

STRIPING METHODS TO REDUCE  
ACCIDENTS AT INTERCHANGES

STATUS REPORT  
BY  
THOMAS M. BATZ

PREPARED BY

NEW JERSEY DEPARTMENT OF TRANSPORTATION  
DIVISION OF RESEARCH AND DEMONSTRATION  
1035 PARKWAY AVENUE  
TRENTON, NJ 08625

IN COOPERATION WITH  
U.S. DEPARTMENT OF TRANSPORTATION  
FEDERAL HIGHWAY ADMINISTRATION

SEPTEMBER, 1991

### NOTICE

The United States Government does not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

### DISCLAIMER STATEMENT

The contents of this report reflect the views of the author who is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the New Jersey Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

1. Report No. FHWA/NJ-91-002-7550		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle Striping Methods to Reduce Accidents at Interchanges - Status Report				5. Report Date September, 1991	
				6. Performing Organization Code	
7. Author(s) Thomas M. Batz				8. Performing Organization Report No. 91-002-7550	
9. Performing Organization Name and Address New Jersey Department of Transportation Division of Research and Demonstration 1035 Parkway Avenue, CN612 Trenton, N.J. 08625				10. Work Unit No. (TRAIS)	
				11. Contract or Grant No. HPR Res. Study #7550	
12. Sponsoring Agency Name and Address Federal Highway Administration U.S. Department of Transportation Washington, D.C. 20418				13. Type of Report and Period Covered Status Report	
				14. Sponsoring Agency Code	
15. Supplementary Notes					
16. Abstract <p>This status report lists the work that has been performed on this project. This includes the literature search, the interchange inventory, the collection of geometric, volume and accident data at cloverleaf interchanges. The report provides a listing of the data and indicates what tasks have not been completed.</p>					
17. Key Words Striping Accidents Volumes			18. Distribution Statement		
19. Security Classif. (of this report) Unclassified		20. Security Classif. (of this page) Unclassified		21. No. of Pages 24	22. Price \$160,000

TABLE OF CONTENTS

	<u>Page Numbers</u>
INTERCHANGE STRIPING STATUS REPORT.....	1
LITERATURE SEARCH.....	2
GEOMETRIC AND VOLUME DATA.....	3
ACCIDENT DATA.....	5
STATUS OF TASKS.....	6
ATTACHMENT A - LITERATURE SYNOPSIS.....	14

LIST OF TABLES AND FIGURES

TABLE 1 - INTERCHANGE STRIPING LIST.....	8
FIGURE 1 - GEOMETRIC DATA.....	10
FIGURE 2 - VOLUME DATA.....	11
FIGURE 3 - ACCIDENT DATA.....	12
FIGURE 4 - ACCIDENT LOCATION STUDY.....	13

## INTERCHANGE STRIPING STATUS REPORT

This status report outlines the work that has been completed to date on the "Striping Methods to Reduce Accidents at Interchanges" Project. Data has been collected on previous interchange striping research, identification of suitable interchanges for study, and geometric, traffic and accident data of these sites.

This research project's primary objective was to develop a more effective ramp merge/diverge striping design. The measures of effectiveness selected were to reduce the number of erratic maneuvers by improving the placement of vehicles entering or exiting the roadway by keeping them in an acceleration lane longer or getting them into a deceleration lane sooner; reduce the speed variance; and reduce the accident occurrence at interchanges. The last section of this report will present a list of items which have already been accomplished and a list of items that have not been performed.

## I. LITERATURE SEARCH

Twenty-four reports have been reviewed and their synopsis is Attachment A. It was found that the behavior of motorists could be modified by changing the delineation. Teply and Nelson (6) reported that certain delineation changes could have beneficial effects on the number of irregular maneuvers, speed, and vehicle placement for the interchange ramps. Many other studies (1, 2, 8, 15, 16, 18, 24) analyzed specific changes to the striping design at interchanges and presented findings that show the effect of the modifications on traffic characteristics.

Potential striping designs were identified from the search. The first of these was the use of colored pavement markings. Roth (18) reported that colored striping had reduced erratic maneuvers and was more readily noticed than conventional striping. Other studies (1, 4, 16, 23) also investigated colored pavement and striping. These showed that coloration may be a problem at night, that fading may also be a major problem, and that a cost/benefit analysis may be needed due to justify any additional cost.

A second possible design is to change the stripe-to-gap ratio. Capelle (8) concluded that increasing the stripe-to-gap ratio would improve driver performance. Although other studies (1, 9, 23, 24) have recommended different stripe-to-gap ratios, none have performed an evaluation to determine their effects.

Wider striping at interchanges is another striping design which has been discussed. Teply and Nelson (6) concluded that wider lines were effective at reducing irregular maneuvers. Wider lines have also been recommended in other studies (1, 7, 9, 10, 23) but none of these actually researched this new design.

