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COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF TRANSPORTATION

PENNDOT RESEARCH

MEDIAN SAFETY STUDY (INTERSTATES AND EXPRESSWAYS)

University-Based Research Education and Technology Transfer
AGREEMENT NO. 359704, WORK ORDER 53

APPENDICES, VOLUME II

JUNE 2001

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16. Abstract

According to the Pennsylvania Department of Transportation's (PENNDOT's) current median barrier guidelines, barrier is not warranted if the median width exceeds ten meters or the average daily traffic is less than 20,000 vehicles, unless there is a significant history of cross median crashes. Over the last five years (1994-1998), there have been 267 cross-median collisions (constituting 55 deaths) on Pennsylvania Interstates and expressways. Research was needed to evaluate median safety in Pennsylvania including the relationship between cross-median collisions and median widths on Interstates and expressways.

The findings indicate that cross-median collisions are rare events on Pennsylvania Interstates and expressways. Despite the low frequency of CMC crashes, they are an important safety concern because, when such crashes occur, they are very severe events. Approximately 15 percent of CMC crashes involve fatalities and another 72 percent involve nonfatal injuries. By contrast, all crashes on the same segments involve only 1 percent fatalities and 52 percent nonfatal injuries.

PENNDOT should continue to determine median barrier warrants based on their current policy until a more extensive evaluation of crashes involving collisions with median barriers can be completed. In addition, PennDOT should evaluate the need to install median barriers in wider medians. PENNDOT should establish a monitoring program to identify the median-related crashes on particular segments or routes. Lastly, PENNDOT should consider revisions to its roadway inventory database to make it easier to use in evaluating median-related crashes.

This report is presented in two volumes. Volume I contains the final report. Volume II contains the appendices.

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MEDIAN SAFETY STUDY (INTERSTATES AND EXPRESSWAYS)

University-Based Research, Education and Technology Transfer Program
Agreement No. 359704
Work Order 53

APPENDICES, VOLUME II

Prepared for

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PTI 2001-32 (II)

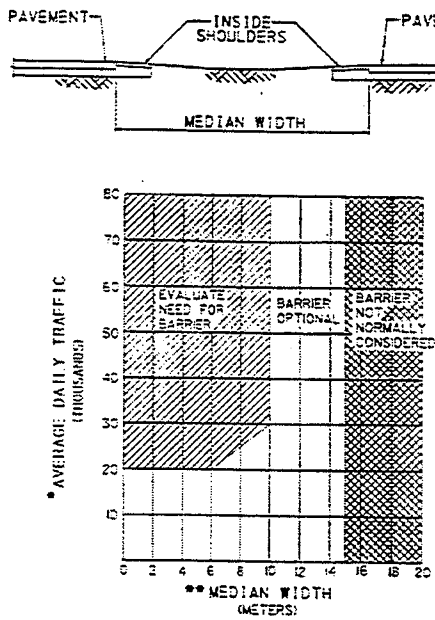
APPENDICES

APPENDIX A

QUESTIONAIRE 1

Pennsylvania Median Safety Study (Interstates and Expressways)
Questionnaire 1

1. The Pennsylvania Department of Transportation's guidelines for evaluating the need for median barrier take into account such factors as median width and five-year projected traffic volumes and these guidelines are presented in Figure 1. According to PENNDOT's current median barrier guidelines, barrier is not warranted if the median width exceeds ten meters or the average daily traffic is less than 20,000 vehicles per day, unless there is a significant history of cross median crashes. Over the last five years, there have been more than 300 crossover crashes (80 deaths) on Pennsylvania's interstates and expressways. Based on your experience, what factors (other than median width, traffic volumes, and accident history) influence the median crossover crash problem?



* BASED ON A 5-YEAR PROJECTION AFTER CONSTRUCTION.

** MEASURED FROM EDGE OF PAVEMENT TO EDGE OF PAVEMENT AND INCLUDES BOTH INSIDE SHOULDERS.

Factors (respond in text box below)

Figure A-1. PENNDOT Median Barrier Warrant Criteria.

2. a.) Based on the Barrier Optional portion of figure 1, is there a specific median width-ADT combination that would require median barrier?

___ Yes; if so, what is the combination? ______________________________

___ No

b.) Based on the Barrier Not Normally Considered portion of figure 1, is there a specific median width-ADT combination(s) that would require median barrier?

___ Yes; if so, what is the combination? ______________________________

___ No

3. Based on the problem stated in question #1, what highway geometric elements (if any) contribute to median crashes?

4. PENNDOT suggests that median barrier is not warranted if the median width exceeds ten meters or the average daily traffic is less than 20,000 vehicles per day, unless there is a significant history of cross median crashes. What do you consider a significant history of cross median crashes?

5. The American Association of State Highways and Transportation Officials *Roadside Design Guide* (1996) states that recoverable slopes are all embankment slopes 4 to 1 or flatter. Traversable slopes are generally categorized as 3 to 1 or flatter.

a. Do you think that the recoverable slope definition is precise?

___ Yes

___ No

If you answered no, why?

b. Do you think that the traversable slope definition is precise?

___ Yes

___ No

If you answered no, why?

6. There are many studies relating cross-sectional elements (i.e., lane widths, shoulder widths, and pavement cross-slopes) to safety on two-lane, rural highways. Table 1 lists cross-sectional elements¥please indicate with an X which, if any, of these can contribute to median crossover crashes. If you indicate that one or more of these factors can contribute to median crossover crashes, please specify how in the space provided in table 1.

Table A-1. Cross-Sectional Element Consideration.

Cross-Sectional Element	**Can Element Contribute to Median Crossover Crash?**	**Reason for Contributing to Median Crossover Crash**
Lane Width		
Shoulder Width		
Pavement Cross-slope		

7. The median safety literature offers little insight on the effect of vehicle mix (percentage of heavy vehicles) as it relates to crossover crashes. Please comment on the significance of vehicles with differing operational characteristics and their implications on median safety.

8. Tables 2-13 contain different median configuration scenarios. In the table there are seven median barrier types each with an approximate deflection distance. Each median configuration consists of a median width (measured from the inside edges of the traveled way on a divided highway to include both inside shoulders), average daily traffic, and median cross slope. Please indicate with an X which barrier type(s) you would consider the most cost-effective and safest in preventing a crossover crash. For each barrier type that you considered, where in the median would you place it (edge of shoulder, on median slope, center of median)? **Note: If you indicated that a barrier should be located on the median slope, where on the slope would you locate it?**

Table A-2. Median Configuration Scenario 1.

Median Width	ADT	Median Slope	Barrier Type	Deflection	Which type(s) do you recommend? Please indicate with "X"	Barrier Placement (Edge of Shoulder, On Slope, Center of Median)?	Where on slope?
10-15 meters (33-50 feet)	20,000-40,000	6:1 or flatter	Three-Strand Cable	3.5 m (11.5 ft.)			
			Weak Post W-Beam	2.1 m (7 ft.)			
			Box Beam	0.9 m (3 ft.)			
			Strong Post W-Beam	0.6-1.2 m (2 - 4 ft.)			
			Strong Post Thrie Beam	0.3 -0.9 m (1 - 3 ft.)			
			Concrete Safety Shape	0 m (0 ft.)			
			Earth Berm	N/A			

Table A-3. Median Configuration Scenario 2.

Median Width	ADT	Median Slope	Barrier Type	Deflection	Which type(s) do you recommend? Please indicate with "X"	Barrier Placement (Edge of Shoulder, On Slope, Center of Median)?	Where on slope?
10-15 meters (30-50 feet)	>40,000	6:1 or flatter	Three-Strand Cable	3.5 m (11.5 ft.)			
			Weak Post W-Beam	2.1 m (7 ft.)			
			Box Beam	0.9 m (3 ft.)			
			Strong Post W-Beam	0.6-1.2 m (2 - 4 ft.)			
			Strong Post Thrie Beam	0.3 -0.9 m (1 - 3 ft.)			
			Concrete Safety Shape	0 m (0 ft.)			
			Earth Berm	N/A			

Table A-4. Median Configuration Scenario 3.

Median Width	ADT	Median Slope	Barrier Type	Deflection	Which type(s) do you recommend? Please indicate with "X"	Barrier Placement (Edge of Shoulder, On Slope, Center of Median)?	Where on slope?
>15 meters (>50 feet)	40,000-60,000	6:1 or flatter	Three-Strand Cable	3.5 m (11.5 ft.)			
			Weak Post W-Beam	2.1 m (7 ft.)			
			Box Beam	0.9 m (3 ft.)			
			Strong Post W-Beam	0.6-1.2 m (2 - 4 ft.)			
			Strong Post Thrie Beam	0.3 -0.9 m (1 - 3 ft.)			
			Concrete Safety Shape	0 m (0 ft.)			
			Earth Berm	N/A			

Table A-5. Median Configuration Scenario 4.

Median Width	ADT	Median Slope	Barrier Type	Deflection	Which type(s) do you recommend? Please indicate with "X"	Barrier Placement (Edge of Shoulder, On Slope, Center of Median)?	Where on slope?
>15 meters (>50 feet)	>60,000	6:1 or flatter	Three-Strand Cable	3.5 m (11.5 ft.)			
			Weak Post W-Beam	2.1 m (7 ft.)			
			Box Beam	0.9 m (3 ft.)			
			Strong Post W-Beam	0.6-1.2 m (2 - 4 ft.)			
			Strong Post Thrie Beam	0.3 -0.9 m (1 - 3 ft.)			
			Concrete Safety Shape	0 m (0 ft.)			
			Earth Berm	N/A			

Table A-6. Median Configuration Scenario 5.

