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MINNESOTA DEPARTMENT OF TRANSPORTATION

Bypass Lane Safety, Operations and Design Study

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16. Abstract (Limit: 200 words)

This study presents statistically reliable conclusions based on a comparison of the operational and safety characteristics of rural intersections without turning lanes, with by pass lanes, and with left turn lanes.

The basic work tasks associated with the research study included: a literature search of nationally published research reports, a survey of bypass lane use,, a summary of the legal issues associated with passing on the right, operations and safety analyses, and review of Mn/DOT's recommended design guidelines and design features.

The results of the safety and operations analyses did not offer a high degree of statistical reli8ability. However, a comparative crash analysis and a before-versus-after analysis suggested that it is impossible to conclude that the use of a bypass lane provides a greater degree of safety, and, therefore, bypass lanes should not be used as a safety device. There also were some concerns expressed about safety issues at four-legged intersections.

Recommendations included:
- Revise Mn/DOT turn lane policies to at least reduce or eliminate the use of bypass lanes at four-legged intersections.
- Consider developing a shorter and less costly exclusive left turn lane design. This suggested policy revision is not meant to infer that in all places by pass lane should be immediately converted to some other design.
- Offer designers positive guidance regarding the use of left-turn lanes, through a prioritized approach based on the functional classification of the major roadway

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BYPASS LANE SAFETY, OPERATIONS, AND DESIGN STUDY

Final Report

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EXECUTIVE SUMMARY

The Minnesota Department of Transportation has used bypass lanes as a rural intersection treatment for years, and for almost as long; there has been a debate about the operational and safety effects of such usage. However, the Department has never assembled definitive data regarding operations and safety at intersections with bypass lanes.

In order to address the lack of operational and safety information relative to the effects of bypass lanes at rural intersections, Mn/DOT retained the services of BRW, Inc. to conduct a comprehensive study of the issue. The primary objective of the study is to present statistically reliable conclusions based on a comparison of the operational and safety characteristics of rural intersections without turning lanes, with bypass lanes and with left turn lanes. The basic work tasks associated with the study included the following:

- A literature search of previously published research reports.
- A survey of usage of bypass lanes by local units of government in Minnesota.
- Providing a summary of legal issues identified by the Attorney General's staff associated with passing on the right based on a review of both case law and Minnesota statutes.
- Conducting operations and safety analyses in order to document any differences between intersections without turning lanes, with bypass lanes and with left turn lanes.
- Conducting a review of Mn/DOT's recommended design guidelines and design features and suggesting any changes that would tend to increase consistency in both the application and design of bypass lanes.

In addition to these tasks, the research process also included coordination with a Technical Advisory Panel made up of Senior Mn/DOT staff representing the Offices of Traffic

Engineering, Research, Geometric Design, Standards, several Districts and the Metropolitan Division.

The study concluded the following:

1. All of the published research addressed the issue of bypass lanes only at three-legged intersections and concluded that bypass lanes are a viable alternative to exclusive left turn lanes based on cost savings and reductions in delay and crashes. However, it was also noted that some states chose not to use any bypass lanes because of concerns regarding safety and driver expectation.

2. A survey of usage by Minnesota cities and counties suggests that most responders find the use of bypass lanes at three-legged intersections to be acceptable. However, the responders expressed concerns about safety at four-legged intersections and the lack of consistency in the design and application of bypass lanes.

3. Minnesota law is very clear that passing on the right is only legal if the maneuver is carried out on the "main traveled portion" of the roadway. However, the definition of just what constitutes the "main traveled portion" of the roadway is subject to the interpretation of individual law enforcement officers and prosecutors.

4. The results of the comparative safety analysis of over 2,700 rural intersections, including both three and four-legged intersections with no turn lanes, with bypass lanes and with exclusive left-turn lanes was inconclusive. Slight differences in crash rates, severity and distributions of types of crashes were documented among the various intersection designs; however, these differences were not statistically significant. As a result, it is impossible to conclude, with any degree of statistical reliability, that the use of either a bypass lane or a left-turn lane provides a greater degree of safety than no turn lane.

5. The results of the comparative crash analysis have a low level of statistical reliability because of the small size of the sample of intersections in Mn/DOT's database for the

bypass lane and left-turn lane categories. In addition, a review of the statewide distribution of intersections in the crash record database indicates a potential bias. Districts 1 and 4 (predominantly rural areas) account for fewer than 5 percent of the total number of intersections analyzed while the Metropolitan Division accounts for almost 20 percent of the total.

6. Because of the inconclusive results of the comparative analysis, a Before versus After analysis was conducted of 69 intersections where bypass lanes were constructed. The results of this analysis indicated a modest decrease in total crashes, crash frequency and average crash rate. However, none of the differences were statistically significant. Two disturbing trends were also noticed. First, the severity index (percentage of injury plus fatal crashes) increased by over 30 percent following construction of the bypass lanes. Second, the average crash rate in the Before period was approximately 25 to 40 percent below the statewide average for similar intersections (with no turn or bypass lanes). This could explain why there was no decrease in crash frequency and also calls into question why these intersections were selected for additional treatment.

7. The results of the traffic operations analysis suggests that even fairly high combinations of main line and cross-street traffic volumes, the presence of either bypass lanes or left-turn lanes does not have a significant quantifiable effect on the overall quality of traffic flow. The results also suggest that there is no objective data to support the recommended left-turn treatment warrants documented in Chapter 5 of the Road Design Manual.

8. Estimated construction costs were developed for each of the design categories. The costs ranged from approximately $50,000 for paved shoulders and bypass lanes to more than $200,000 for a full set of left-turn lanes.

9. Mn/DOT has written warrants for the deployment of bypass and left turn lanes along two-lane rural roads that provide designers with a great deal of discretion. The warrants identify speed, volume, crash and traffic operations conditions that indicate when auxiliary lanes should be provided. A review of this information suggests that the

warrants provide very little actual guidance. The crash warrant is so high that it would likely be met at only a very small number of intersections. The traffic operations warrants cannot be supported based on the output from any computer modeling. The guidance for bypass lanes indicates that they should be considered when the criteria for left-turn lanes are not satisfied. The final guideline addresses the issue of design continuity and suggests that turn lanes should be considered at all intersections if most intersections warrant their use. All of this results in providing individual designers with a great deal of discretion relative to the use of turn lanes and this may at least partially explain what appears to be an inconsistent use of turn lanes from one district to another, even along the same trunk highway.

10. The results of all of the various work tasks revealed no positive effects (other than minimizing construction costs) associated with the use of bypass lanes at *four-legged intersections*. In general, the installation of bypass lanes did not reduce overall crash frequency, did not address the issue of rear end crashes and tended to result in more severe crashes. Also, it can be demonstrated that the use of bypass lanes impairs the visibility of left turning vehicles to opposing through traffic. Therefore, it is recommended that Mn/DOT consider revising their turn lane policies to at least reduce or eliminate the use of bypass lanes at four-legged intersections.

11. The results of the work tasks found some limited support for the use of bypass lanes at *three-legged intersections*. The literature search, the survey of usage and comments by Mn/DOT designers and traffic engineers indicated anecdotal evidence for safety and operational benefits associated with bypass lanes, particularly in low volume situations. However, a review of the crash data indicates that at lower traffic levels (less than 4000 vehicles per day) bypass lanes have the highest crash rate of any of the design categories, the highest severity index, and the highest percentage of rear-end crashes. Also, this use of bypass lanes still results in left turn maneuvers from a through lane, a condition that is often considered to present a hazard on high-speed rural roadways. Therefore, it is also recommended that Mn/DOT consider further revising the turn lane policies to reduce or eliminate the use of bypass lanes at three-legged intersections.

12. The only documented advantage associated with the use of bypass lanes is the lower (than exclusive left-turn lanes) estimated construction cost. If Mn/DOT chooses to reduce or eliminate the use of bypass lanes, it is recommended that consideration be given to developing a shorter and therefore less costly exclusive left turn lane design. It is acknowledged that a shorter left-turn lane design would provide an operating speed less than the prevailing travel speed on most two-lane rural roadways. However, this is exactly the case with the present bypass lane design. Developing a short left turn lane design would provide an opportunity to improve design consistency because more future left-turn improvements would result in left-turn maneuvers from auxiliary lanes instead of through lanes.

13. In order to provide designers with more positive guidance regarding the use of left-turn lanes, it is recommended that Mn/DOT consider a prioritized approach based on the functional classification of the major roadway. The basic guidance for situations where major reconstruction is being considered suggests the following:

- Along principal arterials (where the primary function of the road is mobility), all public street intersections should have the standard design left-turn lane.

- Along minor arterials, intersection designs would range from full left-turn lanes at other minor arterials; minimum design left-turn lanes at lower volume collectors and local streets; and the use of paved shoulders at the lowest volume private driveways.

- Along collector roadways, intersection designs would include the use of minimum design left-turn lanes at other collectors and the use of paved shoulders at lower volume local streets and private driveways.

- Along local streets, the primary turn lane treatment would be the use of paved shoulders.

It should be noted that this suggested policy revision is not meant to infer that all in place bypass lanes should be immediately converted to some other design. It may be appropriate to perpetuate bypass lanes on maintenance/preservation projects or at constrained locations based on the individual designers engineering judgement. However, this policy does suggest that left-turn lanes should be the first choice for rural intersection treatments (particularly when major investments in a corridor are being considered) and provides a prioritized approach that recognizes objectives for maximizing mobility and safety while acknowledging the reality of financial constraints.

14. It is recommended that Mn/DOT consider drafting legislation consistent with whatever turn lane policy is ultimately adopted that provides better definition of legal maneuvers, which could improve the consistency of enforcement.

15. Given the fact that it appears that bypass lanes will continue to be deployed for at least the near future, consideration should be given to developing policies and guidelines that would encourage a higher level of consistency in their design and ultimately in the motorists recognition and use of bypass lanes. Potential revisions include the greater use of standard design features and the development of a new strategy for signs and/or pavement markings to improve driver awareness.

16. The Office of Traffic Engineering should consider initiating a statewide effort to update the crash records files that are used extensively for both the identification of hazardous locations and for safety related research. It is commonly acknowledged that these files are incomplete but is has always been assumed that the intersections in the files represent a random distribution both geographically and across the various design and intersection control categories. Several recent research projects, however, suggest that this assumption is not valid. Updating the files by either adding more or (better) all intersections in each district would improve the quality of the data and increase the statistical reliability of the results of any technical analysis of the data.

1.0 Introduction

The Minnesota Department of Transportation (Mn/DOT) has used bypass lanes (Figure 1.1) as a rural intersection treatment for years, and for almost as long, there has been a debate about the operational and safety effects of such usage. However, the Department has never assembled definitive data regarding operations and safety at intersections with bypass lanes. As a result, the debate continues. No additional guidance has been developed to supplement what is currently in the Road Design Manual (Section 5-3.01.03) and anecdotal information suggests that there is not a high level of consistency in the design and application of bypass lanes around the trunk highway system. There were also concerns expressed about whether the legal use of bypass lanes at some locations encouraged drivers to illegally use paved shoulders to get around left turning vehicles at other locations. Four informal bypass lane designs, that involve the use of wide paved shoulders and/or marked right turn lanes, have been observed and are illustrated in Figure 1.2.