Finally, ITE (23) and FHWA (10) have suggested other striping techniques which may improve traffic conditions at interchanges. They include the installation of chevrons at the ramp area, the use of painted arrows in the lane being dropped, and dotted lane lines (15). Although many different interchange striping designs have been considered and recommended for use, none have been analyzed extensively for their effects on traffic characteristics and therefore may become part of this project.

## II. GEOMETRIC AND VOLUME DATA

An inventory of all interchanges on the state highway system was completed with the use of New Jersey's straight line diagrams and highway photologs. An interchange was defined as any location on one roadway where it was grade separated from another roadway and had ramp access to that roadway. Thus a "normal interchange" area between two major roadways would be defined as two interchanges, one for each roadway and its associated ramps. Exactly 200 interchanges on the New Jersey highway system were identified as a result of this inventory.

Due to the need to study locations where traffic would not only be merging but also weaving, it was decided to study only full cloverleaf interchanges. Fifty five full cloverleaf interchanges were identified. However due to certain striping or geometric characteristics, these interchanges also had to be subdivided into five groups which were

- full cloverleafs with full striping in both weave areas,
- full cloverleafs without full striping in at least one weaving area,
- full cloverleafs with no striping in at least one weaving area,
- full cloverleafs with no auxiliary lane in at least one weaving area, and
- full cloverleafs with added ramps or collector/distributor areas.

The list of interchanges in each of these groups is shown as Table 1.

Once these full cloverleaf interchanges were identified, specific geometric and striping data about each location were collected using trips to the locations. The form used in this data collection is shown as Figure 1 and, also, during the visits, photographs were taken of the entire interchange striping plan.

Volume data was the next information needed. Volumes were collected for two hours, one peak and one non-peak, for all

ramps as well as the mainlines in both directions during the evening hours. From this data all merge and weave volumes could be calculated as shown in Figure 2.

### III. ACCIDENT DATA

The procedure for determining the effectiveness of a striping design called for the comparison of the accident rate under today's conditions versus the rate with the new design. Since the geometric and volume data had been collected, what was needed to determine the present condition accident rate was the accident data. This was collected using the Bureau of Traffic Engineering's on-line accident analysis program. This program provided output including total accidents, accidents by type, severity, weather condition, and an accident rate for each interchange area. This data was collected for the years 1983 through 1985. An example of this output is shown in Figure 3.

The next step was to determine which interchanges would be the best for implementation and study of the new striping designs. Although the accident rates and weaving volumes were known for all the interchange areas, it still was not clear which locations would be the best to study. This was due to the fact that we did not know exactly where in the interchange area the present accidents were occurring.

If we look at our example in Figure 3, you can see the calculated accident rate for this interchange. However, questions such as is there a problem in the weave section, are most of the accidents occurring on the ramps, are the

merge-diverge areas a problem, etc. can not be answered with this information. Also because of these unknowns, the effect of the new striping designs could not be anticipated. For example, a new striping design would not reduce the accident rate at an interchange where a large number of accidents are occurring because of a tight turning radius on one or more of the ramps. Therefore an even more specific accident study was initiated. We went to the actual police report for each accident to determine exactly where in the interchange it occurred. With this information, a better decision on which interchanges to study could be made. Figure 4 is an example of the results of this accident location study for one interchange. This step has been performed for approximately 20 of the interchanges under review.

#### IV. STATUS OF TASKS

A. Items which have been produced from this study up to now include:

- the literature search,
- an inventory of state interchanges,
- the geometrics of all full cloverleaves,
- a photographic inventory of all full cloverleaves,
- volume data for all full cloverleaves,
- accident data for all full cloverleaves,
- and detailed accident location data for some full cloverleaves.

B. Items which have not been completed include:

- accident location data for all full cloverleafs,
- selection of interchanges for new striping designs,
- installation of new striping designs,
- accident location study for new design locations,
- volume study for new design locations,
- analysis of all data items,
- recommendations on the effectiveness of striping designs,
- preparation of a final report.

TABLE 1

INTERCHANGE STRIPING LIST

Group 1: Full cloverleafs with full striping in both weave areas (21).

Routes 9 & 37 + Routes 37 & 9  
Routes 18 & 79 + Routes 79 & 18  
Routes 47 & 55 + Routes 55 & 47 (new interchange)  
Routes 70 & 295 + Routes 295 & 70  
Routes 130 & 322 + Routes 322 & 130  
Routes 9 & 195 (O = G2)  
Routes 18 & 66 (O = G3)  
Routes 34 & 18 (O = G2)  
Routes 195 & 130 (O = G2)  
Routes 322 & 54 (O = G4)  
Route 18 & Milltown Road  
Route 29 & Calhoun Street  
Route 38 & Hampton Road  
Route 195 & Lakewood Road  
Route 208 & Goffle Avenue  
Route 295 & Burlington Road

Group 2: Full cloverleafs without full striping in at least one weave area (13).