Median Width	ADT	Median Slope	Barrier Type	Deflection	Which type(s) do you recommend? Please indicate with "X"	Barrier Placement (Edge of Shoulder, On Slope, Center of Median)?	Where on slope?
3 meters (10 feet)	≥20,000	Flatter than 4:1 & Steeper than 6:1	Three-Strand Cable	3.5 m (11.5 ft.)			
			Weak Post W-Beam	2.1 m (7 ft.)			
			Box Beam	0.9 m (3 ft.)			
			Strong Post W-Beam	0.6-1.2 m (2 - 4 ft.)			
			Strong Post Thrie Beam	0.3 -0.9 m (1 - 3 ft.)			
			Concrete Safety Shape	0 m (0 ft.)			
			Earth Berm	N/A			

Table A-7. Median Configuration Scenario 6.

Median Width	ADT	Median Slope	Barrier Type	Deflection	Which type(s) do you recommend? Please indicate with "X"	Barrier Placement (Edge of Shoulder, On Slope, Center of Median)?	Where on slope?
6-10 meters (20-33 feet)	20,000-30,000	Flatter than 4:1 & Steeper than 6:1	Three-Strand Cable	3.5 m (11.5 ft.)			
			Weak Post W-Beam	2.1 m (7 ft.)			
			Box Beam	0.9 m (3 ft.)			
			Strong Post W-Beam	0.6-1.2 m (2 - 4 ft.)			
			Strong Post Thrie Beam	0.3 -0.9 m (1 - 3 ft.)			
			Concrete Safety Shape	0 m (0 ft.)			
			Earth Berm	N/A			

Table A-8. Median Configuration Scenario 7.

Median Width	ADT	Median Slope	Barrier Type	Deflection	Which type(s) do you recommend? Please indicate with "X"	Barrier Placement (Edge of Shoulder, On Slope, Center of Median)?	Where on slope?
10 meters (33 feet)	≥30,000	Flatter than 4:1 & Steeper than 6:1	Three-Strand Cable	3.5 m (11.5 ft.)			
			Weak Post W-Beam	2.1 m (7 ft.)			
			Box Beam	0.9 m (3 ft.)			
			Strong Post W-Beam	0.6-1.2 m (2 - 4 ft.)			
			Strong Post Thrie Beam	0.3 -0.9 m (1 - 3 ft.)			
			Concrete Safety Shape	0 m (0 ft.)			
			Earth Berm	N/A			

Table A-9. Median Configuration Scenario 8.

Median Width	ADT	Median Slope	Barrier Type	Deflection	Which type(s) do you recommend? Please indicate with "X"	Barrier Placement (Edge of Shoulder, On Slope, Center of Median)?	Where on slope?
3 meters (10 feet)	≥20,000	Flatter than 6:1	Three-Strand Cable	3.5 m (11.5 ft.)			
			Weak Post W-Beam	2.1 m (7 ft.)			
			Box Beam	0.9 m (3 ft.)			
			Strong Post W-Beam	0.6-1.2 m (2 - 4 ft.)			
			Strong Post Thrie Beam	0.3 -0.9 m (1 - 3 ft.)			
			Concrete Safety Shape	0 m (0 ft.)			
			Earth Berm	N/A			

Table A-10. Median Configuration Scenario 9.

Median Width	ADT	Median Slope	Barrier Type	Deflection	Which type(s) do you recommend? Please indicate with "X"	Barrier Placement (Edge of Shoulder, On Slope, Center of Median)?	Where on slope?
6-10 meters (20 feet)	20,000-30,000	Flatter than 6:1	Three-Strand Cable	3.5 m (11.5 ft.)			
			Weak Post W-Beam	2.1 m (7 ft.)			
			Box Beam	0.9 m (3 ft.)			
			Strong Post W-Beam	0.6-1.2 m (2 - 4 ft.)			
			Strong Post Thrie Beam	0.3 -0.9 m (1 - 3 ft.)			
			Concrete Safety Shape	0 m (0 ft.)			
			Earth Berm	N/A			

Table A-11. Median Configuration Scenario 10.

Median Width	ADT	Median Slope	Barrier Type	Deflection	Which type(s) do you recommend? Please indicate with "X"	Barrier Placement (Edge of Shoulder, On Slope, Center of Median)?	Where on slope?
10 meters (33 feet)	≥30,000	Flatter than 6:1	Three-Strand Cable	3.5 m (11.5 ft.)			
			Weak Post W-Beam	2.1 m (7 ft.)			
			Box Beam	0.9 m (3 ft.)			
			Strong Post W-Beam	0.6-1.2 m (2 - 4 ft.)			
			Strong Post Thrie Beam	0.3 -0.9 m (1 - 3 ft.)			
			Concrete Safety Shape	0 m (0 ft.)			
			Earth Berm	N/A			

Table A-12. Median Configuration Scenario 11.

Median Width	ADT	Median Slope	Barrier Type	Deflection	Which type(s) do you recommend? Please indicate with "X"	Barrier Placement (Edge of Shoulder, On Slope, Center of Median)?	Where on slope?
>23 meters (75 feet)	> 60,000	6:1 or flatter	Three-Strand Cable	3.5 m (11.5 ft.)			
			Weak Post W-Beam	2.1 m (7 ft.)			
			Box Beam	0.9 m (3 ft.)			
			Strong Post W-Beam	0.6-1.2 m (2 - 4 ft.)			
			Strong Post Thrie Beam	0.3 -0.9 m (1 - 3 ft.)			
			Concrete Safety Shape	0 m (0 ft.)			
			Earth Berm	N/A			

Table A-13. Median Configuration Scenario 12.

Median Width	ADT	Median Slope	Barrier Type	Deflection	Which type(s) do you recommend? Please indicate with "X"	Barrier Placement (Edge of Shoulder, On Slope, Center of Median)?	Where on slope?
11 meters (36 feet)	20,000-35,000	6:1 or flatter	Three-Strand Cable	3.5 m (11.5 ft.)			
			Weak Post W-Beam	2.1 m (7 ft.)			
			Box Beam	0.9 m (3 ft.)			
			Strong Post W-Beam	0.6-1.2 m (2 - 4 ft.)			
			Strong Post Thrie Beam	0.3 -0.9 m (1 - 3 ft.)			
			Concrete Safety Shape	0 m (0 ft.)			
			Earth Berm	N/A			

9. Have you ever directly dealt with or know of a tort claim that suggested median barrier warrant guidelines were either incorrectly or inappropriately applied?

___ Yes
___ No

If yes, what was the claim and what was the final outcome of the claim?

10. Have you ever directly dealt with or know of an instance where a tort claim was brought against a design professional or organization where the basis of the claim involved incorrect median design?

___ Yes
___ No

If yes, what was the claim and what was the final outcome of the claim?

11. Please indicate which of the following best describes your organizational affiliation.

___ Private
___ Federal Government
___ State Government
___ University/Research Institution
___ Local Government
___ Manufacturer/Supplier
___ Other (please specify) ________________________________

12. How many years experience do you have in the area of highway safety? __________

13. Do you have experience studying the characteristics of median crossover crashes?

___ Yes; if so, what was your experience? ______________________________

___ No

14. Please indicate your name, title, address, telephone number, and e-mail address (if applicable in the space provided). This information will be kept strictly confidential and will only be used if we need to contact you regarding a specific response to a question.

Name: ______________________________

Title: ______________________________

Address: ______________________________

____

____

Phone: ______________________________

E-mail: ______________________________

Thank you for your participation! A second round questionnaire will be mailed to you as soon as the research team compiles the results of this questionnaire.

APPENDIX B
QUESTIONAIRE 2

Pennsylvania Median Safety Study (Interstates and Expressways)
Questionnaire 2

1. Other than median width, average daily traffic, and accident history, first round survey respondents indicated that many other factors influence median crossover crashes. You will find each of the factors listed below. Please use the scale provided to the right of each factor to rank the importance of the factor relative to median safety on interstates and expressways. A #1 indicates that the factor is not important to consider, and #5 indicates that the factor is a very important median safety consideration.

Factor	Not Important		↔	Very Important	
a. Weather Conditions	1	2	3	4	5
b. Vertical Curvature	1	2	3	4	5
c. Operating Speed	1	2	3	4	5
d. Horizontal Curvature	1	2	3	4	5
e. Pavement Cross-slopes/superelevation rates	1	2	3	4	5
f. Pavement Friction	1	2	3	4	5
g. Median Slopes	1	2	3	4	5
h. Truck Traffic Percentage	1	2	3	4	5
i. Shoulder Design	1	2	3	4	5
j. Highway Defects	1	2	3	4	5
k. Alignment Consistency	1	2	3	4	5
l. Median Surface	1	2	3	4	5
m. Pavement Width	1	2	3	4	5
n. Pavement Markings	1	2	3	4	5
o. Driver Behavior	1	2	3	4	5
p. Highway Lighting Conditions/Visibility	1	2	3	4	5
q. Public Perception	1	2	3	4	5
r. Property Impacts	1	2	3	4	5

2. According to the responses from the first questionnaire, 10 geometric elements were listed as possible factors that may contribute to cross-median crashes. Please use the space to the right of each factor to rank the factors according to the likelihood that they may contribute to median crossover crashes. Each factor should be given a different ranking from 1 to 10 with 1 being the most likely to contribute to a cross-median crash, and 10 being the least likely to contribute to a cross-median crash.