In order to address the lack of operational and safety information relative to the effects of bypass lanes at rural trunk highway intersections, BRW, Inc. was retained to conduct a comprehensive study of the issue. The primary objective of the study is to present statistically reliable conclusions relative to a comparison of the operational and safety characteristics of rural intersections without turning lanes, with bypass lanes and with left turn lanes. The basic work tasks associated with the study included the following:

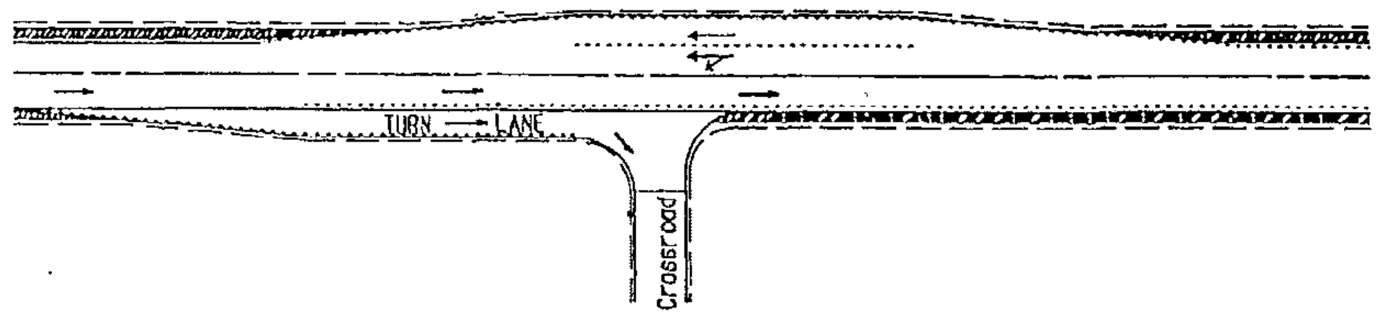
- A literature search of nationally published research reports.
- A survey of usage of bypass lanes by local units of government in Minnesota.
- Providing a summary of the legal issues identified by the Attorney General's staff associated with passing on the right based on a review of both case law and Minnesota statutes.

- Conducting operations and safety analyses in order to document any differences between intersections without turning lanes, with bypass lanes and with left turn lanes.

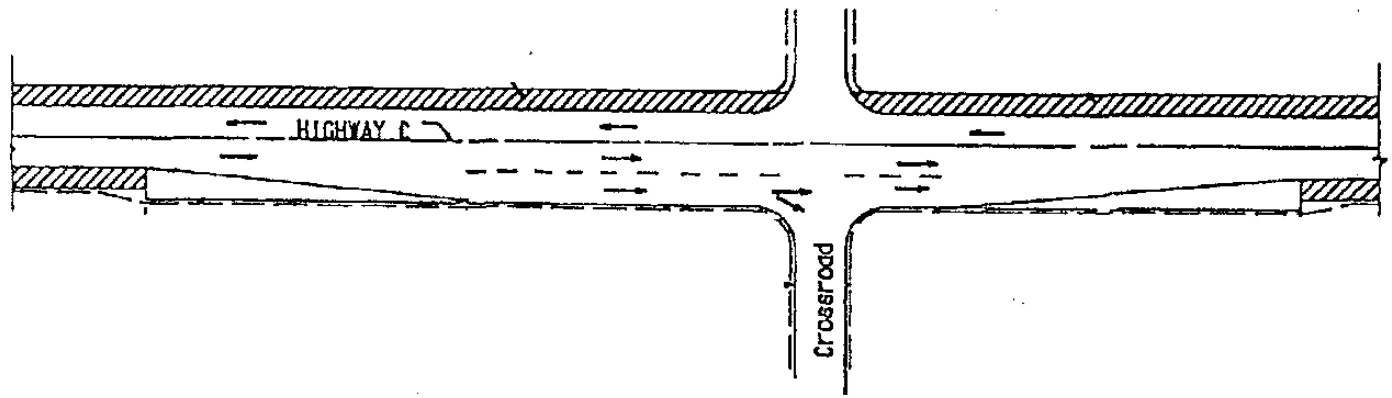
- Conducting a review of Mn/DOT's recommended design guidelines and design features and suggesting any changes that would tend to increase consistency in both the application and design of bypass lanes.

In addition to these specific tasks, the research process also included coordination with a Technical Advisory Panel that consisted of the following individuals:

Name	Title	Agency
Rick Beck	Traffic Operations Research Engineer	Mn/DOT-Traffic Eng.
Loren Hill	State Traffic Safety Engineer	Mn/DOT-Traffic Eng.
Paul Stine	State Aid	Mn/DOT
Amr Jabr	Design Standards Engineer	Mn/DOT-Design Services
Tom O'Keefe	Preliminary Design Engineer	Mn/DOT-Metro Div.
Bruce Kastner	Oakdale Traffic Engineer	Mn/DOT
Michael Spielmann	OTE – Tort Claims Engineer	Mn/DOT
Howard Preston	Senior Traffic Engineer	BRW, Inc.
Ted Schoenecker	Traffic Engineer	BRW, Inc



BY-PASS LANE at "T" INTERSECTION



COMBINED BY-PASS LANE AND RIGHT TURN LANE

Figure 1.1

Typical Bypass Lane Configuration

Source: MnDOT Road Design Manual Figure 5-3.01 E and F

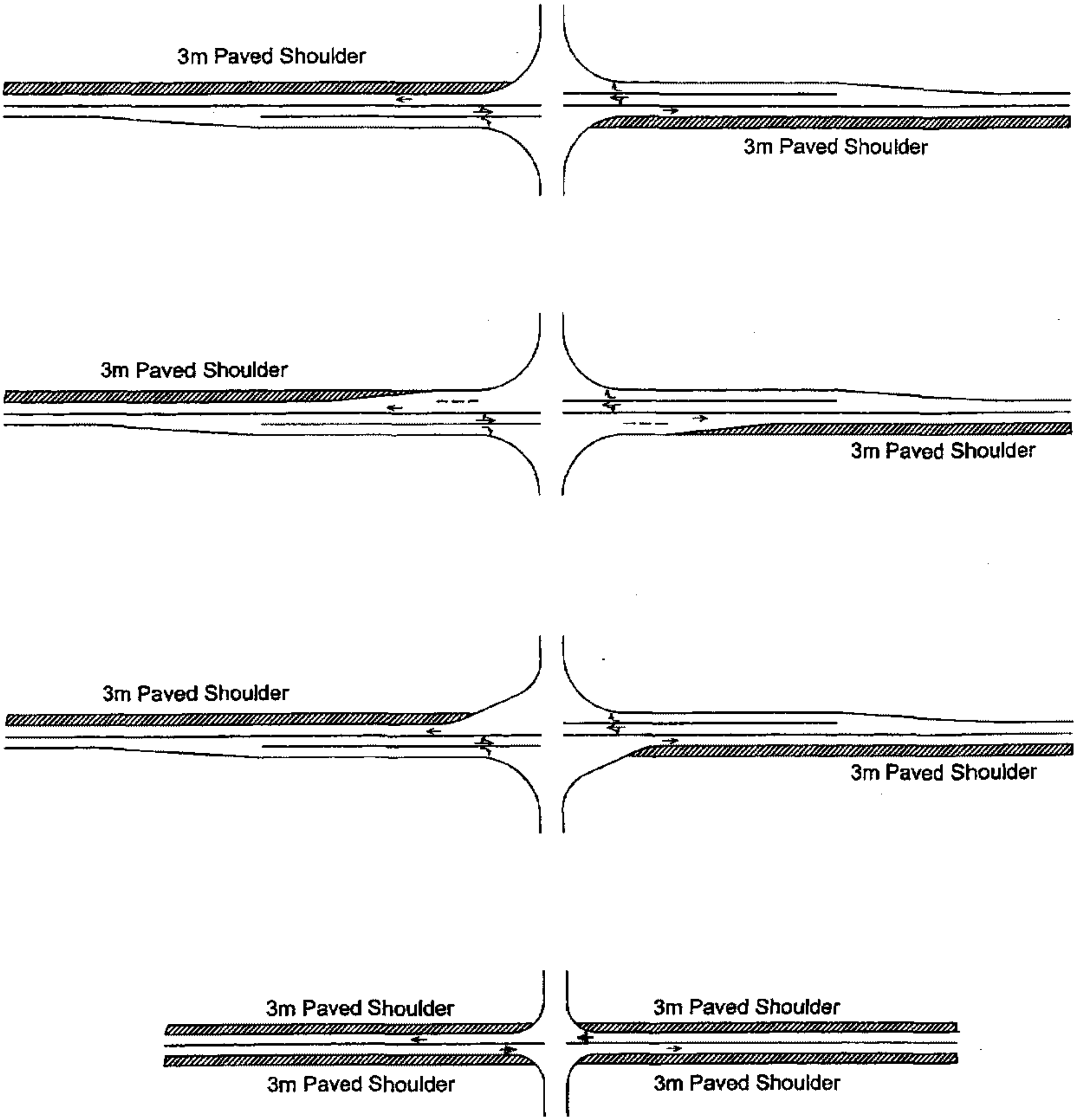


Figure 1.2
Observed Informal
Bypass Lane Designs

2.0 Literature Search

The purpose of this chapter is to document the findings of previously published research reports regarding the safety, operation, and design characteristics of bypass lanes.

2.1 Research Articles

The literature search found five reports and/or articles that pertained to bypass lanes at three-legged intersections. The articles are identified below and the key findings are summarized in the following section:

1. O.L. Sebastian and R.S. Pusey. *Paved Shoulder Left-Turn By-Pass Lanes: A report on the Delaware Experience.* Delaware Department of Transportation, Dover, Delaware, October 1982.
2. E.L. Bruce and J.E. Hummer. *Delay Alleviated by Left-Turn Bypass Lanes*, Transportation Research Record 1299; pp. 1-8. TRB, National Research Council, Washington, D.C.
3. S. Kikuchi. *Analysis of Warrant for Left-Turn Lane at "T" Intersections on Two-Lane Roadway.* University of Delaware, Newark, Delaware, September 1989.
4. A.B. Bakare and P.P. Jovanis. *Analysis of Unsignalized Intersection Capacity*, Transportation Research Record 971; pp. 21-31. TRB, National Research Council, Washington, D.C.
5. K.R. Agent. *Warrants For Left-Turn Lanes*, Transportation Quarterly; pp. 99-114.

2.2 Summary of Articles

Legislation was passed in August of 1976 that allowed drivers in Delaware to pass a stopped, left turning vehicle on the shoulder. A 1982 report prepared by Sebastian and Pusey (1) explained that only six years after this maneuver became legalized, the majority of drivers were passing stopped vehicles on the shoulder whether the pavement was marked as a bypass lane or not. At this stage of bypass lane development, there were no standards in Delaware for the construction dimensions of these lanes. Each case was viewed as different, and the geometry was adjusted accordingly. After implementation of many of these bypass lanes, the State of Delaware conducted a study and determined that the main crash type that was prevented by bypass lanes was the rear-end collision. The advantages of the bypass lanes at three-legged intersections that Delaware used for rationale in the construction costs were:

- Decreased delay to vehicles
- Decreased fuel consumption
- Decreased emission of noxious gasses
- Decreased number of crashes

At the completion of this study, it was found that bypass lanes that were marked had 16% more bypass maneuvers occurring versus the unmarked counterparts. Also, conditions such as poor visibility, adverse geometrics, and narrow shoulders were not as much of a deterrent where bypass lanes were properly marked.

One of the criticisms of bypass lanes at three-legged intersections is that faster vehicles attempt to pass slower vehicles in this short distance, by utilizing the bypass lane. According to Bruce and Hummer (2), the State of Nebraska will not consider the use of bypass lanes for that reason. In the same report, it was suggested at each intersection where a bypass lane is proposed, eight factors should be analyzed to determine if the bypass lane is warranted. Those factors are:

1. Volume of straight through traffic opposing the left turn
2. Volume of right turns onto minor road (conflicting with left turns)
3. Volume of left turning vehicles onto minor road
4. Volume of vehicles straight through in both directions
5. Speed of vehicles going straight through
6. Distance to upstream signal

7. Distance to downstream signal
8. Presence of left-turn bypass lane (if already in place)

The purpose for including the traffic control upstream and downstream is to account for platooning of vehicles that would adversely affect the number of acceptable gaps available for left turns. The issue with the bypass lane proposal is the cost.