Routes 73 & 295 + Routes 295 & 73  
Routes 206 & 295 + Routes 295 & 206  
Routes 18 & 34 (O = G1)  
Routes 34 & 195 (O = G3)  
Routes 130 & 195 (O = G1)  
Routes 195 & 9 (O = G1)  
Routes 287 & 1 (O ≠ CL)  
Route 1 and Ryder's Lane  
Route 17 and Glen Avenue  
Route 195 and Yardville Avenue  
Route 295 and Florence Road

Group 3: Full cloverleafs with no striping in at least one weave area (10).

Routes 1 & 35 + Routes 35 & 1  
Routes 56 & 55 (O = G5)  
Routes 66 & 18 (O = G1)  
Routes 195 & 34 (O = G2)  
Routes 322 & 50 (O = G4)  
Route 1 and Milltown Road  
Route 70 and Cuthbert Avenue  
Route 280 and Eisenhower Parkway  
Route 280 and Livingston Avenue

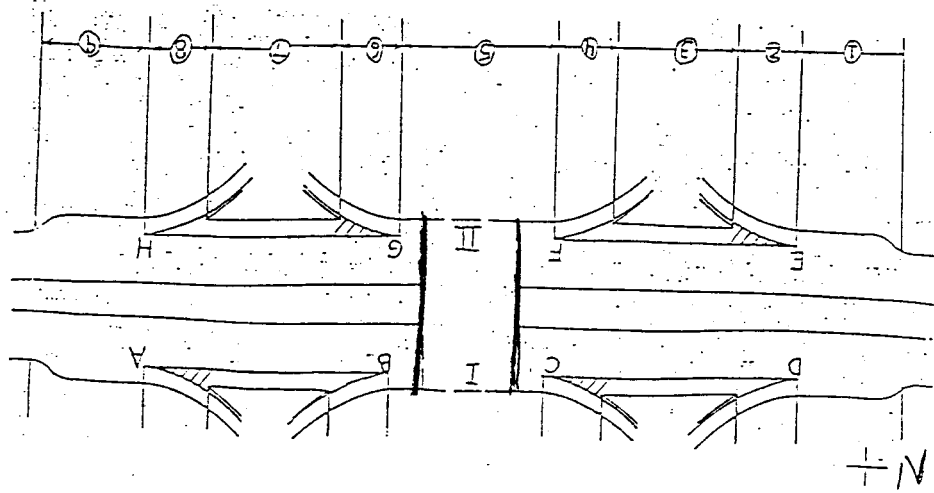
Group 4: Full cloverleafs with no auxiliary lane in at least one weave area (6).

Routes 17 & 4 (O = G5)  
Routes 50 & 322 (O = G3)  
Routes 54 & 322 (O = G1)  
Routes 30 & 73 (O = G5)  
Route 38 and Haddonfield-Sorcel Horse Road  
Routes 130 & 44 (O ≠ CL)

Group 5: Full cloveleafs with added ramps or collector/distributor areas (5).

Routes 4 & 17 (O = G4)  
Routes 55 & 56 (O = G3)  
Routes 73 & 30 (O = G4)  
Route 17 and Allendale Avenue  
Route 208 and Maple Avenue

# INTERCHANGE STRIPING



Rts. 18 + 79  
 Mile Post 25.1  
 Median Gross 20'  
 Pavement Type F-1

Direction	1	2	3	4	5	6	7	8	9
N/B DMI Length	3980	3685	2585	2151	2056	1744	1626	1195	1061
# of lanes	3	2	2	2	2	2	2	2	2
Shoulder	N	N	V	N	N	N	N	N	N
S/B DMI Length	1037	1191	1616	1732	2066	2449	2590	3036	3688
# of lanes	3	2	2	2	2	2	2	2	2
Shoulder	N	N	V	N	N	N	N	N	N

GORE	A	B	C	D	E	F	G	H
LANE LINES %/N	V	V	V	N	V	V	V	N
LANE LINE WIDTH (INCHES)	4"	4"	4"	-	4"	4"	4"	-
LANE LINE LENGTH (FT/PL)	PL	F	FL	-	FL	FL	FL	-
CROSS-HATCHED %/N	V	N	V	N	V	N	V	N
OTHER %/N	-	-	-	-	-	-	-	-
GORE WIDTH (INCHES)	3	3	3	3	3	3	3	3