Factors	Rank
Superelevation Rate	____
Median Cross-slope	____
Shoulder Width	____
Vertical Curvature	____
Median Width	____
Speed	____
Horizontal Curvature	____
Shoulder Slope	____
Pavement Friction	____
Median Surface	____

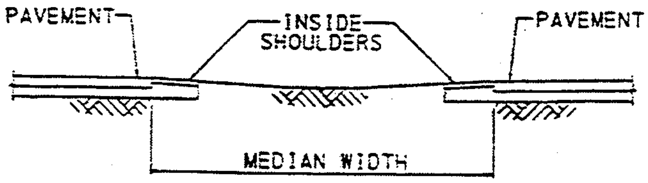
3. PENNDOT suggests that median barrier is not warranted "if the median width exceeds ten meters or the average daily traffic is less than 20,000 vehicles per day, unless there is a significant history of cross median crashes." The first questionnaire produced various quantitative measures to define historical significance—these definitions are listed below. Please circle the two that you think are most appropriate.

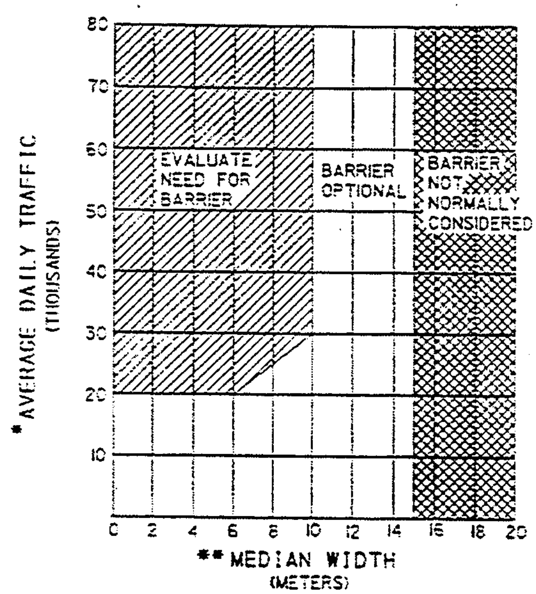
a. Two or more crashes at the same location per year.
b. Crossover accident rate significantly higher than the average accident rate.
c. One crash per year per section or segment over a 3 to 5 year period.
d. More than one crash per year per section or segment.
e. Accident rate $\geq$ 0.20 (Number of crashes per million vehicles).
f. Societal costs exceed $15,000 - $20,000 per mile per year.
g. Reduction of one head-on collision over a 5 to 10 year barrier life.
h. Accident rate of 0.15 accidents per million vehicle-miles.
i. Accident rate of 0.50 accidents per mile per year.

4. Significant heavy vehicle traffic (i.e., percentage of trucks, buses, and recreational vehicles) was indicated as having potential to increase median crossover crashes on high functional class roadways. At what minimum level (percentage of ADT) do you think heavy vehicles will begin to effect the vehicle mix and consequently be a contributing factor to cross-median crashes?

_____ % of ADT

5. Please refer to Figure 1 below to answer the following question.





* BASED ON A 5-YEAR PROJECTION AFTER CONSTRUCTION.

** MEASURED FROM EDGE OF PAVEMENT TO EDGE OF PAVEMENT AND INCLUDES BOTH INSIDE SHOULDERS.

Figure B-1. PENNDOT Median Barrier Warrant

Based on the responses from the first questionnaire, some panelists think that the "Barrier Optional" section of the warrant above (ADT > 20,000 and median width 10 – 15 meters) is a scenario that should always require median barrier. Do you agree with this statement?

____ Yes
____ No

If no, why?

6. More than half of the panelists felt that AASHTO's definition of a recoverable slope (4:1 or flatter) is not precise. Please consider the following six reasons and rank them in order of highest to lowest importance (1 = most important reason for imprecise definition, and 6 = least important reason for imprecise definition).

Factor	Rank
Soil type on slope	____
Drainage adequacy of median	____
Non-uniformity of side slopes	____
Angle of entry	____
Vehicle Type	____
Driver Ability	____

If you think that the AASHTO definition is not precise, please indicate a slope rate that may be more appropriate for a recoverable slope in the median.

Recoverable slope = ______________

7. More than half of the panelists felt that AASHTO's definition of a traversable slope (3:1 or flatter) is not precise. Please consider the following six reasons and rank them in order of most to least important (1 = most important reason for imprecise definition and 6 = least important reason for imprecise definition).

Factor	Rank
Soil type on slope	____
Drainage adequacy of median	____
Non-uniformity of side slopes	____
Angle of entry	____
Vehicle Type	____
Driver Ability	____

If you think that the AASHTO definition is not precise, please indicate a slope rate that may be more appropriate for a traversable median slope.

Traversable slope = ______________

8. PENNDOT's standard cross-section for interstates and expressways requires an inside paved shoulder width of 1.2 meters and 2.4 meters of graded shoulder. Nearly all panelists indicated that narrow inside (or left) shoulders on divided highways can contribute to median crashes, or at least limit the recovery potential of errant vehicles. Do you think that the PENNDOT inside shoulder standard provides for an adequate vehicle recovery area?

____ Yes
____ No

If you answered "no," what is an appropriate inside shoulder width? ________

9. PENNDOT standard drawings indicate that interstate and expressway roadways require 3.6-meter travel lanes. The following scenarios (Table 1) show various ranges of heavy vehicles in the traffic stream and average daily traffic levels for divided, multi-lane interstates and expressways. Please mark which options (if any) that may contribute to cross-median crashes by indicating "yes" in the third column of the table. For those combinations that you marked as "yes," indicate in the fourth column whether or not wider lanes may reduce the probability of cross-median crashes.

Table B-1. ADT and Percent Heavy Vehicle Combinations.

ADT	% Heavy Vehicles	Does Combination Contribute to Cross-Median Crashes?	**Will Wider Lanes Reduce Probability of Cross-Median Crashes?
15,000 – 30,000	5 – 10 %		
15,000 – 30,000	10 – 20 %		
15,000 – 30,000	> 20 %		
30,000 – 50,000	5 –10 %		
30,000 – 50,000	10 – 20 %		
30,000 – 50,000	> 20%		
50,000 – 75,000	5 – 10 %		
50,000 – 75,000	10 – 20 %		
50,000 – 75,000	> 20 %		
> 75,000	5 – 10 %		
> 75,000	10 – 20 %		
> 75,000	> 20 %		

** If you answered "yes" to increasing lane widths above for any of the combinations listed, what lane width would you recommend? ________

10. More than half of the panelists felt that pavement cross-slopes can contribute to cross-median crashes. The two factors cited as being the most influential were vehicle loss of control during wet conditions (i.e., hydroplaning) and poor superelevation rates on curves. For interstates and expressways, do you think that normal pavement cross slopes of 1.5 to 3 percent adequately drain the roadway surface during wet weather conditions so that vehicle loss of control is minimized?

_____ Yes
_____ No

If you answered "No," what would be a more appropriate normal crown cross slope? __________

The maximum superelevation rate commonly used in Pennsylvania for interstates and expressways is 8 percent—other parts of the country may permit up to 10 to 12 percent. Do you think that these rates adequately address the potential for vehicle encroachments into median on high functional class roadways?

_____ Yes
_____ No

If you answered "No," what superelevation rate would be more appropriate to reduce the probability of vehicle encroachments? __________

11. Tables 2-10 contain simple median configuration scenarios. In each table, there will be a maximum of three barrier types listed (most popular choices from round one survey results) as well as a "barrier not recommended" choice. Each median configuration consists of a median width and average daily traffic. You can assume that the median cross slopes are both traversable and recoverable (flatter than 4:1). Please indicate with an "X" which barrier type you would consider the most cost-effective and safest in preventing cross-median crashes. Additionally, indicate if you would place the barrier on the edge of the shoulder or in the center of the median by marking an "X" in the respective column.

Table B-2. Median Scenario 1.

Median Width	ADT	Barrier Type	Which do you recommend? (Choose one with an "X")	Barrier Location	
				Center of Median	Edge of Shoulder
10-15 m (33 – 50 ft)	20,000 – 40,000	Three-Strand Cable			
		Strong Post W-Beam/Thrie Beam			
		Concrete Safety Shape			
		Barrier Not Recommended			

Table B-3. Median Scenario 2.

Median Width	ADT	Barrier Type	Which do you recommend? (Choose one with an "X")	Barrier Location	
				Center of Median	Edge of Shoulder
10-15 m (33 – 50 ft)	> 40,000	Three-Strand Cable			
		Strong Post W-Beam/Thrie Beam			
		Concrete Safety Shape			
		Barrier Not Recommended			

Table B-4. Median Scenario 3.

Median Width	ADT	Barrier Type	Which do you recommend? (Choose one with an "X")	Barrier Location	
				Center of Median	Edge of Shoulder
>15 m (> 50 ft)	40,000 – 60,000	Three-Strand Cable			
		Strong Post W-Beam/Thrie Beam			
		Concrete Safety Shape			
		Barrier Not Recommended			

Table B-5. Median Scenario 4.

Median Width	ADT	Barrier Type	Which do you recommend? (Choose one with an "X")	Barrier Location	
				Center of Median	Edge of Shoulder
>15 m (>50 ft)	> 60,000	Three-Strand Cable			
		Strong Post W-Beam/Thrie Beam			
		Concrete Safety Shape			
		Barrier Not Recommended			

Table B-6. Median Scenario 5.

