMETERS AND THE VARIABLES ARE DEFINED AS BEFORE.

WE GET THE SUM OF SQUARES SSE* OF THE REDUCED MODEL,

$$SSE^* = 17.45865.$$

A SUM OF SQUARES DUE TO X_5, X_6 AND X_7 ADJUSTED BY THE VARIABLES IN THE REDUCED MODEL MAY BE MEASURED BY A DROP-OFF OF THE AMOUNT OF THE ORIGINAL S S E FROM S S E*,

$$SSE^* - SSE = 11.25658.$$

BASED ON THIS DIFFERENCE, AN ESTIMATE S^{*2} OF σ^2 AND F VALUE ARE OBTAINED,

$$
\begin{aligned}
S^{*2} &= 3.75219 \\
F &= 14.52029
\end{aligned}
$$

F HAS AN F-DISTRIBUTION WITH 3 AND 24 DEGREES OF FREEDOM.

THE REJECTION REGIONS ARE

$|F| \geq 3.01$ AND $|F| \geq 4.72$ FOR $\alpha = 0.05$ AND

$\alpha = 0.01$ RESPECTIVELY.

THE HYPOTHESIS THAT B_4, B_5, B_6 AND B_7 SIMULTANEOUSLY EQUAL TO ZERO MAY BE TESTED IN A SAME WAY.

WE GET

$F = 36.31717.$

THE REJECTION REGIONS ARE

$|F| \geq 2.78$ AND $|F| \geq 4.22$ FOR $\alpha = 0.05$ AND

$\alpha = 0.01$ RESPECTIVELY.

THE DATA PRESENTS EVIDENCE TO INDICATE THAT B_5, B_6 AND B_7 CANNOT SIMULTANEOUSLY EQUAL TO ZERO.

APPENDIX 5

Station	Year	Actual ADT Vol.	Actual DHV Fact.	Predicted DHV Fact. (1)	(2)
1029					
	1948	1507	20.2		
	1955	1973	17.7	17.036	
	1962	2242	15.5	14.712	15.1
1049					
	1957	1017	18.4		
	1964	960	16.1	15.796	16.0
1069					
	1957	1313	12.0		
	1964	1057	11.1	11.083	10.7
1089					
	1957	1605	14.3		
	1964	1992	13.3	12.823	12.5
3069					
	1956	1578	19.6		
	1963	1585	17.4	16.716	17.0
3089					
	1957	1198	26.5		
	1964	931	22.3	21.649	22.6

Station	Year	Actual ADT Vol.	Actual DHV Fcct.	Predicted DHV Fact.	
				(1)	(2)
4029					
	1948	1739	15.1		
	1955	2608	14.4	13.343	
	1962	2872	12.4	12.146	11.7
5189					
	1459	630	15.4		
	1964	805	13.4	14.145	14.0
5209					
	1959	1254			
	1964	1443	12.0	11.544	11.1
6069					
	1948	4130	12.9		
	1955	6190	11.2	11.955	
	1962	7271	11.2	11.276	10.2
6089					
	1959	2635	13.7		
	1964	3041	12.9	12.845	12.6

Station	Year	Actual ADT Vol.	Actual DHV Fact.	Predicted DHV Fact.	
				(1)	(2)
8029					
	1948	3502	12.4		
	1955	4391	11.9	11.455	
	1962	6815	12.1	10.762	9.8
8089					
	1948	6611	13.4		
	1955	8664	12.3	12.399	
	1962	9513	12.6	11.559	10.5
8129					
	1948	3765	11.2		
	1955	4454	10.4	10.507	
	1962	2838	10.3	10.066	9.1
8189					
	1958	11451	12.9		
	1964	16121	10.0	12.180	11.5