WEAVE AREA	LANE LINES %/N	Width (")	Length (ft)
I	V	4"	FL
II	V	4"	FL

LIGHTING UNITS	# LOW MAST	# HIGH MAST	BRIDGE	TOTAL
Lower Roadway	20	-	-	20
Upper Roadway	0	0	0	0

Figure 1 - Geometric Data

Notes:

DATE: 4-13-87 5:30-6:30

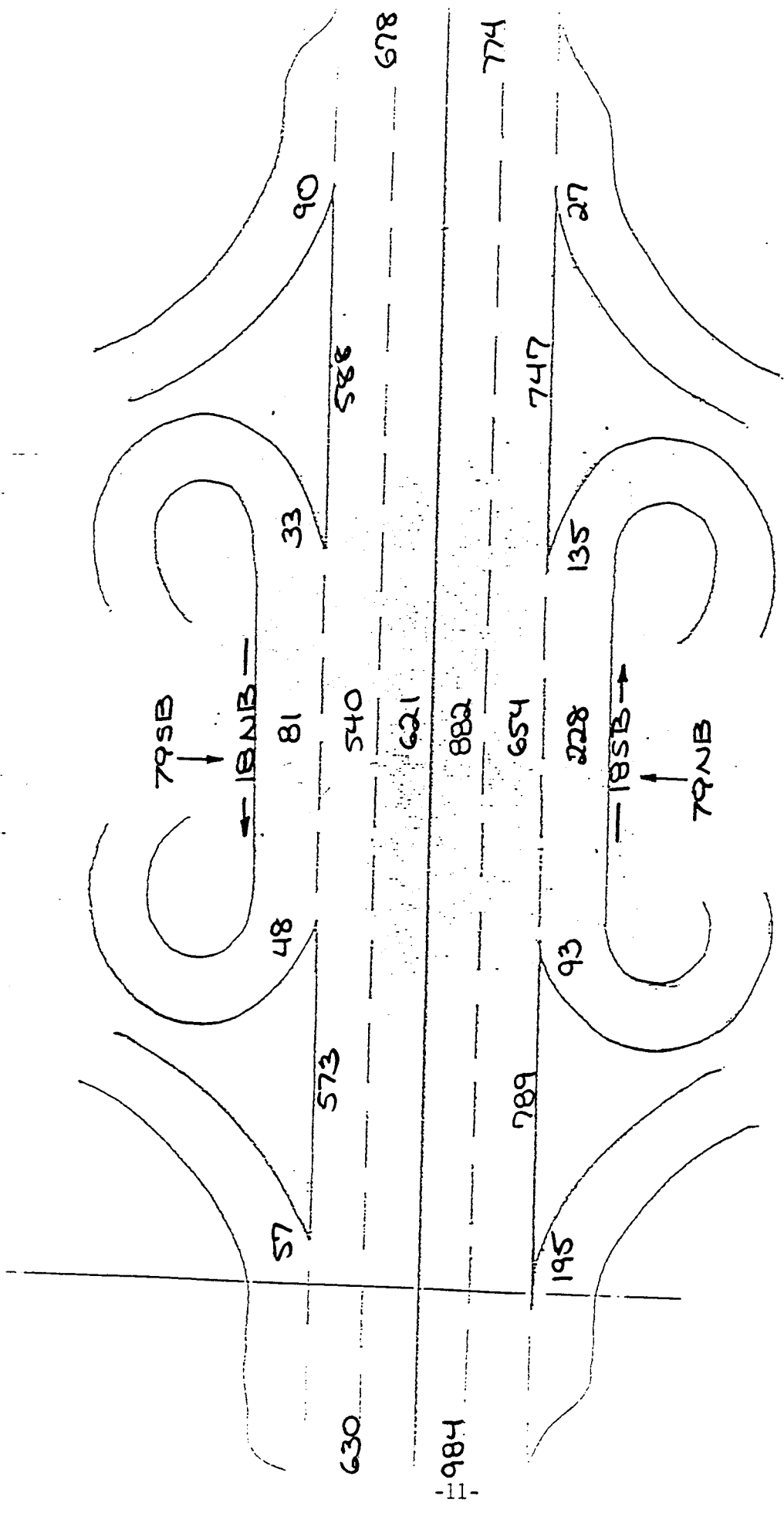


Figure 2 - Volume Data

ACCIDENT SUMMARY FOR ROUTE 004 **RT. 17**  
 FROM MILEPOST 3.22 TO MILEPOST 3.48  
 FOR TIME PERIOD 01/01/83 THROUGH 12/31/85  
 RESTRICTIONS NONE