Median Width	ADT	Barrier Type	Which do you recommend? (Choose one with an "X")	Barrier Location	
				Center of Median	Edge of Shoulder
10-15 m (33 – 50 ft)	20,000 – 40,000	Three-Strand Cable			
		Strong Post W-Beam			
		Concrete Safety Shape			
		Barrier Not Recommended			

Table B-7. Median Scenario 6.

Median Width	ADT	Barrier Type	Which do you recommend? (Choose one with an "X")	Barrier Location	
				Center of Median	Edge of Shoulder
6 - 10 m (20 - 33 ft)	20,000 – 30,000	Strong Post W-Beam/Thrie Beam			
		Concrete Safety Shape			
		Weak Post W-Beam			
		Barrier Not Recommended			

Table B-8. Median Scenario 7.

Median Width	ADT	Barrier Type	Which do you recommend? (Choose one with an "X")	Barrier Location	
				Center of Median	Edge of Shoulder
10 m (33 ft)	> 30,000	Strong Post W-Beam/Thrie Beam			
		Concrete Safety Shape			
		Three-Strand Cable			
		Barrier Not Recommended			

Table B-9. Median Scenario 8.

Median Width	ADT	Barrier Type	Which do you recommend? (Choose one with an "X")	Barrier Location	
				Center of Median	Edge of Shoulder
>23 m (> 75 ft)	>60,000	Three-Strand Cable			
		Earth Berm			
		Strong Post W-Beam/ Thrie Beam			
		Barrier Not Recommended			

Table B-10. Median Scenario 9.

Median Width	ADT	Barrier Type	Which do you recommend? (Choose one with an "X")	Barrier Location	
				Center of Median	Edge of Shoulder
12 m (40 ft)	20,000 – 40,000	Three-Strand Cable			
		Strong Post W-Beam/Thrie Beam			
		Weak Post W-Beam			
		Barrier Not Recommended			

Print Name: ______________________________

Thank you for your participation! After the results of this survey have been recorded and reviewed, there may be a need for a third survey that will be comparatively shorter in length.

APPENDIX C
LOCATIONS OF CMC CRASHES (1994-1998)

Table C-1 summarizes the distribution of CMC crashes on Interstates and expressways by county from 1994 through 1998, inclusive. In addition, Table C-2 shows the distribution of CMC crashes on Interstates and expressways by route from 1994 through 1998, inclusive. Lastly, Table C-3 summarizes the locations of CMC crashes on Interstate highways and expressways in Pennsylvania during the five-year period from 1994 through 1998, inclusive. There were 215 segments that experienced one CMC crash and 21 segments that experienced more than one CMC crash during the study period. The remaining 7,812 segments experienced no CMC crashes during the study period.

Table C-1. Distribution of Cross-Median Collisions by County (1994-1998)

County	County code	Number (%) of CMC crashes					
		Interstate		Expressway		Total	
Adams	01	0	(0.0)	1	(0.8)	1	(0.4)
Allegheny	02	9	(6.5)	21	(16.3)	30	(11.2)
Armstrong	03	0	(0.0)	0	(0.0)	0	(0.0)
Beaver	04	0	(0.0)	8	(6.2)	8	(3.0)
Bedford	05	0	(0.0)	1	(0.8)	1	(0.4)
Berks	06	4	(2.9)	5	(3.9)	9	(3.4)
Blair	07	3	(2.2)	0	(0.0)	3	(1.1)
Bradford	08	0	(0.0)	0	(0.0)	0	(0.0)
Bucks	09	13	(9.4)	2	(1.6)	15	(5.6)
Butler	10	1	(0.7)	2	(1.6)	15	(5.6)
Cambria	11	0	(0.0)	3	(2.3)	3	(1.1)
Carbon	13	0	(0.0)	0	(0.0)	0	(0.0)
Centre	14	0	(0.0)	1	(0.8)	1	(0.4)
Chester	15	0	(0.0)	25	(19.4)	25	(9.4)
Clarion	16	1	(0.7)	0	(0.0)	1	(0.4)
Clearfield	17	0	(0.0)	0	(0.0)	0	(0.0)
Clinton	18	0	(0.0)	0	(0.0)	0	(0.0)
Columbia	19	0	(0.0)	0	(0.0)	0	(0.0)
Crawford	20	0	(0.0)	0	(0.0)	0	(0.0)
Cumberland	21	4	(2.9)	0	(0.0)	4	(1.5)
Dauphin	22	6	(4.4)	5	(3.9)	11	(4.1)
Delaware	23	12	(8.7)	0	(0.0)	12	(4.5)
Erie	25	9	(6.5)	0	(0.0)	9	(3.4)
Fayette	26	0	(0.0)	2	(1.6)	2	(0.8)
Franklin	28	7	(5.1)	0	(0.0)	7	(2.6)
Fulton	29	1	(0.7)	0	(0.0)	1	(0.4)
Greene	30	1	(0.7)	0	(0.0)	1	(0.4)
Indiana	32	0	(0.0)	0	(0.0)	0	(0.0)
Jefferson	33	0	(0.0)	0	(0.0)	0	(0.0)
Juniata	34	0	(0.0)	0	(0.0)	0	(0.0)
Lackawanna	35	1	(0.7)	0	(0.0)	1	(0.4)
Lancaster	36	0	(0.0)	0	(0.0)	0	(0.0)
Lawrence	37	0	(0.0)	0	(0.0)	0	(0.0)
Lebanon	38	0	(0.0)	0	(0.0)	0	(0.0)
Lehigh	39	1	(0.7)	1	(0.8)	2	(0.8)
Luzerne	40	2	(1.5)	0	(0.0)	2	(0.8)
Lycoming	41	3	(2.2)	2	(1.6)	5	(1.9)
McKean	42	0	(0.0)	0	(0.0)	0	(0.0)
Mercer	43	3	(2.2)	0	(0.0)	3	(1.1)
Mifflin	44	0	(0.0)	11	(8.5)	11	(4.1)
Monroe	45	2	(1.5)	12	(9.3)	14	(5.3)
Montgomery	46	4	(2.9)	7	(5.4)	11	(4.1)
Montour	47	0	(0.0)	0	(0.0)	0	(0.0)
Northampton	48	2	(1.5)	3	(2.3)	5	(1.9)
Northumberland	49	1	(0.7)	1	(0.8)	2	(0.8)
Perry	50	0	(0.0)	1	(0.8)	1	(0.4)
Pike	51	0	(0.0)				
Schuylkill	53	2	(1.5)	0	(0.0)	2	(0.8)
Snyder	54	0	(0.0)	1	(0.8)	1	(0.4)
Somerset	55	0	(0.0)	1	(0.8)	1	(0.4)
Susquehanna	57	7	(5.1)	0	(0.0)	7	(2.6)
Union	59	0	(0.0)	1	(0.8)	1	(0.4)

County	County code	Number (%) of CMC crashes					
		Interstate		Expressway		Total	
Venango	60	3	(2.2)	0	(0.0)	3	(1.1)
Warren	61	0	(0.0)	0	(0.0)	0	(0.0)
Washington	62	9	(6.5)	4	(3.1)	13	(4.8)
Wayne	63	0	(0.0)	0	(0.0)	0	(0.0)
Westmoreland	64	0	(0.0)	0	(0.0)	0	(0.0)
York	66	0	(0.0)	5	(3.9)	5	(1.9)
Philadelphia	67	27	(19.6)	3	(2.3)	30	(11.2)
Total		138		129		267	

Table C-2. Distribution of Cross-Median Collisions (1994-1998) by Route

Route	Number (%) of CMC crashes	
Interstate Highways		
70	3	(2.2)
76	1	(0.7)
78	6	(4.4)
79	16	(11.6)
80	10	(7.3)
81	26	(18.8)
83	0	(0.0)
84	0	(0.0)
90	9	(6.5)
95	51	(37.0)
99	3	(2.2)
176	1	(0.7)
180	3	(2.2)
279	3	(2.2)
283	1	(0.7)
376	1	(0.7)
380	0	(0.0)
476	4	(2.9)
579	0	(0.0)
676	0	(0.0)
Total	138	
Expressways		
1	5	(3.9)
6	0	(0.0)
8	0	(0.0)
11	1	(0.8)
13	1	(0.8)
15	2	(1.6)
19	0	(0.0)
22	16	(12.4)
26	0	(0.0)
28	6	(4.7)
29	0	(0.0)
30	6	(4.7)
33	9	(7.0)
40	2	(1.6)
43	0	(0.0)
51	0	(0.0)
56	0	(0.0)
60	12	(9.3)
61	2	(1.6)
65	1	(0.8)
119	1	(0.8)
147	1	(0.8)
202	23	(17.8)
209	6	(4.7)
219	3	(2.3)
220	2	(1.6)
222	0	(0.0)
248	0	(0.0)
286	0	(0.0)

Route	Number (%) of CMC crashes	
Expressways (continued)		
300	2	(1.6)
309	2	(1.6)
322	15	(11.6)
378	0	(0.0)
422	10	(7.8)
581	0	(0.0)
611	0	(0.0)
837	0	(0.0)
1077	0	(0.0)
2023	0	(0.0)
2089	0	(0.0)
3001	0	(0.0)
3020	0	(0.0)
3032	0	(0.0)
3036	0	(0.0)
3091	0	(0.0)
3160	0	(0.0)
4002	0	(0.0)
4010	0	(0.0)
6015	1	(0.8)
Total	129	