The authors (Bruce and Hummer) discussed the issue of cost-effectiveness of bypass lanes and offered the example of Charlotte, North Carolina. The construction of a bypass lane was estimated to cost about $5000 (1976 Dollars). Assuming 0% interest, it was determined that the bypass lane would pay for itself in 5 years, based on delay costs (7 years at 6% and 8 years at 10%).

Obviously, these costs are based on the assumption that significant traffic volumes exist at the intersection. When the approach volume on the major road is less than 200 vehicles per hour, the use of an exclusive left turn lane, or a bypass lane is not needed since there is little chance that a queue length of any more than one car would develop. This analysis was done by Kikuchi (3) in a report developed at the University of Delaware. This report also noted that bypass lanes were not as affective at reducing either delays or the potential for rear end crashes as a median exclusive left turn lane. However, the construction of bypass lanes is cheaper than a median left turn lane, so the benefits should be weighed carefully. In the preparation of the report at the University of Delaware, surveys were sent to all 50 states asking if there existed warrants based on volume criteria for bypass lanes. Of the 50 surveys sent, 22 responses were received. Of those 22 states, only 8 states have warrants based on volume: Colorado, Delaware, Indiana, Minnesota, Mississippi, Missouri, Montana and Washington. All the other states that utilized bypass lanes had warrants based on subjective criteria.

In the previous two studies, many of the assumptions used in modeling the intersection traffic patterns are based in the size of the critical gap between oncoming vehicles. Bakare and Jovanis (4) suggested that the size of the critical gap in the 1980's (at the time the report was written) was smaller than the critical gap in the 1960's. However, this assumption was based on the fact that cars are getting smaller and faster, and admittedly the critical gap is also a function of how comfortable the driver is with the turn. Both Sweden and the United States have conducted studies on the size of the critical gap and affective level of service of the intersection. The finding of this report was that Americans usually under predict the critical gap, not assuming that left turning vehicles may take chances with smaller gaps, which may improve the overall level of service at the intersection but at the expense of compromising safety.

When drivers start to take chances with the turning movements, the frequency of crashes would also increase. The four main types of crashes at three-legged intersections where bypass or left turn lanes are used are:

- Left turn collide with oncoming straight through move
- Rear-end with approaching vehicle and car waiting to turn left
- Weave crash with person merging into car in bypass lane
- Running of red light (not applicable at non-signalized intersections)

These crash types were compiled by Agent (5) and his report from 1979 suggested that the critical number of crashes at unsignalized intersections should be 4 per year. If the crash frequency was higher than that, a left turn should be installed. Additional criteria include if excessive volumes were present at the intersection, or if more than 30 left turn conflicts exist in a three-hour period. With the installation of left turn lanes at three-legged intersections, Agent reported that the crash rate was 77% lower at unsignalized intersections with no turn lanes.

2.3 Conclusions of the Published Research

- All of the research addressed the issue of bypass lanes at three-legged intersections, while no mention was made as to the use of bypass lanes at four-legged intersections.

- The installation of bypass lanes at three-legged intersection reduces assumed delay, fuel consumption, emissions and crashes, particularly rear-end collisions.

- Warrants should be utilized on proposed bypass projects that are based on traffic volumes and conflicting movements.

- Bypass lanes can be cost justified based on reductions in crashes and / or delay.

- Being less expensive than exclusive left turn lanes, bypass lanes offer a viable alternative for three-legged intersections where traffic volumes warrant.

3.0 Survey of Practice

The purpose of this chapter is to document and summarize the results that were found from the surveys that were distributed by Mn/DOT's Office of Traffic Engineering to determine characteristics of in-place bypass lanes at unsignalized three and four-legged intersections. These included design and warrant characteristics, pavement markings, and also comment on the operation of the bypass lanes. A copy of the survey that was distributed is included in Appendix A.

3.1 Survey Response

Mn/DOT distributed the survey form entitled "Bypass Lanes at Unsignalized, 3-Legged Intersections" to 125 city engineers and all 87 county engineers throughout the State. Of the 125 surveys sent to the cities, 36 completed surveys were received, giving a response rate of 29%. For the county responses, 46 were received, giving a response rate of 53%. The other survey form, entitled "Combination Right-Turn/Bypass Lanes at Unsignalized Intersections" was distributed as a follow-up to a previous survey with the same intent. This form was distributed to 3 city engineers and 19 county engineers (all those who had responded to the first survey). Only 1 city engineer responded, for a response rate of 33%, while 13 county engineers completed and returned the form, for a response rate of 68%.

3.2 Three-Legged Intersection Bypass Lanes

The objective of a bypass lane at a three-legged intersection is to allow for a vehicle on the major street to move around and pass a stopped or decelerating vehicle traveling in the same direction making a left turn onto the minor street. With a three-legged intersection, there is no street on the opposite side of the one minor street approach, so the bypass lane can be constructed on that side of the intersection with no conflicting traffic. The length and exact geometrics of the bypass lane are functions of the design speed of the road, or are based on other criteria as set by the agency with jurisdiction over the major street.

Several types of signage were offered in the survey as being typically used, including "Pass With Care," "Road Narrows," another type, or no signage at all. Likewise, pavement markings can range from solid white to skip white to no markings.

A typical layout of a three-legged intersection bypass lane is shown in Figure 1.1.

3.3 Four-Legged Intersection Bypass Lanes

The survey results suggested a greater concern at four-legged intersections due to the potential safety consequences, due to conflicting traffic movements on both sides of the main road. The basic objective of the bypass lane is to provide a combined right turn/bypass lane on the right side of the through (and combination left turn) lane. The increased number of conflicts creates more points where crashes may occur. This conflict may become increasingly more important with the use of turn signals by motorists, as confusion may occur regarding what exactly the turn signal is identifying. As with the three-legged intersection, the exact length of bypass lane is a function of the design speed and/or the criteria set by the agency with jurisdiction over the bypass lane.

The signage that was suggested in the survey included a right turn sign, right turn only, combined right/through, or none at all. Pavement makings can also be used, similar to the three-legged intersection. A typical layout of a four-legged intersection bypass lane is included in shown 1.1.

3.4 Summary of Response Data for Three-Legged Intersections

The design guidelines used by the county and city agencies are shown above in Figure 3.1. Note that 53% of the cities (16 out of 29) have no design guidelines. In the matter of signing used for bypass lanes at three-legged intersections, only two county agencies and two cities use signage for this instance. The two cities that use signage use a "Pass With Care" sign or a Left-Turn combination with Straight Arrow sign. The two counties that responded with signage used a "Pass With Care" in combination with "Bypass Ahead" or a "Right Turn Lane" sign.

The pavement markings used at three-legged intersections with bypass lanes are summarized in Figure 3.2. For both the county and city agencies, a skip white line is the most frequently utilized form of pavement marking.

In addition and/or in place of the pavement markings, Figure 3.3 contains results regarding pavement messages. The majority of both the county and city agencies use no forms of pavement messages.

The length of time that the bypass lanes had been in place varied between the county and city agencies. Approximately 81% of the bypass lanes that were listed by county agencies had been in place on January 1, 1995, while only 62% of the bypass lanes were in place on that date, as referenced by the city agencies.

3.4.1 Field Operation of Bypass Lanes at Three-Legged Intersections

When the previously described surveys were returned, some agencies chose to utilize the last section to write opinions and observations regarding the operation of bypass lanes. In all 46 surveys that were returned by county agencies, none had negative comments on bypass lanes at three-legged intersections. There existed a consensus among the county engineers that completed this section of the survey that the bypass lanes are safe, efficient, and effective tools at three-legged intersections. Some concerns brought up by the county engineers included school bus stops and concerns that bypass lanes may only be cost effective on roads that have heavy volumes.

Of the 36 city engineers that returned the surveys, the comments spanned a much larger range. For example, some city engineers felt that the bypass lanes were only effective at low operating speeds (below 45 miles per hour), while other city engineers felt that these lanes were only helpful at speeds above 45 miles per hour. Some city engineers wrote that they were pleased with the operation of these lanes in their municipality, but many cited that the bypass lanes belong on rural routes and not inside the city.

However, a majority of the city engineers mentioned that the use of these bypass lanes is a safer alternative than not having them at all. Although some cities mentioned that a left turn lane would be better, the bypass lanes were less expensive.

3.5 Summary of Response Data for Four-Legged Intersections

Since the data return from the cities did not reflect a sufficient number to base conclusions from, only responses from county engineers are reflected in the data presentation. Some comments were received from the city engineers on the three-legged survey forms that relate to the four-legged intersections, and those comments are listed below with the comments from the county engineers.

Figures 3.4 through 3.6 below contain data for design guidelines, pavement markings, and pavement messages, respectively.

The signing options included in the survey for combined right turn/bypass lanes included a right turn sign, right turn only, a combined right/through arrow, or no signing at all. Of the 13 county agencies that responded to the survey, 73% of the intersections with these lanes under the jurisdiction of the county used no signing. The other 27% of the intersections were posted with the right turn sign. Similar to the three-legged intersections, 84% of the 4-legged bypass lanes were in place on January 1, 1995.

3.5.1 Field Operation of Bypass Lanes at Four Legged Intersections

The county engineers that completed and returned the surveys with comments regarding the operation of combination right turn/bypass lanes at four-legged intersections were not in agreement as to the use of such lanes. Some county engineers felt that these lanes seemed safe in operation and were necessary for higher traffic volumes. Other county engineers felt that this geometry was unsafe, citing that drivers have a tendency to pass a left turning vehicle at higher speeds and do not have adequate visibility of the intersection. One county engineer suggested that as a possible mitigation measure, either signing could be installed, or simply allow people to pass on the shoulder if at a slower speed.

Some of the city engineers who responded on the three-legged intersection survey form offered comments regarding bypass lanes at four-legged intersections. These comments were all in agreement that the construction of such lanes is unsafe and no bypass lane should be constructed at any intersection with greater than three legs.

3.6 Conclusions of the Survey of Practice

- Most counties in Minnesota are consistent with the design of bypass lanes at three-legged and four-legged intersections, most using Mn/DOT guidelines.

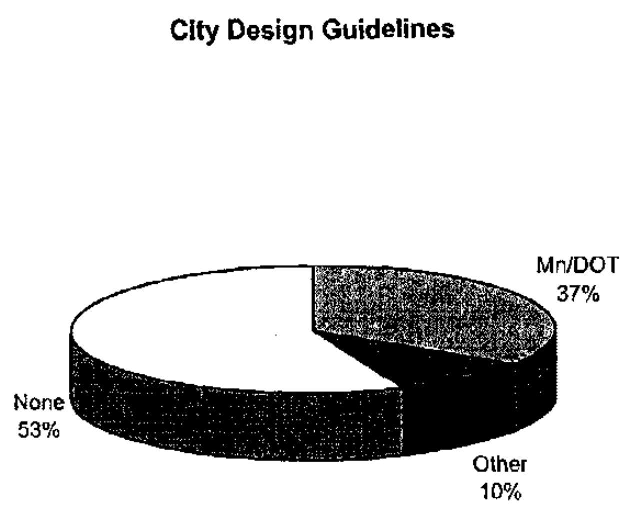
- Over one-half of the cities that returned the survey form do not follow Mn/DOT guidelines for design of bypass lanes at three-legged intersections, and also are inconsistent with the pavement messages and markings used.

- Although some minor concerns were addressed, such as school bus stops, county engineers agree that operation of bypass lanes at three-legged intersections is a safe, efficient, and effective tool.

- Some city engineers did not endorse bypass lanes at three-legged intersections within the city, but agreed that they were a safer option than having no bypass or left turn lanes. However, none of the city engineers felt that bypass lanes should be used at four-legged intersections.