259	TOTAL ACCIDENTS	240	99.2%	-AT INTER.	0F
10	10% FATAL	2	.8%	-BET. INTER.	0F
133	34.8% INJURY	0	.0%	-RR CROSSING	0F
	25.2% PROP. DAMAGE				
206	82.4% SAME DIRECT.	182	72.5%	-DRY	0F
10	4.0% ANGLE	53	22.4%	-WET SURF.	0F
2	.8% LEFT-TURN	9	3.6%	-SNOW OR ICE	0F
2	.8% HOVER-TURN	3	1.2%	-UNKNOWN, OTHER	0F
1	.4% OVER-TURNED				
2	.8% PEDESTRIAN	183	73.2%	-DAY	0F
23	9.2% FIXED OBJ.	66	26.4%	-NIGHT, DAWN, DUSK	0F
0	.0% ANIMAL	1	.4%	-UNKNOWN	0F
1	.4% PARKED VEH.				
0	.0% PEDALCYCLE				
5	2.0% OTHER TYPES	0	0%	-UNLOCATABLE WITHIN MUNIC	0F

VM READ

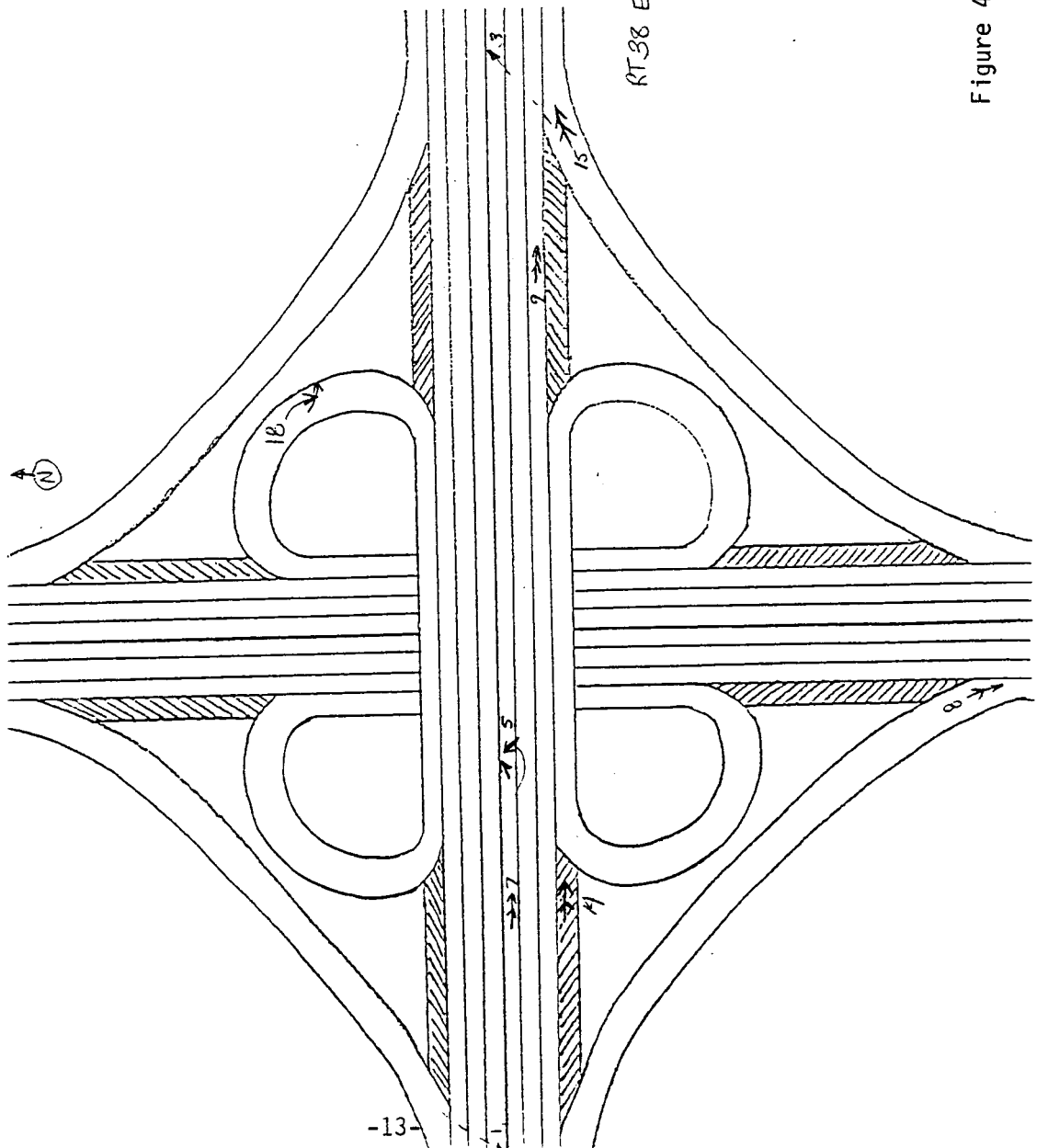
AVERAGE DATA FOR ROUTE 004 FROM MILEPOST 003.22 TO MILEPOST 003.48  
 FOR TIME PERIOD 01/01/83 THROUGH 12/31/85