Table C-3. Locations of Cross-Median Collisions (1994-1998)

County	Route	Segment	Number of CMC crashes
Interstate highways—Earth-divided medians			
Allegheny	79	524	1
Allegheny	79	541	1
Allegheny	79	575	1
Allegheny	79	690	1
Allegheny	79	744	1
Allegheny	279	140	1
Allegheny	279	145	1
Allegheny	279	151	1
Allegheny	376	44	1
Berks	78	94	1
Berks	78	141	1
Berks	176	41	1
Blair	99	240	2
Blair	99	270	1
Bucks	95	330	1
Bucks	95	334	1
Bucks	95	335	1
Bucks	95	340	2
Bucks	95	374	1
Bucks	95	410	1
Bucks	95	411	1
Bucks	95	444	1
Bucks	95	454	1
Bucks	95	490	1
Bucks	95	491	1
Bucks	95	494	1
Butler	79	960	1
Clarion	80	541	1
Cumberland	81	420	1
Cumberland	81	465	1
Cumberland	81	570	1
Cumberland	81	640	1
Dauphin	81	661	1
Dauphin	81	665	1
Dauphin	81	705	1
Dauphin	81	784	1
Dauphin	81	804	1
Dauphin	283	25	1
Delaware	95	3	1
Delaware	95	4	1
Delaware	95	5	1
Delaware	95	14	1
Delaware	95	15	1
Delaware	95	20	1
Delaware	95	80	1
Delaware	95	100	1
Erie	90	20	1
Erie	90	111	1
Erie	90	151	1
Erie	90	191	2

County	Route	Segment	Number of CMC crashes
Interstate highways—Earth-divided medians (continued)			
Erie	90	321	1
Erie	90	340	1
Erie	90	354	1
Erie	90	395	1
Franklin	81	71	1
Franklin	81	115	1
Franklin	81	121	1
Franklin	81	140	1
Franklin	81	170	1
Franklin	81	175	1
Franklin	81	204	1
Fulton	70	1714	1
Greene	79	144	1
Lackawanna	81	2020	1
Lehigh	78	610	1
Luzerne	80	2490	1
Luzerne	80	2581	1
Lycoming	180	315	1
Lycoming	180	351	1
Lycoming	180	371	1
Mercer	79	1150	1
Mercer	79	1155	1
Mercer	80	5	1
Monroe	80	2994	1
Monroe	80	3015	1
Montgomery	476	154	1
Montgomery	476	161	1
Montgomery	476	164	1
Montgomery	476	194	1
Northampton	78	650	1
Northampton	78	651	1
Northumberland	81	1111	1
Schuylkill	81	1334	1
Susquehanna	81	2160	1
Susquehanna	81	2215	1
Susquehanna	81	2230	1
Susquehanna	81	2235	1
Susquehanna	81	2251	1
Susquehanna	81	2254	1
Susquehanna	81	2304	1
Venango	80	334	1
Venango	80	375	1
Venango	80	414	1
Washington	70	164	1
Washington	79	334	1
Washington	79	405	1
Washington	79	411	1
Washington	79	460	1
Washington	79	471	1
Washington	79	484	2
Philadelphia	95	304	2

County	Route	Segment	Number of CMC crashes
Interstate highways—Earth-divided medians (continued)			
Philadelphia	95	305	1
Philadelphia	95	310	5
Philadelphia	95	311	1
Philadelphia	95	314	3
Philadelphia	95	315	4
Philadelphia	95	320	1
Philadelphia	95	321	1
Philadelphia	95	324	3
Interstate highways—Fixed-barrier medians			
Berks	78	361	1
Delaware	95	44	1
Delaware	95	61	1
Delaware	95	64	1
Delaware	95	75	1
Washington	70	335	1
Philadelphia	76	3465	1
Philadelphia	95	181	1
Philadelphia	95	210	1
Philadelphia	95	255	1
Philadelphia	95	290	1
Philadelphia	95	301	1
Expressways—Earth-divided medians			
Adams	15	171	1
Allegheny	22	11	1
Allegheny	22	50	1
Allegheny	22	51	1
Allegheny	22	70	1
Allegheny	22	101	1
Allegheny	22	111	1
Allegheny	22	121	1
Allegheny	22	131	1
Allegheny	22	141	1
Allegheny	28	240	1
Allegheny	28	241	1
Allegheny	28	251	1
Allegheny	28	271	1
Allegheny	28	300	1
Allegheny	60	292	1
Allegheny	60	411	3
Beaver	60	31	1
Beaver	60	40	1
Beaver	60	51	1
Beaver	60	120	1
Beaver	60	121	1
Beaver	60	161	1
Beaver	60	221	1
Beaver	60	245	1
Bedford	220	430	1
Berks	61	371	1
Berks	422	680	1

County	Route	Segment	Number of CMC crashes
Expressways—Earth-divided medians (continued)			
Berks	422	690	1
Bucks	13	261	1
Bucks	202	171	1
Butler	422	140	1
Butler	422	391	1
Cambria	22	341	1
Cambria	219	10	2
Centre	322	538	1
Chester	1	231	1
Chester	1	411	1
Chester	30	300	1
Chester	202	150	3
Chester	202	161	1
Chester	202	220	1
Chester	202	250	1
Chester	202	260	1
Chester	202	270	1
Chester	202	281	1
Chester	202	310	1
Chester	202	341	1
Chester	202	361	1
Chester	202	391	1
Chester	202	401	1
Chester	202	410	2
Chester	202	420	1
Chester	202	421	1
Chester	202	430	1
Chester	202	441	2
Chester	202	450	1
Dauphin	300	31	1
Dauphin	300	61	1
Dauphin	322	171	1
Dauphin	322	181	1
Dauphin	322	200	1
Fayette	40	41	1
Fayette	119	486	1
Lycoming	220	51	1
Lycoming	220	6015	1
Mifflin	322	190	1
Mifflin	322	230	1
Mifflin	322	260	2
Mifflin	322	280	2
Mifflin	322	281	1
Mifflin	322	290	2
Mifflin	322	301	1
Monroe	33	11	1
Monroe	33	30	1
Monroe	33	50	1
Monroe	33	70	1
Monroe	33	80	1

County	Route	Segment	Number of CMC crashes
Monroe	33	120	1
Expressways—Earth-divided medians (continued)			
Monroe	209	251	1
Monroe	209	290	2
Monroe	209	321	1
Monroe	209	340	1
Monroe	209	360	1
Montgomery	422	171	1
Montgomery	422	210	3
Montgomery	422	221	1
Northampton	33	240	1
Northampton	33	241	1
Northampton	33	250	1
Northumberland	147	840	1
Perry	22	311	1
Snyder	11	251	1
Somerset	219	971	1
Union	15	280	1
Washington	22	10	1
Washington	22	91	1
Washington	22	170	1
Washington	40	840	1
York	30	210	1
York	30	230	1
York	30	421	1
York	30	531	1
Philadelphia	1	101	1
Expressways—Fixed-barrier medians			
Allegheny	22	141	1
Allegheny	28	20	2
Berks	61	374	1
Berks	422	471	1
Lehigh	22	110	1
Mifflin	322	270	1
Montgomery	309	140	1
Montgomery	309	400	1
Philadelphia	1	101	1
Philadelphia	1	140	1

Note: a number of segments with earth-divided medians that experienced CMC crashes during the study period have since had fixed barriers installed.

APPENDIX D
FIELD STUDIES OF CMC CRASH SITES AND COMPARABLE NON-CRASH SITES

A field study was undertaken to compare the geometric and roadside design characteristics of sites at which CMC crashes occurred and representative sites where CMC crashes did not occur. The purpose of collecting the field study data was to determine whether specific geometric features, such as roadside slopes, horizontal curves, and interchange ramps were over- or under-represented at CMC crash sites and whether such over- or under-representation has implications concerning the causation of CMC crashes.

The general procedure for the field study was as follows:

- Select a representative set of CMC crashes on Interstate highways with earth-divided medians, including CMC crashes that occurred at a wide range of median widths.
- For each CMC crash site, select a comparable non-crash site with an earth-divided median of similar width, on the same roadway as the crash site, but far enough from the crash site that the roadside features at the crash and non-crash site are independent.
- Identify roadside and geometric design features of interest to the study and establish field data collection procedures.
- Collect field data on roadside and geometric design features at each pair of crash and non-crash sites.
- Perform an analysis to compare the roadside and geometric features at the crash and non-crash sites.

Each element of this procedure is discussed below.

Selection of a Representative Set of CMC Crashes

The first step in the collection and analysis of field data was to select a representative set of CMC crashes on Interstate highways with earth divided medians, including CMC crashes that occurred at a wide range of median widths. The manner in which CMC crashes were selected for study is presented below.

The representative field data collection sample set of CMC crashes contained 22 sites of a possible 51 sites for rural Interstate highways. The median widths ranged from 28 to 136 ft for the 51 potential CMC crash data collection sites. Table D-1 shows the range of median widths, the number of sites that had the associated width, and the number of sample data collection sites used as a representative sample from the potential 51 CMC crash sites.