- County engineers did not form a consensus regarding the operation of bypass lanes at four-legged intersections, but many expressed concerns with the safety of such lanes with increased chances of a crash occurring.

- The majority of the counties provide pavement markings that suggest a "right turn only" situation and are, therefore, inconsistent with any type of bypass function.



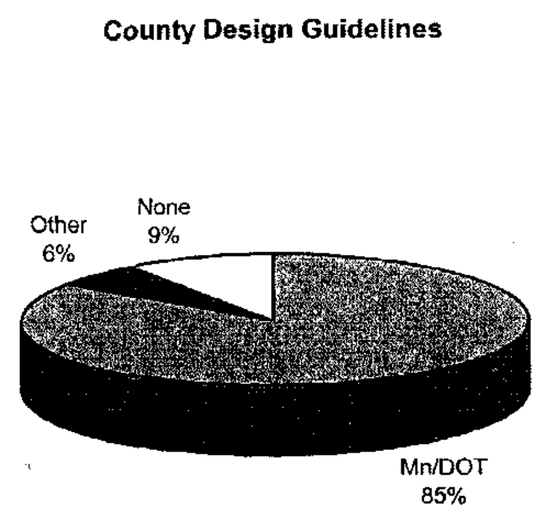


Figure 3.1
Design Guidelines for City and County Agencies At Three-Legged Intersections

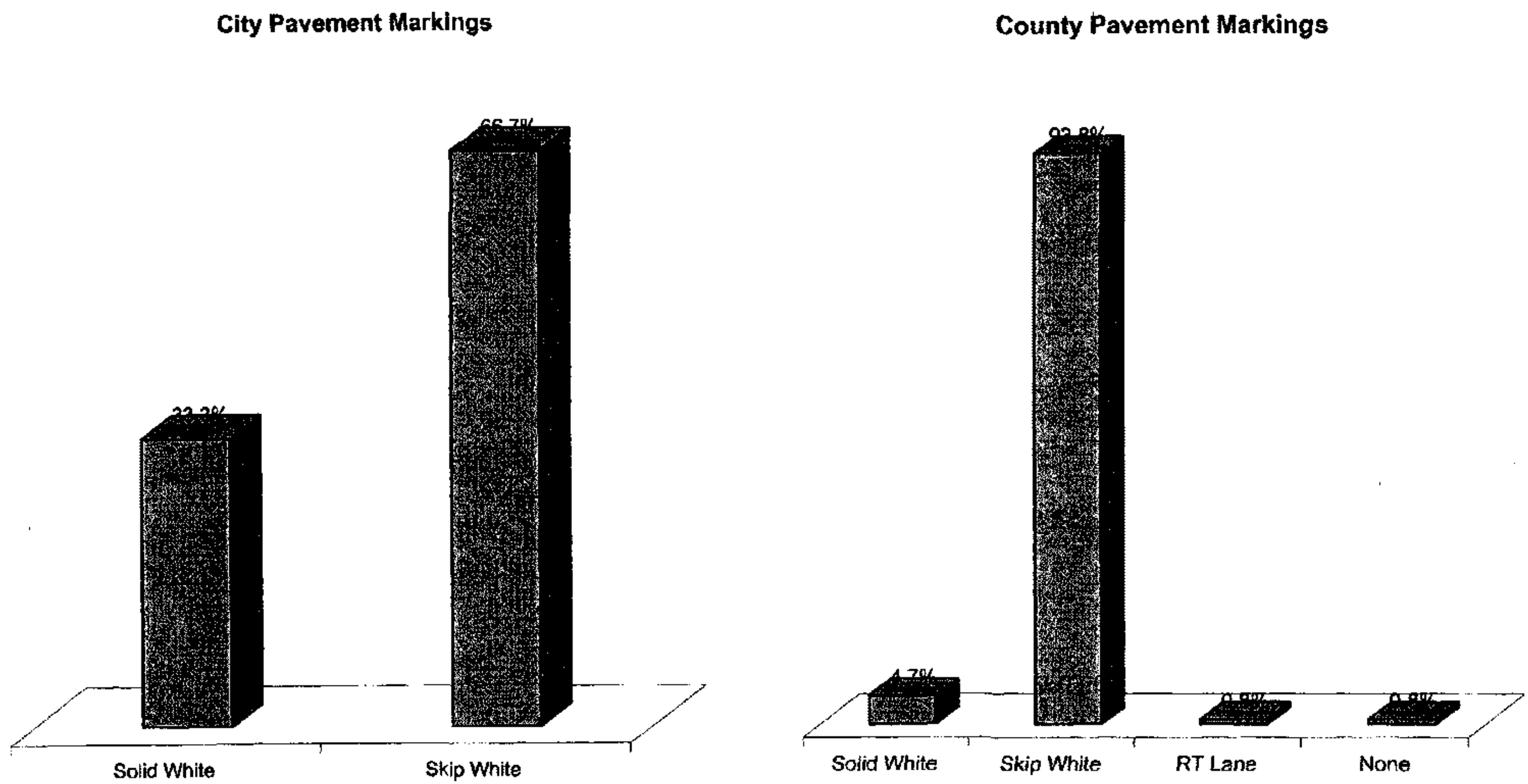


Figure 3.2
Pavement Markings at Three-Legged Intersections With Bypass Lanes

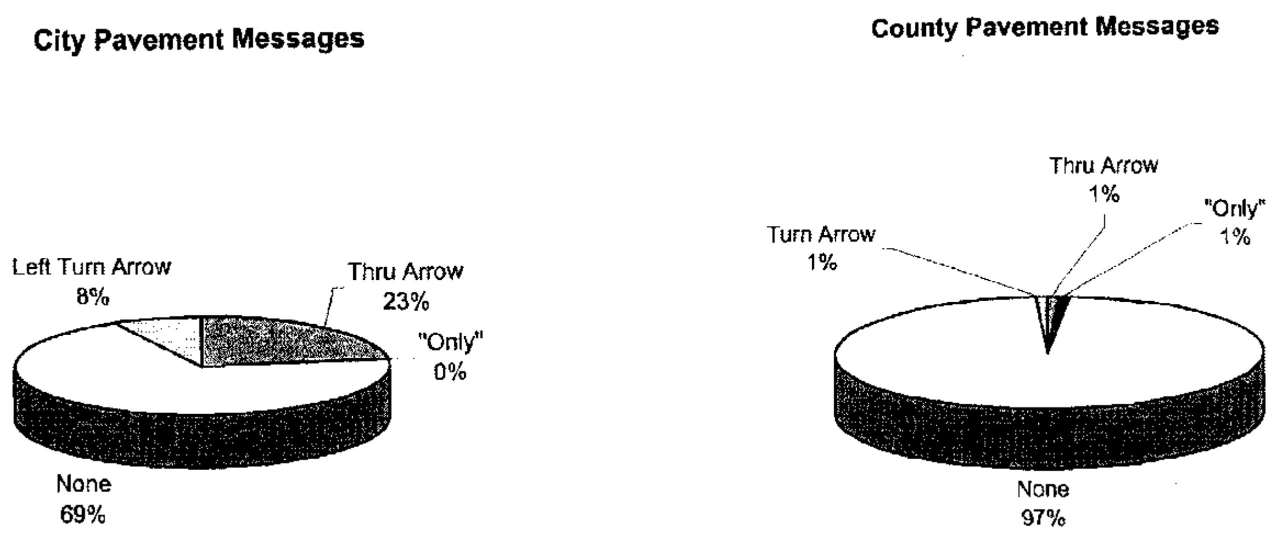


Figure 3.3
Pavement Messages at Three-Legged Intersections With Bypass Lanes

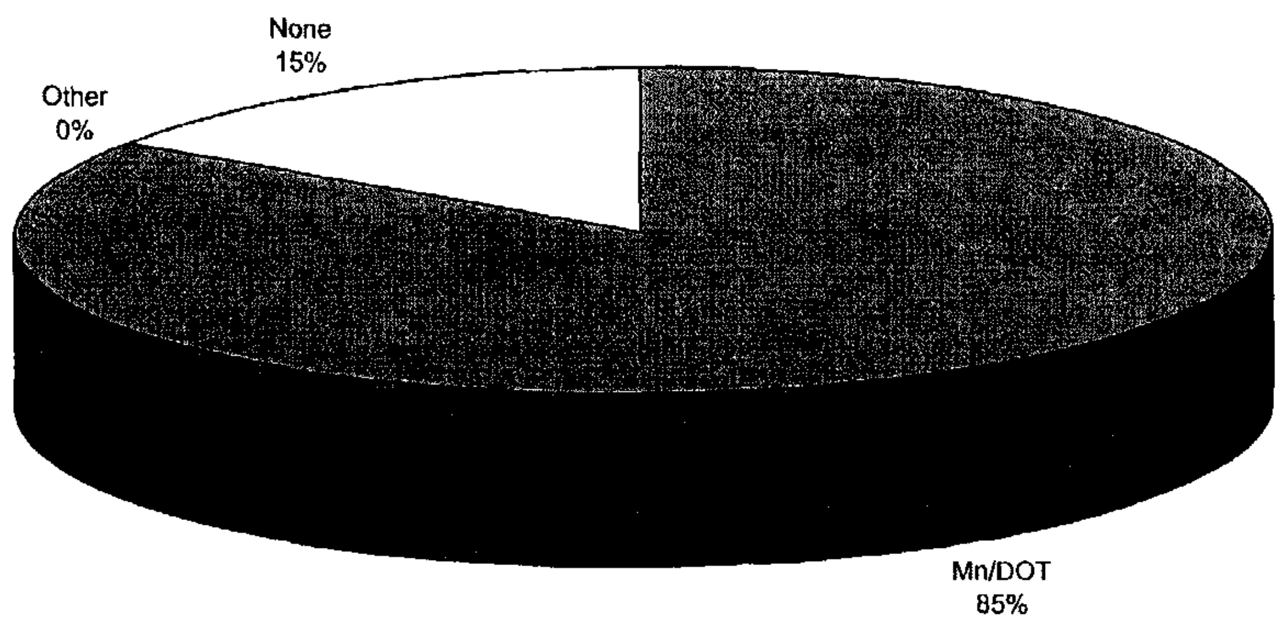


Figure 3.4

Design Guidelines for *County* Agencies at Four-Legged Intersections With Bypass Lanes