RESTRICTIONS NONE  
 ACCIDENT RATE = ACC/MVM  
 (VAL. AND CROSS-SECTN. DATA BASED ON MOST RECENT YR. AVAILABLE IN THIS PROGRAM)

A.P. TO	N.P.	SECTION LENGTH	ADOT	COUNTY	CROSS-SECTION	ROADWAY	NUMBER OF ACCIDENTS	CALC. ACC. RATE
3.02	3.31	.29	93757	02	4L; R; NO SHOULDER	4L; R; NO SHOULDER	20	2.16
3.31	3.45	.14	93757	02	4L; R; NO SHOULDER	4L; R; NO SHOULDER	220	15.29
3.45	3.55	.10	93757	02	4L; R; NO SHOULDER	4L; R; NO SHOULDER	10	3.24
( .26 MI.) ACC. RATE FOR ROADWAY CROSS-SECTN., 4L, R, NO SHOULDER								9.36
OVERALL ACCIDENT RATE								9.36

(HIT ENTER TO CLEAR SCREEN)  
VM READ

Figure 3 - Accident Data



Rt. # 38 E, Hampton N.  
 mp. 1.15 - 1.65  
 county CAMDEN  
 twp. MERRY HILL  
 year 1983 - Book # 6

month	# of accidents
1	0
2	4
3	1
4	2
5	1
6	4
7	2
8	2
9	0
10	1
11	2
12	3
tot.	22

Figure 4 - Accident Location Study

## ATTACHMENT A - LITERATURE SYNOPSIS

1. Roadway Delineation Systems, J. I. Taylor, E. L. Sequin, and R. S. Hostetter, NCHRP Report No. 130, 1972.

This report looked into delineation at interchanges. Treatments looked into were color coding, raised pavement markers and striping alternatives. Results showed color coding the pavement has the following problems: lack of agreement on color use, colors not effective at night and fade with time, materials are expensive, and effectiveness as delineation treatment has not been adequately demonstrated. Raised pavement markers have been shown to be an excellent treatment for diverge gore area. Pavement paint marking suggestions include 8-12" wide gore markings and 8" wide markings with 10 ft. mark and 10 ft. gap separating through lanes and acceleration-deceleration lanes.

2. Traffic Operation at Two interchanges in California, L. Newman, Highway Research Record No. 27, 1963.

This study evaluated the effects of a method of striping a weaving section that was intended to encourage greater use of the auxiliary lane. It consisted of a solid stripe to guide vehicles into a position parallel to the main freeway lanes and a dashed lane stripe to encourage vehicles to stay in the auxiliary lane a longer period of time, thus permitting merging at a flatter angle and higher speed. Results showed that a significantly greater number of on ramp vehicles used the weaving lane more extensively,

approach speeds did not vary significantly, fewer on ramp vehicles stopped prior to merging into lane one, and actual capacity may have increased.

3. Driver Performance Related to Interchange Marking and Nighttime Visibility Conditions, J. P. E. Darrell and M. D. Dunnette, Highway Research Board Bulletin 255, 1960.

Through driver interviews, different illumination levels and methods of delineation were studied. Results showed that "full illumination" and "experimental reflectorization" appeared equally effective in reducing the incidence of driver difficulty in transversing the interchange.

4. Unified Reflective Sign, Pavement, and Delineation Treatments for Night Traffic Guidance, Joseph T. Fitzpatrick, Highway Research Board Bulletin 255, 1960

This report discussed the color coding of pavement, signs, and delineators for Reference 3. It states that both yellow and blue surfaces when first installed were much brighter than ordinary pavement surface, but no data on life of this increased luminance was shown.

5. East Los Angeles Interchange Operation Study, Roger T. Johnson and Leonard Newman, Highway Research Record No. 244, 1968

This report dealt with restriping two major interchanges in the Los Angeles area. The conclusions reached were that when two major freeways meet, channelizing traffic can be extremely important and transversible pavement markings during congested periods

are used by some traffic causing an increase in capacity. Also, striping that is less restrictive, and therefore, more flexible in meeting variable demands, will result in less delay than striping that attempts to divide up the approach roadways in proportion to forecast overall demand.