Table D-1. Number of CMC Crash Sites and Sample Size Selected for Field Data Collection

Median width	Number of crash sites	Selected sample size
28	2	2
46	1	1
54	1	1
60	1	1
64	8	2
66	8	2
68	9	2
70	1	0
72	3	2
77	2	0
78	1	1
92	6	2
96	1	0
98	1	1
100	3	2
115	1	1
126	1	1
136	1	1
Total	51	22

Note: All sites are on rural Interstate highways

In selecting the representative sample size, an attempt was made to minimize the number of site visits while maintaining the full range of median widths in the sample. As shown in Table D-1, when a single CMC crash occurred for a given median width, the site was included in the data collection sample. The CMC crashes that occurred on Interstate highways with a median width of 70 and 96 ft, respectively, where omitted from the data collection effort as they were neither in the same geographic area nor significantly different in width from other data collection sites. Where two or more CMC crashes occurred for a given median width, two sites were included in the data collection effort. The CMC crashes that occurred at 77-ft medians were omitted from the data collection effort because the sites at which these crashes occurred were neither in the same geographic area nor significantly different in width from other data collection sites.

In addition to the site selection outlined above, an effort was made to collect (where applicable) a representative sample of CMC crash data on each rural Interstate highway and in opposite directions of travel. Table D-2 shows the data sample size for each Interstate highway and the sample for each direction of travel.

Table D-2. CMC Crash Sites and Sample Size Selected for Field Data Collection by Route Number

Interstate route number	Number of crash sites	Selected sample size	Selected sample size by direction of travel
78	4	1	1 Eastbound
79	5	2	1 Northbound
			1 Southbound
80	8	5	3 Eastbound
			2 Westbound
81	22	9	5 Northbound
			4 Southbound
90	9	2	2 Westbound
99	2	2	2 Northbound
176	1	1	1 Westbound
Total	51	22	

Note: All sites are in rural Interstate highways

Selection of a Comparable Non-crash Site Near Each Selected CMC Crash Site

For each selected CMC crash site, a comparable non-crash site was selected at a location with an earth divided median of similar width to the crash site, on the same roadway as the crash site, but far enough from the crash site that the roadside features at the crash and non-crash site are independent. To remove potential bias from the site selection process, we applied a systematic set of rules to the selection of the non-crash sites. Specifically, whenever possible, the non-crash site was located on the same roadway, in the same direction of travel, exactly 1.0 miles upstream of the crash site. The use of a fixed distance from the crash site has been implemented before in safety research applying the case-control method; the use of a fixed distance removes any potential bias from the selection of the non-crash site. The location of the non-crash site upstream of the selected CMC crash site is conceptually appealing because it is likely that the vehicle that crossed the median in the CMC crash passed the selected non-crash site without incident very shortly before losing control.

The site 1.0 miles upstream of the selected CMC crash site was not always suitable for use as the non-crash site. For example, the selected non-crash site had an earth divided median of the appropriate width, but a feature that would prevent a median traversal, such as a guiderail or an earth mound, was present, the non-crash site was moved in one direction or another until a suitable location for data collection was found. If the location 1.0 mi upstream of the CMC crash site had a substantially different median width than the crash site or had a median that was not earth divided (i.e., there may have been a median barrier present), the non-crash location was moved to a location 1.0 miles downstream of the CMC crash site. If necessary, a site farther than 1.0 miles from the crash site was used, if neither of the sites at 1.0 miles upstream and 1.0 miles downstream of the data collection site were suitable; in all but one case, the non-crash site was within 2 to 3 miles of the selected crash site. In all cases, the comparable crash and non-crash sites were on the same route within the same county.

Appendix E identifies the locations of the CMC crash sites and comparable non-crash sites that were included in the field survey.

Identify Roadside and Geometric Features of Interest

The roadside and geometric features chosen for data collection at the selected CMC crash and non-crash sites were as follows:

- inside (median) shoulder width in primary and opposing directions of travel
- total median width, including both inside shoulders
- presence of a horizontal curve
- presence of a ramp junction
- elevation difference between opposing directions of travel
- roadway grade in primary and opposing directions of travel
- median foreslopes
- presence of roadside obstacles in median

Field Data Collection Procedures

The definitions of the field survey data items and the field data collections procedures are presented below. The field data collection form used to record these data is presented in table D-3.

Inside Shoulder Width

The width of the inside shoulder was measured to provide an indication of the variability of cross-sectional element treatments. The paved inside shoulder width was measured from the inside edge of the travel way to the edge of the pavement. In cases where the earth-divided portion of the median was graded at the same slope as the paved shoulder, a width measurement was recorded for the unpaved inside shoulder width. A 100-ft tape measure was used to determine the width of both the paved and unpaved portions of the inside shoulder.

Total Median Width

The total median width was measured using a 100 ft tape. This element comprised both the width of the earth-divided section of the median as well as the combined width of the inside shoulder in the primary and opposing directions of travel.

Presence of a Horizontal Curve

Each data collection site was visually inspected to determine the presence of a horizontal curve. When a curve was present, a determination was made regarding its deflection (left or right). In addition, construction plan sheets were retrieved from each PENNDOT district office so that a determination could be made regarding the horizontal curve radius.

In some instances, a horizontal curve was not present at the site, but was located near the site. When a curve was within 1,500 ft of the site, the location (upstream or downstream) and the radius of the curve were recorded. Construction plan sheets were used to determine the radius of the horizontal curve and the distance from the data collection point to the nearest point of curvature (PC) or point of tangency (PT).

Presence of a Ramp Junction

The presence of an entrance or exit ramp was recorded for each CMC crash site and comparable non-CMC site. If a ramp was present, the location of the ramp relative to the measurement point was recorded (upstream or downstream). In addition, the distance from the measurement point to the ramp was recorded. When an exit ramp was downstream of the measurement point, the distance to the beginning of the deceleration lane was recorded. When an exit ramp was located upstream from the measurement point, the distance to the gore area was recorded. In the case of an entrance ramp being located downstream of the measurement point, the distance to the gore area was recorded. If the entrance ramp was located upstream from the measurement point, the distance to the end of the acceleration lane was recorded. The distance from the ramp junction to the field measurement point was determined using a measuring wheel.

Elevation Difference between Opposing Directions of Travel

The elevation of the roadway in opposing directions of travel was measured to provide information regarding the symmetry of the median. The roadway elevation at the inside edge of the travel way was retrieved from construction profile sheets or from field measurements. The elevation difference between the inside edges of the travel way were recorded and reference was made to the direction with the higher elevation.

Roadway Grades

The vertical grade of the primary and opposing directions of travel were measured using an electronic slopemeter.

Median Foreslopes

The foreslope of the earth-divided median was measured using an electronic slopemeter. The slopemeter measured the cross-slope as a percentage. In some cases, the median was symmetric and noted as such. In others, the median was asymmetrical. When the median was not symmetric, the slope of the primary and opposing directions of travel were measured using the slopemeter. In addition, a 100-ft tape was used to measure the offset from the inside edge of the shoulder in the primary direction of travel to the lowpoint (i.e., the swale point) where the median foreslopes met.

Presence of Roadside Obstacles

The median was visually inspected to determine if roadside obstacles were present. If a roadside obstacle was present (e.g., W-beam guiderail prior to a bridge parapet), the type of obstacle and its offset from the inside edge of the shoulder in the primary direction of travel was recorded.

Field data were collected using the definitions and procedures presented above. In the field, current roadway construction was encountered at two sites, limiting the ability to collect all variables of interest. Therefore, the analysis results below are generally based on 20 CMC crash sites and comparable non-crash sites, rather than 22 sites.

Table D-3. Field Data Collection Form

Site No. __________ District No. __________

☐ Accident SiteCounty __________
☐ Non-accident Site

Route No. __________

Primary Direction of Travel:
NB SB EB WB (Circle One)

Segment __________

Offset __________

Do the elevations of the roadways in opposing directions of travel differ? Y N
If yes, what is the elevation difference between the inside edges of pavement? __________ ft
Which direction has the higher elevation? NB SB EB WB

What is inside shoulder width in primary direction of travel? __________ ft (paved)
__________ ft (unpaved)

What is inside shoulder width in opposite direction of travel? __________ ft (paved)
__________ ft (unpaved)

What is total median width (include both inside shoulders)? __________ ft

Is there a horizontal curve present at site? Y N
If YES,
Is it a curve to the right or to the left? Right Left
What is approximate horizontal curve radius? __________ ft

If NOT,
Is there a horizontal curve present near the accident site? Y N
What is approximate horizontal curve radius? __________ ft
In what direction is horizontal curve? Upstream or Downstream
What is approximate distance from the measurement point to the nearest PC or PT of curve? __________ ft

Is there a ramp junction near the accident site? Y N
If YES, what type Entrance or Exit
What is the location of the ramp relative to measurement point? Upstream or Downstream
What is approximate distance to ramp? __________ ft

Table D-3. Field Data Collection Form

What is the vertical grade in the primary direction of travel?

-5 -4 -3 -2 -1 0 1 2 3 4 5 (Circle One)

What is the vertical grade in the opposing direction of travel?

-5 -4 -3 -2 -1 0 1 2 3 4 5 (Circle One)

Is the median symmetrical? Y N (Circle One)

If symmetrical, what are the median foreslopes? ________

If not symmetrical, what is slope of primary direction of travel? ________

What is slope of opposing direction of travel? ________

At what offset from the inside edge of shoulder of the primary direction of travel do the slopes meet? ________ ft

Are there any roadside obstacles present in the median? Y N

If YES, what is the obstacle? ____________________

At what offset from the inside edge of shoulder of the primary direction of travel is the obstacle? ________ ft

Comments: ____

____

____

SKETCH OF SITE

Analysis Results

The results obtained from analysis of the field study data are presented below.