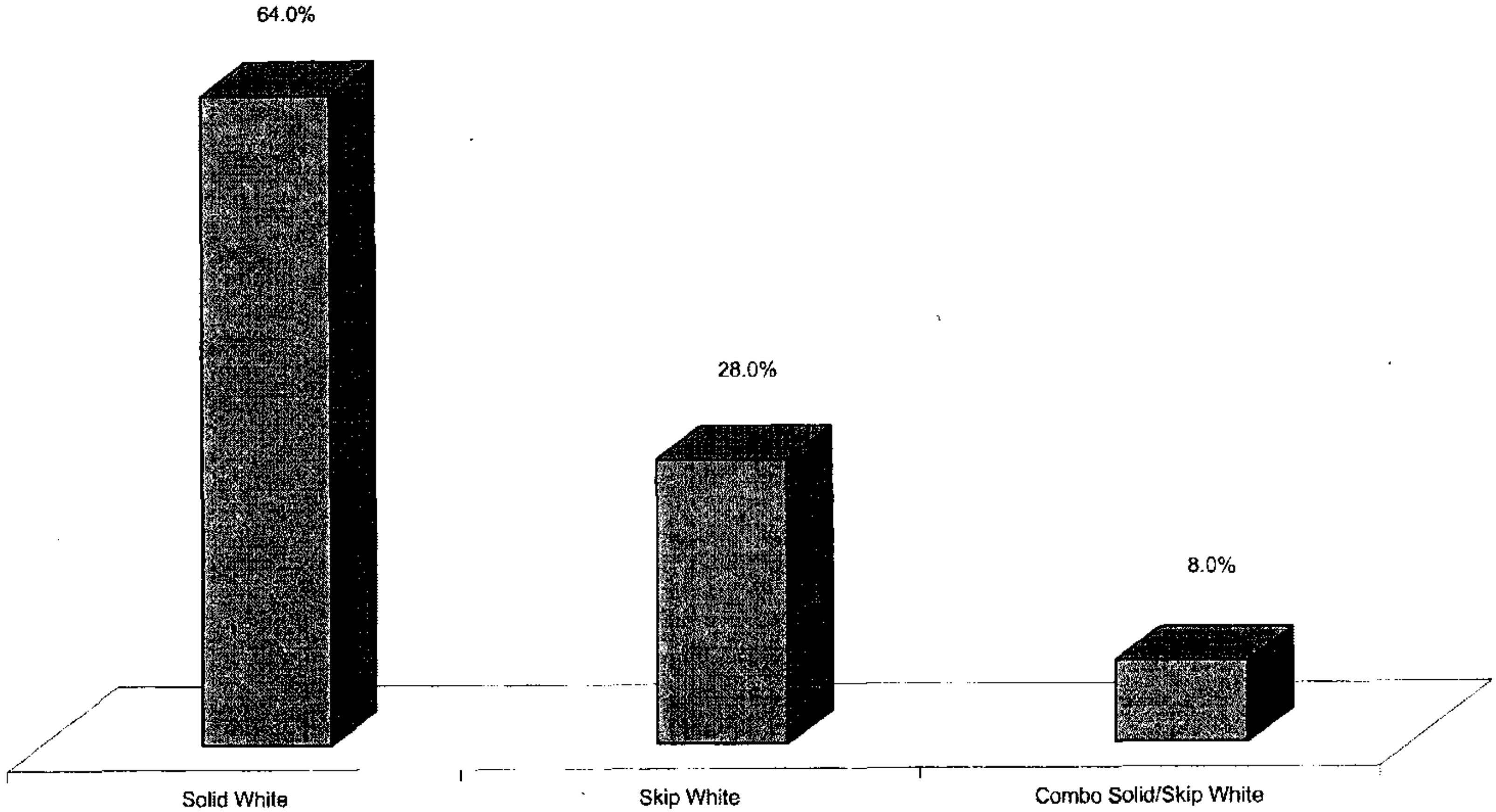


Figure 3.5

Pavement Markings for County Agencies at Four-Legged Intersections With Bypass Lanes

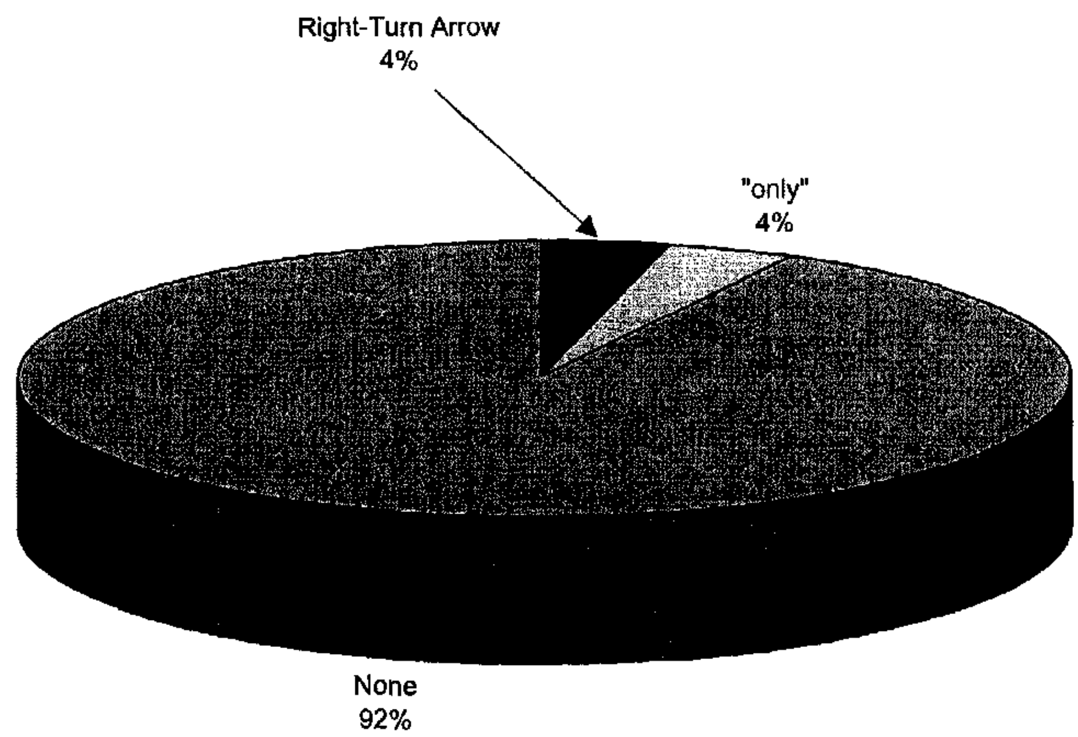


Figure 3.6

Pavement Messages for County Agencies at Four-Legged Intersections With Bypass Lanes

4.0 Legal Issues

Legal issues about bypass lanes and the related issue of passing on the right have existed for at least 25 years. At that time, Mn/DOT staff from the former District 9 met with representatives of the State Patrol, the Washington County Sheriff's office, and the City of Forest Lake Police Department regarding traffic safety issues along Trunk Highway (TH) 97. The reason for the meeting was concerns about how drivers were using the newly reconstructed highway that included bypass lanes at a limited number of public road intersections and 10 foot wide paved shoulders along the remainder of the highway.

The key issue seemed to focus on two facts:

- motorists were not only using the bypass lanes to get around the left turning vehicles stopped in the through lanes,
- they were also using the wide paved shoulder to get around vehicles making left turns at the intermediate minor streets and private driveways.

At this time, the law enforcement agencies decided that passing on the right on the paved shoulder was not legal and began ticketing the offending motorists. Some of these motorists challenged the tickets based on the premise that the Department's use of the bypass lanes only at a few select intersections was in fact encouraging motorists to use the wide shoulders as a de-facto continuous bypass lane and that the paved shoulders should therefore be considered to be part of the "main traveled portion" of the roadway.

It appears that the lack of clarity about passing on the right continues to this day. Twice during the course of preparing this research report, law enforcement personnel have been interviewed in the media and described their agency's attempts to ticket the motorists they observed passing on the right.

As a result of these continuing legal issues, Mn/DOT requested that the Attorney Generals Office conduct appropriate research relative to passing on the right and provide documentation of their opinion. The memorandum submitted by the Office of the Attorney General summarized below:

- Minnesota Statutes are very explicit that passing on the right is only lawful if the pass is made on the "main traveled portion" of the roadway.

- The statutes do not specifically address the issue as to whether passing a left turning vehicle may be done on the shoulder.

- The Attorney General's Office is aware that a City Attorney has provided an opinion that the Statute regarding passing on the right is sufficiently ambiguous such that drivers using the shoulder to get around left turning vehicles will not be prosecuted in that City.

- There is no case law in Minnesota regarding passing on the right.

- There is case law in Wisconsin. In that case the Court rejected the assertion that customary use of the shoulder to bypass left turning vehicles at a particular location established the shoulder as part of the "main-traveled portion" of the roadway. The Court further found that a custom in direct violation of a safety statute does not justify a drivers conduct.

A review of the legal research indicates that the law is very clear about passing on the right. The maneuver is allowed only if it is carried out on the "main-traveled portion" of the roadway. However, the definition of just what constitutes the "main-traveled portion" of the roadway is subject to the interpretation and subsequent enforcement of individual law enforcement officers and prosecutors. Also, it appears that there is little or no consistency in either the interpretation or the application of the existing laws.

5.0 Safety Analysis

The purpose of this chapter is to document a comparative system-wide and Before versus After crash analysis of a sample of rural, through-stop intersections along Minnesota's Trunk Highway system. The reason for conducting the analyses was to determine the safety effects of bypass lanes by comparing crash statistics at the intersections with bypass lanes versus intersections with either no turn lanes or left turn lanes.

5.1 Comparative Crash Analysis

A comparative crash analysis was conducted to determine basic crash characteristics for two categories of intersections:

1. Three-legged Intersections
2. Four-Legged Intersections

Each of these categories was then subdivided into intersections with no turn lanes, with bypass lanes, or with left turn lanes. The comparative analysis included the following:

- 1,155 three-legged intersections (966 with no turn lanes, 163 with bypass lanes, and 26 with left turn lanes)
- 1,582 four-legged intersections (1,509 with no turn lanes, 53 with bypass lanes, and 20 with left turn lanes)

The distribution of the studied intersections, grouped by Mn/DOT District, is illustrated in Table 5.1.

Three years of crash data from 1995 to 1997 was obtained from Mn/DOT's crash records for each intersection in each of the basic categories. The following statistics were documented for each category:

- Total and average number of crashes per intersection
- Average crash rate
- Distribution of crashes by severity (property damage, personal injury, fatal)
- Distribution of crashes by type (rear end, right angle, etc.)

To determine if there is any correlation between crash frequencies and mainline volume levels, a comparative analysis of the crash data and a statistical analysis of the difference in crash frequencies and rates were conducted for the six categories of intersections.

The crash rate is the number of crashes per million vehicles entering the intersection. The number of vehicles entering the intersection is calculated from the approach Average Daily Traffic (ADT) and the period of time over which crashes were observed.

5.1.1 Three-Legged Intersections

The three design categories of three-legged intersections include:

- No Turn Lanes
- Bypass Lanes
- Left Turn Lanes

Tables 5.2 and 5.3 document number of intersections included in the study and the average approach volume range for each of the six intersection categories, respectively. This data indicates two key points. First, the vast majority of the rural three-legged intersections in Mn/DOT's database have no turn lanes (84%). Second, the average approach volume at the intersections with no turn lanes (3100 vehicles per day or vpd) is about 55% lower than the approach volumes at intersections with either bypass or left turn lanes (7000 vpd).

From the Mn/DOT crash data, an average crash rate was determined for each category of three-legged intersections (Table 5.4 and Figure 5.1). Intersections with a left turn lane had the highest crash rate of the three categories at 0.55 whereas intersections that included a bypass lane had the lowest crash rate at 0.49. However, a statistical analysis indicated that the difference between the crash rates for various intersection categories was not significant at a 90 percent confidence interval.

Figure 5.2 shows the number of three-legged intersections studied by approach volume for each category. The 0 to 2000 approach volume range had the highest number of intersections with no turn lanes, and the 2000 to 4000 approach volume range had the highest number of intersections for both intersections with bypass lanes and intersections with left turn lanes.

5.1.1.1 Crash Rates Grouped by Intersection Design Category

From the breakdown of intersections by approach volume, an average crash rate was determined for each intersection design category by approach volume.

Figures 5.3 through 5.5 show the average crash rates based on approach volume ranges for the three different intersection categories. The statistical reliability of the data for the three categories is moderate to low. The difference between the levels of statistical reliability (high, moderate, and low) is related to the number of intersections in each approach volume range. The greater the number of intersections in each range, the higher the level of statistical reliability. The average crash rates for each approach volume range were also compared to the Minnesota statewide averages for similar intersection categories. The crash rates for intersections with no turn lanes were similar to the crash rates of the statewide population at the lower approach volume ranges. The crash rates for intersections with a bypass lane or a left turn lane were much more varied. However, none of the categories showed a noticeable correlation with the volume of approach traffic at the intersections.