6. Evaluation of Pavement Marking Patterns for Merging and Diverging Areas, S. Teply and T. Nelson, Canada, 1980

This report deals with a three part study of interchange striping. First, the gore areas were striped normally with 10 cm. stripe width. Then, the edge and continuity lines were made 10 cm. wide with some of the continuity lines closed and, finally, these lines were made 30 cm. wide. The results were that wider lines were better at stopping irregular maneuvers. Also, that open continuity lines caused a more uniform speed pattern at both on and off ramps and a more uniform placement of vehicles at on ramps while closed continuity lines cause a more uniform placement at off ramps. One problem with this study is that all three patterns were implemented and studied within a four month period. This may not have been enough time for the motorists to get accustomed to the changes. Other factors which this project noted for future research were line/gap ratio, pattern of gore chevrons, line/gap separation pattern, and arrows and symbols.

7. Roadway Delineation Practices Handbook, I. J. Fullerton, JHK & Associates, 1981

This report presented the present day practices of roadway delineation. Although it mainly discussed the

application procedures for delineation devices, the report does state that eight inch lines should be used in gore areas and in markings between a freeway through lane and auxiliary or exit lane.

8. An Overview of Roadway Delineation Research, D. G. Cappelle, Voorhees and Associates, Inc., June 1978

This report contained results of major delineation studies from across the country. Findings of these studies which concerned interchange striping included: increasing the stripe-to-gap ratio will improve steering performance; the variability of lateral placement is the best performance measure for effectiveness of a delineation system; there is considerable skepticism that a good relationship between accidents and small changes in delineation treatments can be found; and there is a general consensus that there is a lack of good information regarding the safety aspects of delineation.

9. State of the Art on Roadway Delineation Systems, S.G. Bali, H.W. McGee, and J. I. Taylor, Science Applications, Inc., May 1976

This report deals with the state of the art of roadway delineation systems and is considered an update of NCHRP report 130 (1). At interchanges, it recommends that at a parallel type deceleration lane, a 3' skip line to 10' gap dotted line could be used from the beginning of the taper up to the full width of the deceleration lane; the dotted line would then change to 10' skip line to 10' gap up to 200' before the physical exit gore; from there to the gore

a solid line would be introduced. The reverse of this pattern is suggested for acceleration lanes. Other recommendations include 8 or 12 inch lines for gore markings and zebra striping (within gore lines) seems not to be cost effective.

10. Manual on Uniform Traffic Control Devices, National Advisory Committee on Uniform Traffic Control Devices, 1978

This manual is the guide most traffic engineers in the U.S. use for delineation. It recommends use of regular skip lines for one-half the length of full acceleration and deceleration lanes. For deceleration lanes, extended dotted lane lines are allowed. Also, chevrons at exit gores are allowed. It notes that doubling the width of a lane line in gore areas also is appropriate.

11. Effect of Raised Pavement Markers on Traffic Performance, William Mallowney, New Jersey Department of Transportation, 1982

This study found that raised pavement markers could significantly reduce the instances of erratic maneuvers through painted gore areas at exits. However, they did not cause drivers to enter the deceleration lanes any earlier.

12. Improving Traffic Operations and Safety at Exit Gore Areas, James I. Taylor and Hugh W. McGee, NCHRP Report 145, 1973

This report did an erratic maneuver study and driver interview study at exit gores. Its findings were that an erratic maneuver rate of 0.2 percent is an indication that corrective treatments should be considered; delineation of the deceleration lane and gore areas can improve traffic

operations and safety at freeway exits during periods of darkness. Gore delineation, including post delineation and RPM, can result in fuller use of the deceleration lane and assist the through motorists in identifying the main line.

13. The Relationship of Accidents to Length of Speed-Change Lanes and Weaving Areas on Interstate Highways, J. A. Cirillo, HRR #313, 1970

This study stated that increasing the length of a weave area or an accel or decel lane would decrease the accident rate. Included were Tables comparing length of these three areas to volumes or percentage of merging traffic to accident rates for existing locations. One problem seen with this approach however, is the use of percentages instead of volume. An actual decrease in total volume would increase the percentage of merging traffic. The Tables would suggest an increase in accidents would probably decrease.

14. Freeway Lane Drops, D. N. Goodwin, NCHRP Report 175, 1976

This study dealt with five types of lane drops, two of which are of interest to our study. The first, a lane drop at an exit gore, was found to need an escape area with adequate dimensions to allow for a smooth transition into through lanes. The other, adding a lane between an on and an off ramp, was found to need adequate notification to the driver that the lane is not a through lane. This could be accomplished by contrasting pavement, special-purpose lane delineations or signing.

15. The Effect of Dotted Extended Lane Lines on Right, Single Deceleration Lane Use, W. P. Keck and A. W. Roberts, NJDOT, January 1978

This study looked at the effect of extending the dotted lane line at a decel lane. Two foot lines with 25 foot spacings were placed at five parallel decel lanes and 5 tapered decel lanes on Interstate freeways. Before and after studies were performed and the results were that the dotted extension was more effective than no dotted line in orienting exiting traffic into the decel lane sooner. Also, the dotted line had no effect on vehicles crossing the painted gore.