Cross Section Widths and Roadway Grade Parameters

Table D-4 presents a comparison of cross section widths and roadway grade parameters for the CMC crash sites and the comparable non-crash sites. The table shows only minimal differences in cross section widths and roadway grades between the crash and non-crash sites. Specifically, the paved median shoulder widths in both directions of travel were nearly always the same, 4 ft.

Table D-4. Comparison of Key Cross Section Widths and Roadway Grade Parameters for CMC Crash Sites and Comparable Non-crash Sites

Parameter	CMC crash sites		Non-crash sites	
	Mean	Range	Mean	Range
Median shoulder width (paved) (ft)	3.95	3 to 4	4.00	4
Opposing direction median shoulder width (paved) (ft)	3.95	3 to 4	4.00	4
Median width (ft)	68	36 to 130	75	36 to 144
Roadway grade (%)	+0.24	–3.4 to +3.0	+0.77	–3.0 to +3.6
Roadway grade (opposing direction)(%)	–0.04	–4.0 to +3.4	–0.69	–3.6 to +3.0

The median widths, as shown in table D-4, differed only slightly between the crash and non-crash sites; the mean median width was 68 ft for the CMC crash sites and 71 ft for the non-crash sites. The selected sites, by design, included a full range of median widths of interest from less than 40 ft to over 100 ft in width.

Numerous differences were found between the median widths measured in the field and those indicated for the segment in question in PENNDOT's RMS database. However, such differences are to be expected because the RMS database presents a representative value for an entire 0.5-mi segment, while the field measurements were made at one particular point within the segment. Most of the differences in median width between the field-measured and RMS database values were 8 ft or less and there were an approximately equal number of positive and negative differences. Thus, there is no indication of any overall inaccuracy or bias in the median width data used in the analyses presented in Section 6 of this report.

The roadway grades at the crash and non-crash sites were relatively small, as shown in table D-4; the mean roadway grade in the primary direction of travel was +0.2 percent at the CMC crash sites and +0.8 percent at the non-crash sites. Thus, the CMC crashes occurred, on the average, on nearly level grades, although the CMC crashes included almost the entire range of grades likely to be found on the rural Interstate highway system, from a downgrade of 3.4 percent to an upgrade of 3.0 percent. None of the observed differences in roadway grade between the CMC crash sites and the comparable non-crash sites were statistically significant, based on the results of both two-sample and paired t-tests.

Table D-5 compares the proportion of downgrades and upgrades on the mainline roadway in the primary direction of travel. The table shows that approximately 40 percent of the CMC crashes occurred on downgrades and 55 percent occurred on upgrades. The pattern at non-crash sites is nearly the opposite, with 35 percent on downgrades and 60 percent on upgrades. However, these differences in the proportion of upgrades and downgrades between the CMC crash sites and the comparable non-crash sites are not statistically significant based on the results of a chi-squared test for equality of proportions. These data suggest that, within the range of grades typically found on rural Interstate highways, CMC crashes are equally likely on upgrades and downgrades.

Table D-5. Comparison of Proportion of Upgrades and Downgrades on Mainline Roadway for CMC Crash Sites and Comparable Non-crash Sites

Roadway grade category	CMC crash sites		Non-crash sites	
	Number	(%)	Number	(%)
Downgrade (primary direction)	8	(40.0)	7	(35.0)
Level (primary direction)	1	(5.0)	1	(5.0)
Upgrade (primary direction)	11	(55.0)	12	(60.0)
	20		20	
Downgrade (opposing direction)	10	(50.0)	12	(60.0)
Level (opposing direction)	1	(5.0)	0	(0.0)
Upgrade (opposing direction)	9	(45.0)	8	(40.0)
	20		20	

Median Cross Slopes

The field survey documented the roadside slopes found in the medians of rural Interstate highways at CMC crash sites and comparable non-crash sites. Typically, the median of a rural Interstate highway includes foreslopes that slope downward from the inside edge of the median shoulder to the low point of the median. Depending upon terrain, this low point may be at the center of the median (i.e., the median is symmetrical), or at an off-center location (i.e., the median is non-symmetrical). A comparison of roadside slopes for these conditions is shown in table D-6. It was found that, in general, the mean foreslope at CMC crash sites is slightly flatter than the mean foreslope at non-crash sites, for both symmetrical and non-symmetrical medians. However, this difference was not statistically significant based on the results of a two-sample t-test.

Table D-6. Comparison of Roadside Slopes in the Median for CMC Crash Sites and Comparable Non-crash Sites

Roadside slope type	CMC crash sites		Non-crash sites	
	Mean slope	Range of slopes	Mean slope	Range of slopes
Symmetrical medians[a]				
Foreslope	7:1	3:1 to 10:1	5:1	4:1 to 16:1
Non-symmetrical medians[b]				
Foreslope—primary direction of travel	6:1	3:1 to 14:1	4:1	3:1 to 10:1
Foreslope—opposing direction of travel	7:1	3:1 to 17:1	6:1	4:1 to 10:1

[a] Includes data for 12 CMC crash sites and 12 comparable non-crash sites.
[b] Includes data for 8 CMC crash sites and 8 comparable non-crash sites.

One hypothesis suggested during the research was that CMC crashes might be most likely where the elevation of the roadway from which the cross-median vehicle departed was greater than that of the opposing roadway, so that the cross-median vehicle followed a trajectory that was generally downhill across the median. However, the data in tables D-4 and D-5 do not support this hypothesis. Table D-7 shows that there was a net downslope across the median for 25 percent of CMC crashes, a level median for 50 percent of CMC crashes, and a net upslope for the remaining 25 percent of CMC crashes. If the hypothesis advanced above were correct, one would expect a higher proportion of CMC crashes on downslopes than on upslopes. The non-crash sites show a higher proportion of the upslopes than downslopes, but this finding cannot be taken as representative. It is almost certain that, over the rural Interstate highway system as a whole, the proportion of medians with net downslopes and upslopes should be equal.

Table D-7. Comparison of Direction of Median Elevation Difference Between Opposing Roadways at CMC Crash Sites and Comparable Non-crash Sites

Median elevation difference category[a]	CMC crash sites		Non-crash sites	
	Number	(%)	Number	(%)
Downslope	5	(25.0)	3	(15.0)
Level	10	(50.0)	11	(55.0)
Upslope	5	(25.0)	6	(30.0)
	20		20	

[a] The downslope category represents medians with a net downslope from the departure roadway to the opposing roadway; the up category represents medians with a net upslope from the departure roadway to the opposing roadway.

Table D-8 shows that for medians with both net downslopes and net upslopes, the net cross-slope of the medians studied, based on the difference in elevation between the inside edges of shoulder for the opposing roadways, is relatively flat and that the median cross slopes do not differ substantially between the CMC crash sites and comparable non-crash sites.

Table D-8. Comparison of Steepness of Net Median Cross Slopes Based on Elevation Differences Between Opposing Roadways at CMC Crash Sites and Comparable Non-crash Sites

Median cross slope category[a]	CMC crash sites		Non-crash sites	
	Mean slope	Range of slopes	Mean slope	Range of slopes
Downslope	13:1	9:1 to 19:1	14:1	4:1 to 28:1
Level	0	–	0	–
Upslope	18:1	7:1 to 28:1	17:1	8:1 to 42:1

[a] The downslope category represents medians with a net downslope from the departure roadway to the opposing roadway; the up category represents medians with a net upslope from the departure roadway to the opposing roadway.

Horizontal Curves

Another hypothesis investigated was that CMC crashes are more likely on horizontal curves than on tangents and that CMC crashes are particularly likely on the outside of horizontal curves (i.e., on the median side of curves to the right). Table D-9 shows a comparison of the location of the CMC crash sites and comparable non-crash sites with respect to horizontal curves. Overall, 50 percent of the CMC crash sites visited in the field were on horizontal curves and 50 percent were not. This same proportion held true for the non-crash sites. Thus, there is no evidence that horizontal curves are over involved in the causation of CMC crashes.

Table D-9. Horizontal Curvature At and Near CMC Crash Sites and Comparable Non-crash Sites

Horizontal curvature category	CMC crash sites				Non-crash sites			
	Number (%) of sites		Curve to:		Number (%) of sites		Curve to:	
			Left	Right			Left	Right
At horizontal curve	10	(50.0)	4	6	10	(50.0)	6	4
Near horizontal curve	4	(20.0)	–	–	5	(25.0)	–	–
No horizontal curve	6	(30.0)	–	–	5	(25.0)	–	–
	20				20			

Table D-9 shows that, of the CMC crashes on horizontal curves, 60 percent occurred on curves to the right and 40 percent on curves to the left. The opposite percentages were found at the non-crash sites: 40 percent of these sites were on curves to the right and 60 percent on curves to the right. This finding suggests that the hypothesis of over involvement of curves to the right in the causation of CMC crashes may be correct, but the observed differences are not large enough to be statistically significant based on the chi-squared test for equality of proportions.

Table D-9 shows that 20 percent of the CMC crash sites and 25 percent of the non-crash sites occurred near horizontal curves. Table D-10 shows that these nearby horizontal curves were located 350 to 1,500 ft from the crash or non-crash site and were most likely to be downstream of the crash site. It does not appear that these downstream curves would be likely to have a causal relationship to the CMC crashes because the vehicles that crossed the median had not yet reached the curve in question.