5.1.1.2 Crash Rates Grouped by Approach Volume

Figure 5.6 shows the average crash rate grouped by approach volume for each intersection design category. The approach volumes were broken into three ranges:

- 0 to 4000 vehicles per day (vpd) approach volume
- 4000 to 10,000 vpd approach volume
- > 10,000 vpd approach volume

For intersections with no turn lanes and intersections with a left turn lane, the differences in the crash rates between the greater than 10,000 vpd approach volume range and the other two approach volume ranges were statistically significant at a 90 percent confidence interval. For intersections with a bypass lane, the difference in the crash rates is only significant at a 90 percent confidence interval between the 0 to 4000 vpd approach volume range and the greater than 10,000 vpd approach volume range.

Figure 5.7 shows the average crash rate grouped by no turn lanes / bypass lane / left turn lane with the approach volumes ranges used in the previous figure.

For the 0 to 4000 vpd and 4000 to 10,000 vpd approach volume ranges, the crash rates between each intersection category are not statistically significant at a 90 percent confidence interval. For the greater than 10,000 vpd approach volume range, the difference in crash rates between the left turn lane category and both of the other intersection categories was statistically significant at a 90 percent confidence interval.

This data suggests two key points. First, at the lowest volume levels (0 to 4000 vpd), the number of intersection conflicts is low enough so that it appears that intersection geometry does not have a large influence on crash rates. There is little variance and no significant difference in crash rates among intersection designs. Second, at the highest volume levels (greater than 10,000 vpd) the positive effects of exclusive left turn lanes are both noticeable and significant. The intersections with left turn lanes had significantly lower crash rates than either of the other categories.

5.1.1.3 Crash Severity

The distribution of crash severity for three-legged intersections was calculated to determine the effect of intersection geometry. Table 5.5 and Figure 5.8 show the average crash severities for the three intersection categories. At intersections with a left turn lane, there was an approximate 20 percent decrease in the crash severity (percent injury plus fatal crashes) compared to intersections with no turn lanes; while at intersections with a bypass lane, there was an approximate 10 percent decrease in the crash severity over intersections with no turn lanes. However, the difference in the crash severities is not statistically significant at a 90 percent confidence interval.

Figure 5.9 shows the percentage of personal injury and fatal crashes grouped by approach volume for each intersection category. For all three intersection categories, the greater than 10,000 vpd approach volume range has the highest percentage of personal injury and fatal crashes. For intersections with no turn lanes, the difference in the percent of personal injury and fatal crashes is statistically significant at a 90 percent confidence interval between all three approach volume ranges. For intersections with a bypass lane, the difference in the percent of injury and fatal crashes is statistically significant at a 90 percent confidence interval between the greater than 10,000 vpd approach volume range and both of the other approach volume ranges. Due to the small number of intersections and crashes at intersections with left turn lanes, the percent of injury and fatal crashes is not statistically significant at a 90 percent confidence interval for intersections with a left turn lane.

This data suggests that there is a noticeable positive relationship between intersection approach volume and crash severity. For all three intersection design categories, the severity index increased as the volume of traffic increased. In addition, intersections with bypass lanes had the lowest severity index in two of the three volume categories (0 – 4,000 vpd and >10,000 vpd) and intersections with left turn lanes had the lowest severity index in the remaining volume category (4,000 – 10,000 vpd). However, these differences were not statistically significant.

5.1.1.4 Types of Crashes

The distribution of types of crashes occurring at the various design categories at various three-legged intersections is documented in Table 5.6. This data illustrates two key points. First, the percentage of rear end crashes is highest (26%) at intersections with bypass lanes and lowest (14%) at intersections with left turn lanes. Second, the percentage of right angle crashes is highest (27%) at intersections with left turn lanes and lowest (16%) at intersections with no turn lanes.

5.1.1.5 Summary of Crash Information at Three-Legged Intersections

- Intersections with left turn lanes appear to have the highest average crash rate (0.55) compared to intersections with no turn lanes (0.52) and intersections with bypass lanes (0.49). However, the difference in the crash rates is not statistically significant at the 90 percent confidence interval

- The analysis of crash rates did not indicate a noticeable relationship with approach traffic volumes.

- At the lowest volume levels (0 to 4000 vpd), the positive effects of exclusive left turn lanes are noticeable but not significant. The intersections with left turn lanes had lower crash rates than either of the other design categories.

- At the highest volume levels (greater than 10,000 vpd) the positive effects of exclusive left turn lanes are both noticeable and significant. The intersections with left turn lanes had significantly lower crash rates than either of the other design categories.

- At the intermediate volume level (4000 to 10,000 vpd), the differences in design category crash rates are not significant.

- There was a 10 percent reduction in the severity index from intersections with no turn lanes to intersections with bypass lanes; there was a 20 percent reduction in the severity index from intersections with no turn lanes to intersections with left turn lanes. The reductions in the severity indices were not statistically significant at the 90 percent confidence interval.

- The highest percentage of personal injury and fatal crashes for each intersection design category occur in the greater than 10,000 vpd approach volume range. However, the differences in the severity indices for each design category are not statistically significant.

- There is a noticeable positive relationship between intersection approach volume and crash severity (percentage of injury plus fatal crashes). The higher the volume, the greater the severity of crashes.

- Intersections with left turn lanes have the lowest percentage of injury plus fatal crashes.

- Intersections with bypass lanes had the highest percentage of rear end crashes and intersections with left turn lanes had the lowest percentage.

- Intersections with left turn lanes had the highest percentage of right angle crashes and intersections with no turn lanes had the lowest percentage.

5.1.2 Four-Legged Intersections

The same three intersection design categories that were used for three-legged intersections were used for four-legged intersections. These include:

- No Turn Lanes
- Bypass Lanes
- Left Turn Lanes

Tables 5.2 and 5.3, again, show the number of intersections included in the study and the average approach volumes for each of the intersection categories. As was the case with three-legged intersections, the data indicates that the vast majority of rural four-legged intersections have no turn lanes (96%). In addition, the average approach volume at intersections with no turn lanes (2500 vpd) is about 40% to 60% lower than the approach volume at intersections with either bypass or left turn lanes.

Table 5.4 and Figure 5.10 show the average crash rates that were determined for each type of intersection design category from the Mn/DOT crash data. All three categories have approximately the same average crash rate (0.60). A statistical analysis indicated that the differences in the crash rates between intersection categories were not statistically significant at a 90 percent confidence interval.

Figure 5.11 shows the number of four-legged intersections studied by approach volume. The 0 to 2000 vpd approach volume range had the greatest number of intersections with no turn lanes. For both intersections with bypass lanes and intersections with left turn lanes, the greatest number of intersections is in the 2000 to 4000 vpd approach volume range.

5.1.2.1 Crash Rates Grouped by Intersection Design Category

Figures 5.12 through 5.14 show the average crash rate based on approach volume ranges for the three different intersection design categories. The statistical reliability of the data for the three intersection categories is moderate to low because of the low number of intersections in certain volume ranges. The average crash rates were again compared to the Minnesota statewide averages for crash rates at similar intersections. The crash rates for four-legged intersections with no turn lanes were similar to the statewide averages for each of the volume ranges. The crash rates for intersections with a bypass lane or a left turn lane were much more varied for the different volume ranges. However, none of the categories showed a noticeable relationship between the crash rate and the volume of approach traffic at the intersections.

5.1.2.2 Crash Rates Grouped by Approach Volume

Figure 5.15 shows the average crash rate grouped by approach volume for each intersection design category. These approach volume ranges are the same as those for the three-legged intersections and include:

- 0 to 4000 vpd approach volume
- 4000 to 10,000 vpd approach volume
- > 10,000 vpd approach volume

For the three intersection design categories, the crash rate is the highest for the 4000 to 10,000 vpd approach volume range. Of these intersection design categories, intersections with no turn lanes and bypass lanes had statistically significant differences in crash rates at a 90 percent confidence interval between specific volume ranges. The differences in the crash rates between the volume ranges for the other intersection design categories were not statistically significant at a 90 percent confidence interval.

A final review of the crash data was conducted and Figure 5.16 shows the average crash rate grouped by no turn lane / bypass lane / left turn lane with the approach volume ranges used in the previous figure. For each of these categories, the differences in the crash rates were not statistically significant at a 90 percent confidence interval.

5.1.2.3 Crash Severity

A distribution of the crash severity for each intersection category was calculated to determine the effect of intersection geometry. Figure 5.17 indicates that intersections with a bypass lane or a left turn lane had a slightly greater percentage of personal injury and fatal crashes (11% and 14%, respectively) than intersections with no turn lanes. However, the differences in crash severity for each intersection category are not statistically significant at a 90 percent confidence interval.

Figure 5.18 shows the percentage of personal injury and fatal grouped by approach volume for each intersection category. The differences in the crash severities between each volume range for each intersection category are not statistically significant at a 90 percent confidence interval.

5.1.2.4 Types of Crashes

The distribution of types of crashes occurring at the various design categories of four-legged intersections is documented in Table 5.7. The data illustrates the same two key points as for three-legged intersections. First, the percentage of rear end crashes is highest at intersections with bypass lanes and lowest at intersections with left turn lanes. Second, the percentage of right angle crashes is highest at intersections with left turn lanes and lowest at intersections with no turn lanes.

5.1.2.5 Summary of Crash Information at Four-Legged Intersections

- Intersections with no turn lanes have the highest average crash rate (0.613) for the three intersection categories. However, the differences in the crash rates are very small and are not statistically significant at a 90 percent confidence interval.

- For intersections with no turn lanes, the highest average crash rate (0.77) occurs in the 6000 – 8000 vpd approach volume range. The crash rate data has a moderate level of statistical reliability.

- For intersections with a bypass lane, the highest average crash rate (0.84) occurs in the 8000 – 10,000 vpd approach volume range. This crash rate data has a low level of statistical reliability.

- For intersections with a left turn lane, the highest average crash rate (1.70) occurs in the 4000 – 6000 vpd approach volume range. This crash rate data has a low level of statistical reliability because of the very small sample size of the available data.

- When the average crash rate is grouped by approach volume, the 4000 – 10,000 vpd approach volume range has highest crash rate for each intersection category.

- Intersections with a bypass lane or a left turn lane have a 10 percent and 14 percent, respectively, higher crash severity than intersections with no turn lanes.

- Intersections with bypass lanes had the highest percentage of rear end crashes and intersections with left turn lanes had the lowest percentage.

- Intersections with left turn lanes had the highest percentage of right angle crashes and intersections with no turn lanes had the lowest percentage.

5.2 Before versus After Crash Analysis

A Before versus After crash analysis was conducted to provide additional information about the safety effects of bypass lanes. A total of six years of crash data was collected from Mn/DOT's crash records. This included three years before the construction of the bypass lane and three years after this construction (not including the year that the bypass lanes were constructed). The crash data was collected for a total of 69 intersections where bypass lanes had been constructed between the years 1983 and 1994. These years were used because Mn/DOT can only retrieve crash records as far back as 1980.

5.2.1 Total Crash Frequency / Rate

There were a total of 204 crashes (0.99 crashes per year) before construction and 194 crashes (0.94 crashes per year) after construction (Figure 5.19). It was determined that the average intersection crash rate was 0.37 crashes per million entering vehicles (MEV) in the Before period and 0.35 crashes per MEV in the After period. None of these differences are statistically significant.

5.2.2 Crash Types

The data was analyzed in order to determine the Before versus After distribution of crash types (rear end, right angle, head on, etc.). Figure 5.20 shows the distribution of crash types based on crash rates and Figure 5.21 shows the distribution based on percentage of crashes.

The analysis of the crash type data indicates two interesting trends. First, in the Before period, the frequency of rear end, left turn, and off road crashes was higher than expected. After construction of the bypass lanes, the frequency of left turn and off road crashes decreased to the expected levels but the frequency of left turn crashes remained high and virtually unchanged. Second, after construction of bypass lanes, there were noticeable increases in the frequency of both right angle and head on crashes. However, none of the differences are statistically significant.