16. Red Colored Pavement, D. W. Gwynn and J. Seifert, NJDOT, January 1968

A ramp ending with a stop sign was repaved with a red pigment in the mixture to determine the effect of pavement color on various driver characteristics. Before and after measurements of speed, gap acceptance and rejection and disregard of stop sign were made. Results showed that during the day, speeds were reduced approaching the stop sign. At night, however, no change was observed. The probable cause of this was that the color was not discernible at night. The other measures also showed no statistically significant change.

17. Red Colored Pavement: Evaluation of Material, NJDOT, November 1969

This study evaluated the colored pavement material which was applied during the study discussed in reference

16. The red colored pavement performed well in the areas of material durability and skid resistance. However, the reflectometer readings showed higher readings as time passed. This data reinforced the visual observation that the red colored pavement had faded.

18. Interchange Ramp Color Delineation and Marking Study, W. J. Roth, Michigan Department of State Highways, 1970 HRR # 325

On US-23, 18 interchange ramp areas in one direction were color coded. At entrance ramps yellow edgelines and delineators were used while at exit ramps, blue 8" edgelines, delineators, and background signs were used. Results showed a significant reduction in erratic maneuvers especially at other than diamond ramps. The color code was as effective at night as during the day. Edge markings were noticed 5 to 11 times more with color coding. Accidents were not directly relatable to the color codes; however, the increase in accidents in non-color-coded direction was three times higher than the color coded direction. Thus the study concluded that color coding eases the driver's task by presenting a better delineated, more easily understood path, while possibly producing fewer accidents.

19. Highway Design and Operational Practices Related to Highway Safety, American Association of State Highway and Transportation Officials, 1974.

This report discusses the recommendations of the AASHTO Safety Committee concerning the various aspects of highway design and practices in relation to safety. For interchanges, it talks about patterns, spacings, gore areas, cross street effects, frontage roads, lane drops, and route continuity, along with a separate discussion on entrance, exit, and slip ramps. It also discusses pavement markings and delineation. It states that the MUTCD striping patterns are the accepted standards.

20. Interchange Accident Exposure, S.M. Breuning and A. J. Bone, HRR Bulletin 240, 1959

This report comes up with a new exposure rate for accidents at interchanges. Instead of the rate per million vehicle miles, the new rate would be based on the volumes travelling through the interchange and the exposure interval. With this new exposure index, the accident rates for different designs easily become comparable so that a direct analysis can be accomplished.

21. Vehicle Operating Characteristics on Outer Loop Deceleration Lanes of Interchanges, M. M. Davis and K. M. Williams, 1968

This study used a movie camera to record lateral placement, longitudinal placement, headway speeds, and deceleration rates of vehicles using six exit ramps. The findings were that approximately 90% of all exiting vehicles begin to enter the deceleration lane before the end of the taper. However, only 90% were entirely in the deceleration lane by the end of the tangent section of the

ramp. Approximately 5% of the vehicles were traveling at headways of 1 second or less. A major conclusion is that drivers aim for the inside edge of the curve at the end of the deceleration lane rather than using the decel lane as designed.

22. Traffic Control and Roadway Elements - Their Relationship to Highway Safety/Revised - Chapter 9 - Interchanges, J. C. Oppenlander and R. F. Dawson, 1970

This study reported on accidents relationship with interchange design elements. The findings are that the safer designs are main freeway passing over the minor facility and ramp terminals at least 750 feet from the structure. On ramps are a problem in urban areas, with off ramps a problem in rural areas. Decel, accel, and weaving areas of at least 800 feet reduce accidents if adequate sight distance is available. The report did not discuss markings.

23. Current Practice of Application of Traffic Control Devices at Freeway, Lane Drops, ITE Technical Council Committee 4D-A, Traffic Engineering, Nov. 1976

This study included a survey of the states on their procedures for lane drops. Most of the findings dealt with signing. However, a few responses dealt with pavement markings. For example, contrasting color and diagonal arrows were mentioned as options which may improve the lane drop problem. Also, after a literature search, the following pavement markings were suggested for research: painted arrows in the lane being dropped, heavy yellow

zebra-stripes in the taper area of width reductions, use of eight inch wide line with equal gap to stripe spacing on approaches to the lane drop ramp situation, and colored pavements.

24. Is Delineation Needed? R. N. Schwab and D. G. Capelle, ITE Journal, May 1980

This report looked at accident analysis data for striping, raised pavement markers, and post mounted delineators. It concluded that edgelines reduce accidents on two lane roadways and that the gap to stripe ratio of 3:1 is adequate for most roadways but may need to be supplemented in hilly or mountainous terrain.