Table D-10. Distance to Horizontal Curves for CMC Crash Sites and Comparable Crash Sites Near Horizontal Curves

Location of horizontal curve relative to crash or non-crash site[a]	CMC crash sites			Non-crash sites		
	Number (%) of sites	Mean distance (ft)[b]	Range of distances[b]	Number (%) of sites	Mean distance (ft)[b]	Range of distances[b]
Downstream	3 (75.0)	580	350 to 1,000	4 (80.0)	500	200 to 800
Upstream	1 (25.0)	1,500	1,500	1 (20.0)	800	800
	4			5		

[a] Downstream means that the horizontal curve is located downstream from the crash or non-crash site.
[b] This distance is measured from the crash or non-crash site to the nearest end (PC or PT) of the horizontal curve.

Table D-11 compares the radii of the horizontal curves located at the CMC crash sites and comparable non-crash sites and those located near the crash and non-crash sites. The curves at or near the CMC crash sites generally had smaller radii than those located at or near the non-crash sites, but the differences are small and all of the horizontal curves involved have relatively large radii. None of the differences in mean curve radii shown in table D-8 are statistically significant based on the results of two-sample t-tests.

Table D-11. Horizontal Curve Radii At or Near CMC Crash Sites and Comparable Non-crash Sites

Horizontal curvature category	CMC crash sites		Non-crash sites	
	Mean radius (ft)	Range of radii (ft)	Mean radius (ft)	Range of radii (ft)
At horizontal curve	4,770	1,910 to 11,460	5,130	2,920 to 5,730
Near horizontal curve	4,540	2,870 to 5,730	5,690	2,870 to 7,640
No horizontal curve	–	–	–	–

Interchange Ramps

Table D-12 shows the frequency of interchange entrance and exit ramps located at or near the CMC crash sites and comparable non-crash sites. The data shown in the table were used to investigate whether entrance and exit ramps may be over involved in CMC crashes. A review of table D-12 found only one statistically significant difference between the crash on non-crash sites. Specifically, there were six CMC crash sites at locations where an entrance ramp was present within 100 to 800 ft upstream and there was only one of the comparable non-crash sites with an exit ramp located immediately upstream. This difference was statistically significant based on a chi-squared test for equality of proportions suggesting that CMC crashes are more likely immediately downstream of an entrance ramp.

Table D-12. Interchange Ramps At or Near CMC Crash Sites and Comparable Non-crash Sites

Type of ramp	Location of ramp relative to crash or non-crash site[a]	CMC crash sites			Non-crash sites		
		Number (%) of sites	Mean distance[b] (ft)	Range of distances[b] (ft)	Number (%) of sites	Mean distance[b] (ft)	Range of distances[b] (ft)
Entrance	Downstream	2 (10.0)	450	400 to 500	1 (5.0)	50	50
Entrance	At site	0 (0.0)	–	–	1 (5.0)	0	0
Entrance	Upstream	6 (30.0)	380	100 to 800	1 (5.0)	500	500
Exit	Downstream	1 (5.0)	100	100	1 (5.0)	1,600	1,600
Exit	At site	0 (0.0)	–	–	0 (0.0)	–	–
Exit	Upstream	0 (0.0)	–	–	2 (10.0)	170	130 to 200
No ramp	–	11 (55.0)	–	–	14 (70.0)	–	–
		20			20		

[a] Downstream means that the ramp junction is downstream of the crash or non-crash site.
[b] This distance is measured from the crash or non-crash site to the nearest end of the speed-change lane for the ramp in question.

The finding concerning entrance ramps discussed above was carefully reexamined in light of the field survey design discussed earlier in this appendix. It was noted that the default location for the non-crash site was 1.0 mi upstream or downstream of the corresponding CMC crash site; in a number of cases, the 1 mi location was unsuitable and had to be moved, but many of the non-crash sites were 1 mi from the crash site. In hindsight, the 1 mi criterion may have been a poor choice for investigating the relationship of CMC crashes to interchange ramps, because if a CMC crash occurs immediately downstream of an entrance ramp, it is unlikely that a non-crash location exactly 1.0 mi away will also be adjacent to an entrance ramp. The mean spacing of interchanges on rural Interstate highways in Pennsylvania is between 2.5 and 4.0 mi, a relatively few ramps are located exactly 1 mile apart.

On the other hand, it is possible to demonstrate from a review of entrance ramp frequencies on rural Interstate highways in Pennsylvania that it, if CMC crashes occurred at random locations unrelated to entrance ramps, it is highly unlikely that 6 of the 20 CMC crashes studies would have occurred within 800 ft downstream of an entrance ramp. Computerized map software was used to review the interchange locations and configurations for two representative rural Interstate highways in Pennsylvania, I-80 and I-81. Urban sections of I-80 and I-81 were omitted from the review. This review found that there were 210 entrance ramps in 958 mi of roadway (treating both directions of travel separately). The sections within 800 ft downstream of these ramps would constitute 3.3 percent of the total roadway length. The 20 CMC crashes whose sites were reviewed represented 39.2 percent of all CMC crashes on 1,238 mi of rural Interstate highway. If CMC accident locations were random, the number of CMC crashes within 800 ft downstream of an entrance ramp should have been 1.7, rather than the 6 that were observed. Thus, there appears to be clear evidence that CMC crashes are more likely to occur immediately downstream of entrance ramps than at other locations.

Interchange Ramps and Horizontal Curves Combined

Table D-13 shows the data used to investigate whether interchange ramps and horizontal curves together have an effect different from their separate effects investigated above. The table shows that five CMC crashes occurred both at a horizontal curve and near an interchange ramp. Three of these five crashes occurred at a location with an entrance ramp immediately upstream. There was only one of the non-crash sites that was both on a curve and near an interchange ramp, and this one site also had an entrance ramp immediately upstream. However, because of the potential flaw in the field study design concerning ramp locations, discussed above, no definite conclusion can be reached about whether the presence of a horizontal curve increases the likelihood of a CMC crash immediately downstream of an entrance ramp.

Table D-13. Interchange Ramps and Horizontal Curves At or Near CMC Crash Sites and Comparable Non-crash Sites

Type of ramp/curve combination	CMC crash sites		Non-crash sites	
	Number	(%) of sites	Number	(%) of sites
Horizontal curve and entrance ramp downstream	1	(5.0)	0	(0.0)
Horizontal curve and entrance ramp upstream	3	(15.0)	1	(5.0)
Horizontal curve and exit ramp downstream	1	(5.0)	0	(0.0)
Horizontal curve and exit ramp upstream	0	(0.0)	0	(0.0)
Curve but no ramp	5	(25.0)	9	(45.0)
Ramp but no curve	4	(20.0)	5	(25.0)
No curve or ramp	6	(30.0)	5	(25.0)
	20		20	

Roadside Obstacles

Another hypothesis investigated was that CMC crashes are more likely at sites near roadside obstacles in the median; this might occur if colliding with or maneuvering to avoid a collision with a roadside obstacle in the median increased the likelihood that an out-of-control vehicle would fully cross the median. Table D-14 illustrates that the proportion of roadside obstacles in the median at CMC crash sites was identical to the proportion of roadside obstacles in the median at the comparable non-crash sites. Thus, there is no evidence that the presence of roadside obstacles increases the likelihood of CMC crashes.

Table D-14. Frequency of Roadside Obstacles in Earth-divided Medians at CMC Crash Sites and Comparable Non-crash Sites

Roadside obstacle present in median?	CMC crash sites		Non-crash sites	
	Number (%) of sites		Number (%) of sites	
Yes	2	(10.0)	2	(10.0)
No	18	(90.0)	18	(90.0)
	20		20	

Summary

The field study analysis led to one conclusion about the factors that contribute to the causation of CMC accidents – it appears that there is an increased likelihood of CMC crashes within 800 ft downstream of an entrance ramp (measured from the end of the acceleration lane or taper). There is no evidence that horizontal curvature or the other geometric and roadside factors considered increase the likelihood of CMC crashes.

APPENDIX E
LIST OF CMC CRASH SITES
AND
COMPARABLE NON-CRASH SITES INCLUDED IN FIELD STUDIES

List of CMC Crash Sites and Comparable Non-crash Sites Included in Field Studies

Table E-1 presents a list of the locations of CMC crash sites and comparable non-crash sites that were included in the field studies described in Appendix D. The locations at which measurements were made are described in terms of route, county, segment, and offset.

Table E-1. Locations of CMC Crash Sites and Comparable Non-Crash Sites Included in Field Studies

Site No.	Route	County	CMC crash site		Non-crash site	
			Segment	Offset	Segment	Offset
1	78	Berks	94	2075	104	2062
2	79	Butler	960	20	950	42
3	79	Mercer	1155	2101	1145	2119
4	80	Clarion	541	1584	551	1842
5	80	Luzerne	2490	2640	2500	2624
6	80	Luzerne	2581	2582	2591	500
7	80	Venango	334	2089	344	2440
8	80	Venango	414	51	404	2640
9	81	Cumberland	420	2640	430	2647
10	81	Cumberland	465	2575	455	2441
11	81	Cumberland	570	290	580	485
12	81	Franklin	140	2642	150	2640
13	81	Franklin	175	2677	171	0065
14	81	Lackawanna	2020	216	2034	0216
15	81	Schuylkill	1111	1584	1121	1628
16	81	Schuylkill	1334	2115	1100	2115
17	81	Susquehanna	2215	1649	2205	1588
18	90	Erie	191	2522	181	2557
19	90	Erie	395	1329	385	1543
20	99	Blair	240	1584	250	1584
21	99	Blair	240	1794	250	1794
22	176	Berks	41	278	31	445