In an attempt to increase the sample size and statistical reliability, the crash type data was then aggregated into two groups, single vehicle and multiple vehicle crashes. Figure 5.22 shows the crash rates for single and multiple vehicles before and after the construction of a bypass lane. The data shows that there was not a statistically significant change in the crash rate of either single vehicle or multiple vehicles from before to after the construction of the bypass lanes.

5.2.3 Crash Severity

The distribution of crashes by severity (percentage of injury plus fatal crashes) was determined for both the Before and After periods. Figure 5.23 shows that the severity index actually increased after the bypass lane was constructed. However, the differences are not statistically significant at a 90 percent confidence interval.

5.2.4 Before versus After Summary

- The analysis of the Before versus After crash data shows a modest decrease in total crashes, crash frequency, and crash rate associated with the construction of bypass lanes.
- None of the differences are statistically significant.
- The severity index increased by 25 percent After construction of the bypass lanes.
- The average crash rate in the Before period was 0.37 crashes per MEV. This rate is approximately 25 to 40 percent lower than the statewide average for similar intersections and raises the question as to why these intersections were selected for additional treatment.

5.3 Safety Summary

The results of the system-wide comparative analysis of over 2700 intersections are shown in Table 5.8 and are summarized below.

1. Three-legged intersections have lower crash rates than four-legged intersections in all three intersection design categories.

2. Differences in crash data do not appear to be a function of total volume entering the intersection.

3. There are small differences in average crash rates between the three design categories, but the differences are not statistically significant.

4. There appears to be a positive relationship between traffic volume and severity indices, with higher volumes resulting in a higher percentage of injury plus fatal crashes.

5. Intersections with left turn lanes have the lowest percentage of rear end crashes and the highest percentage of right angle crashes. Intersections with bypass lanes have the highest percentage of rear end crashes.

6. At low volume levels (0 – 4000 vpd), the positive effects of left turn lanes are noticeable. The intersections with Left Turn Lanes had the lowest crash rates and those with Bypass Lanes had the highest crash rates.

7. At intermediate volume levels (4000 – 10,000 vpd), intersections with left turn lanes had the highest crash rates and those with no turn lanes had the lowest crash rates.

8. At high volume levels (greater than 10,000 vpd), the results were mixed. Three-legged intersections with left turn lanes had the lowest crash rate, but four-legged intersections with left turn lanes had the highest crash rate.

9. The results of the comparative crash analysis have a low level of statistical reliability because of very small sample sizes in the bypass lane and left turn lane categories. In addition, a review of the statewide distribution of the intersections in Mn/DOT's database indicates a potential bias. Districts 1 and 4 (predominantly rural areas) account for fewer than 5 percent of the total intersections analyzed, while the metropolitan area accounts for almost 20 percent of the intersections.

The results of the Before versus After analysis of 69 intersections where Bypass Lanes were constructed are shown in Table 5.9 and are summarized below.

1. Following the construction of the Bypass Lanes, there was a modest decrease in total crashes, average intersection crash frequency, and average crash rate. However, none of these changes were statistically significant.

2. The severity index increased by 25 percent following construction of the Bypass Lanes.

3. The average crash rate in the Before period was approximately 25 to 40 percent lower than the statewide average for similar intersections. This could explain why there was no decrease and also calls into question why these intersections were selected for additional treatment.

Table 5.1
Distribution of Intersections by MnDOT District

System-Wide Comparative Analysis

	Three-Legged Intersections						Four-Legged Intersections							
	No Turn Lane		Bypass Lane		Left Turn Lane		No Turn Lane		Bypass Lane		Left Turn Lane			
	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Total	Percent
District 1	14	1.4%	2	1.2%	1	3.8%	15	1.0%	0	0.0%	1	5.0%	33	1.2%
District 2	173	17.9%	1	0.6%	3	11.5%	377	25.0%	1	1.9%	4	20.0%	559	20.4%
District 3	174	18.0%	17	10.4%	3	11.5%	225	14.9%	8	15.1%	3	15.0%	430	15.7%
District 4	19	2.0%	25	15.3%	1	3.8%	54	3.6%	5	9.4%	1	5.0%	105	3.8%
District 6	145	15.0%	17	10.4%	2	7.7%	190	12.6%	4	7.5%	2	10.0%	360	13.2%
District 7	116	12.0%	15	9.2%	3	11.5%	289	19.2%	4	7.5%	2	10.0%	429	15.7%
District 8	69	7.1%	13	8.0%	2	7.7%	252	16.7%	4	7.5%	1	5.0%	341	12.5%
Metro	256	26.5%	73	44.8%	11	42.3%	107	7.1%	27	50.9%	6	30.0%	480	17.5%
Total	966	100%	163	100%	26	100%	1509	100%	53	100%	20	100%	2737	100%

Table 5.2
Summary of Studied Intersections

Three-Legged Intersections			
No Turn Lanes 966 Intersections	Bypass Lane 163 Intersections	Left Turn Lane 26 Intersections	Total 1,155 Intersections
Four-Legged Intersections			
No Turn Lanes 1,509 Intersections	Bypass Lane 53 Intersections	Left Turn Lane 20 Intersections	Total 1,582 Intersections

Source: Mn/DOT Crash Data

Table 5.3
Approach Volume by Intersection Type

State-Wide Comparative Analysis

Three-Legged Intersections		
NoTurn Lanes Range: 163 - 23,045 vehicles Average App. Vol: 3102	Bypass Lane Range: 758 - 23,575 vehicles Average App. Vol: 7113	Left Turn Lane Range: 755 - 18,750 vehicles Average App. Vol: 6891
Four-Legged Intersections		
No Turn Lanes Range: 120 - 39,904 vehicles Average App. Vol: 2477	Bypass Lane Range: 1,443 - 20,500 vehicles Average App. Vol: 7524	Left Turn Lane Range: 2,035 - 13,780 vehicles Average App. Vol: 5881

Source; Mn/DOT Crash Data

Table 5.4
Comparison of Crash Rates
Three-Legged versus Four-Legged Intersections

System - Wide Comparative Analysis

	No Turn Lanes		Bypass Lanes		Left Turn Lanes	
	Number of Intersections	**Crash Rate**	**Number of Intersections**	**Crash Rate**	**Number of Intersections**	**Crash Rate**
Three-Legged Intersections	966 (0.7 crashes/Int)	0.52	163 (1.2 crashes/Int)	0.49	26 (4.3 crashes/Int)	0.55
Four-Legged Intersections	1,509 (0.6 crashes/Int)	0.61	53 (1.6 crashes/Int)	0.59	20 (12.4 crashes/Int)	0.61

Source: Mn/DOT Crash Data

8/1/2000

Table 5.5
Comparison of Severity Indices
Three-Legged versus Four-Legged Intersections

System - Wide Comparative Analysis

	No Turn Lanes		Bypass Lanes		Left Turn Lanes	
	Number of Intersections	Severity Index*	Number	Severity Index*	Number	Severity Index*
Three-Legged Intersections	966	38.3%	163	34.2%	26	30.7%
Four-Legged Intersections	1,509	41.6%	53	46.0%	20	47.4%

* Severity Index = Percent Personal Injury plus Fatal Crashes

Source: Mn/DOT Crash Data

8/1/2000

Table 5.6
Distribution of Crashes by Crash Type
Three-Legged Intersections

System-Wide Comparative Analysis

Crash Type	No Turn Lane		Bypass Lane		Left Turn Lane	
	Total Number of Crashes	Percent	Total Number of Crashes	Percent	Total Number of Crashes	Percent
Not Applicable	175	8.7%	56	9.7%	22	6.6%
Rear End	374	18.6%	152	26.3%	48	14.3%
Sideswipe - Passing	113	5.6%	18	3.1%	16	4.8%
Left Turn	64	3.2%	26	4.5%	20	6.0%
Off Road - Left	154	7.6%	32	5.5%	28	8.4%
Right Angle	324	16.1%	100	17.3%	92	27.5%
Right Turn	8	0.4%	2	0.3%	3	0.9%
Off Road - Right	291	14.4%	46	8.0%	46	13.7%
Head On	66	3.3%	23	4.0%	8	2.4%
Sideswipe - Opposing	61	3.0%	11	1.9%	2	0.6%
Other	161	8.0%	46	8.0%	14	4.2%
Unknown	225	11.2%	66	11.4%	36	10.7%
Total	2016	100%	578	100%	335	100%

Source: MnDOT Crash Data

Table 5.7
Distribution of Crashes by Crash Type
Four - Legged Intersections

System-Wide Comparative Analysis

Crash Type	No Turn Lane		Bypass Lane		Left Turn Lane	
	Total Number of Crashes	Percent	Total Number of Crashes	Percent	Total Number of Crashes	Percent
Not Applicable	154	5.8%	15	6.0%	54	7.3%
Rear End	396	14.9%	61	24.6%	91	12.3%
Sideswipe - Passing	155	5.8%	6	2.4%	37	5.0%
Left Turn	93	3.5%	4	1.6%	27	3.6%
Off Road - Left	148	5.6%	6	2.4%	39	5.3%
Right Angle	897	33.7%	89	35.9%	329	44.4%
Right Turn	13	0.5%	3	1.2%	2	0.3%
Off Road - Right	258	9.7%	23	9.3%	69	9.3%
Head On	68	2.6%	8	3.2%	9	1.2%
Sideswipe - Opposing	61	2.3%	4	1.6%	7	0.9%
Other	176	6.6%	9	3.6%	38	5.1%
Unknown	246	9.2%	20	8.1%	39	5.3%
Total	2665	100%	248	100%	741	100%

Table 5.8
Results of Comparative Analysis

System-Wide Comparative Analysis

	No Turn Lanes		Bypass Lanes		Left Turn Lanes	
	Three-Legged Intersections	Four-Legged Intersections	Three-Legged Intersections	Four-Legged Intersections	Three-Legged Intersections	Four-Legged Intersections
Number of Intersections	966	1509	163	53	26	20
Average Volume (vpd)	3102	2477	7113	7524	6891	5881
Average Crashes / Intersection	0.7	0.6	1.2	1.6	4.3	12.4
Average Crash Rate	0.52	0.61	0.49	0.59	0.55	0.61
Severity Index	38.3%	41.6%	34.2%	46.0%	30.7%	47.4%
Percentage of Crashes						
Rear End	18.6%	14.9%	26.3%	24.6%	14.7%	12.3%
Left Turn	3.2%	35.0%	45.0%	1.6%	6.0%	3.6%
Right Angle	16.1%	33.7%	17.3%	35.9%	27.5%	44.4%
Crash Rates by Volume Category						
0 - 4000 vpd	0.56	0.6	0.64	0.65	0.53	0.41
4000 - 10,000 vpd	0.45	0.71	0.48	0.72	0.93	0.97
> 10,000 vpd	0.25	0.55	0.34	0.37	0.04	0.58
Severity by Volume Category						
0 - 4000 vpd	33.3%	41.0%	23.2%	54.5%	29.4%	38.5%
4000 - 10,000 vpd	42.4%	42.3%	39.0%	44.7%	32.7%	51.5%
> 10,000 vpd	66.1%	43.1%	65.1%	44.3%	83.3%	46.9%

Source: MnDOT Crash Data

8/1/2000

Table 5.9
Results of Before versus After Analysis

System-Wide Comparative Analysis

	Before	After	Difference	Statistical Significance
Number of Intersections	69	69		
Total Number of Crashes	204	194	-4.9%	No
Average Number of Crashes / Year	0.99	0.94	-5.0%	No
Average Crash Rate	0.37	0.35	-5.4%	No
Crash Types - Percentage				
Rear End	22.5%	22.7%	0.9%	No
Left Turn	7.4%	3.6%	-51.4%	No
Right Angle	15.2%	20.1%	32.2%	No
Head On	2.9%	5.7%	96.6%	No
Severity Index	31.4%	41.2%	31.2%	Yes

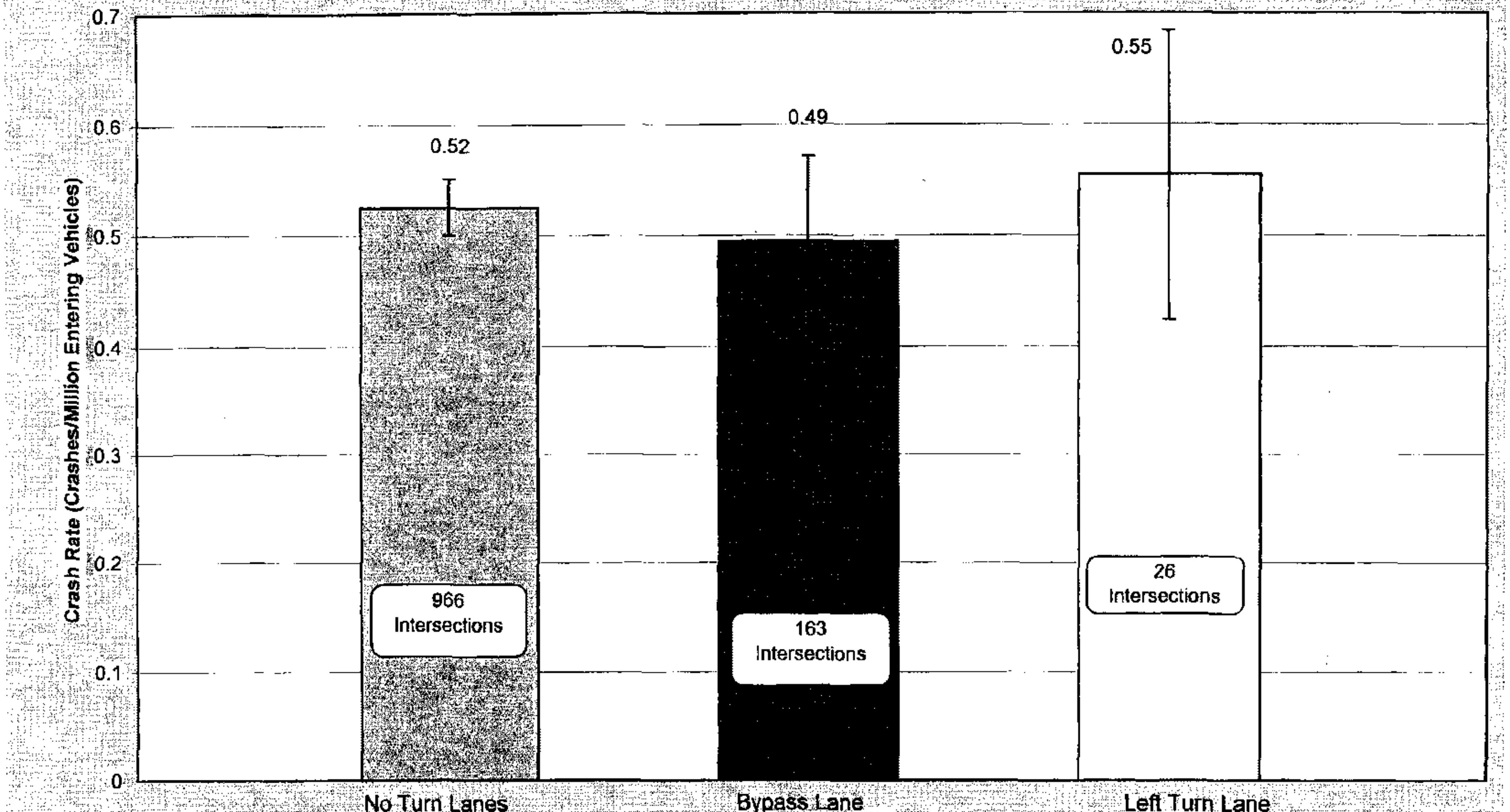


Figure 5.1

Average Crash Rate for Three-Legged Intersections

System-Wide Comparative Analysis

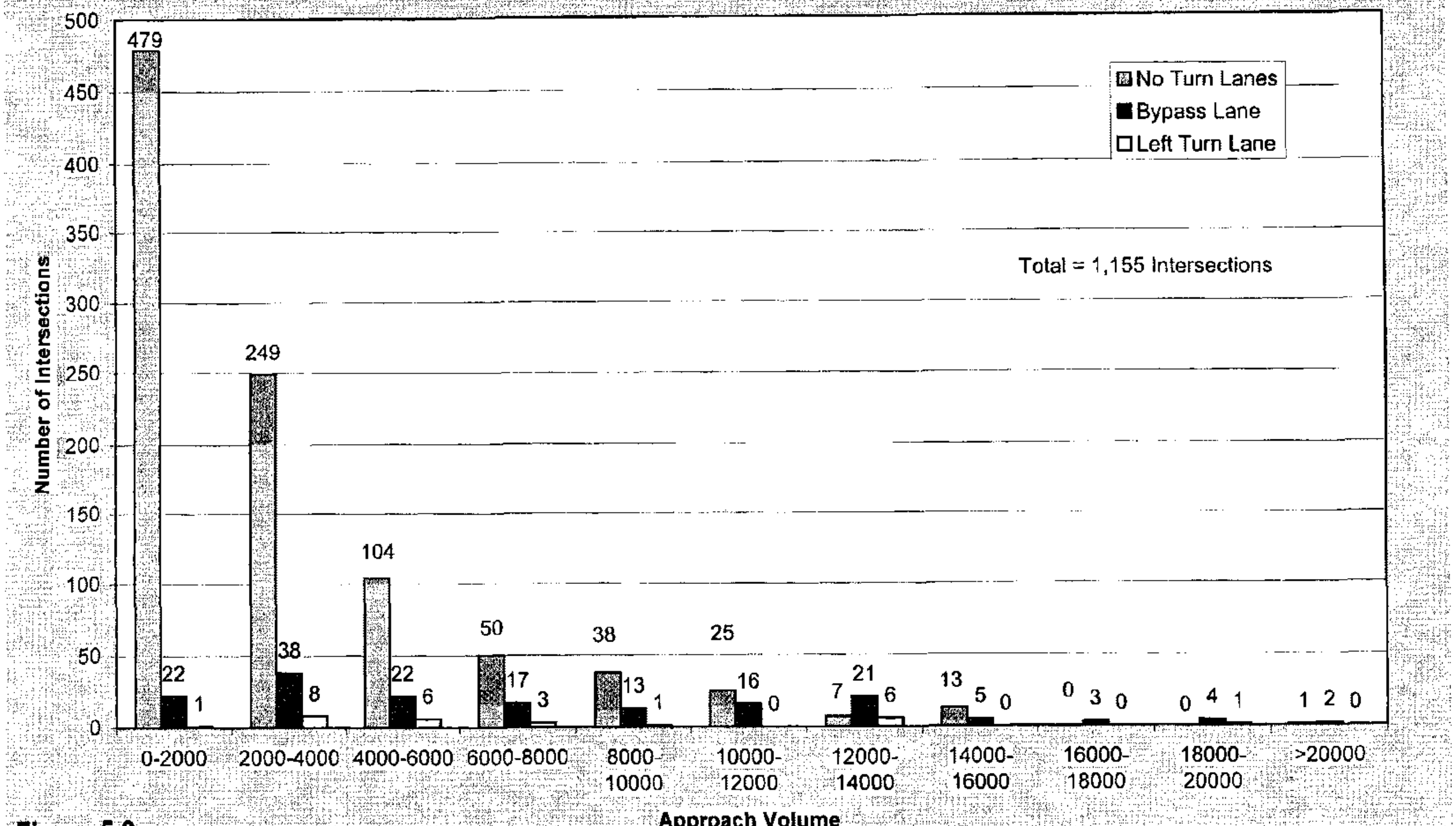


Figure 5.2
Number of Three-Legged Intersections Studied by Approach Volume

System-Wide Comparative Analysis

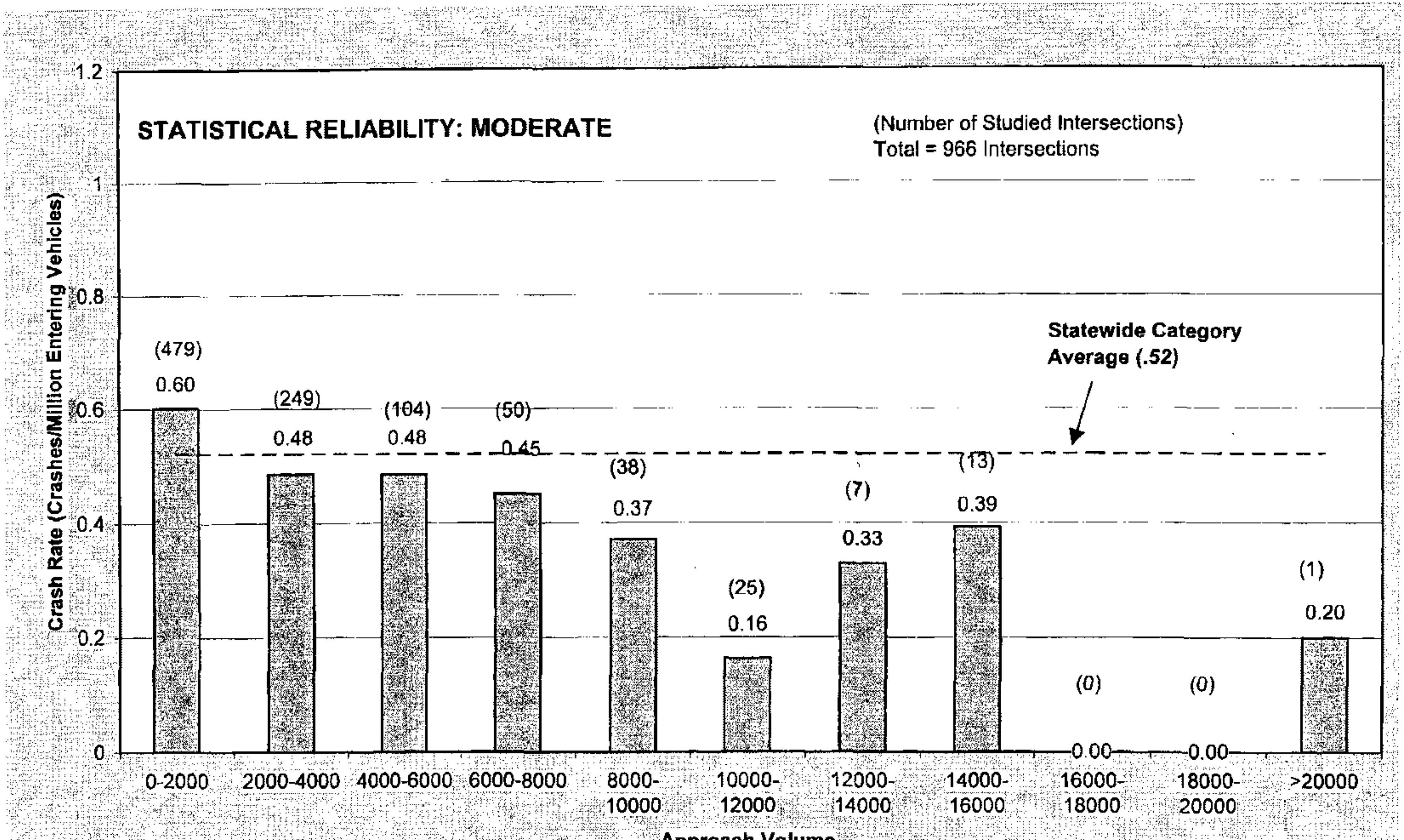


Figure 5.3

Average Crash Rate for Three-Legged Intersections with No Turn Lanes by Approach Volume

System-Wide Comparative Analysis

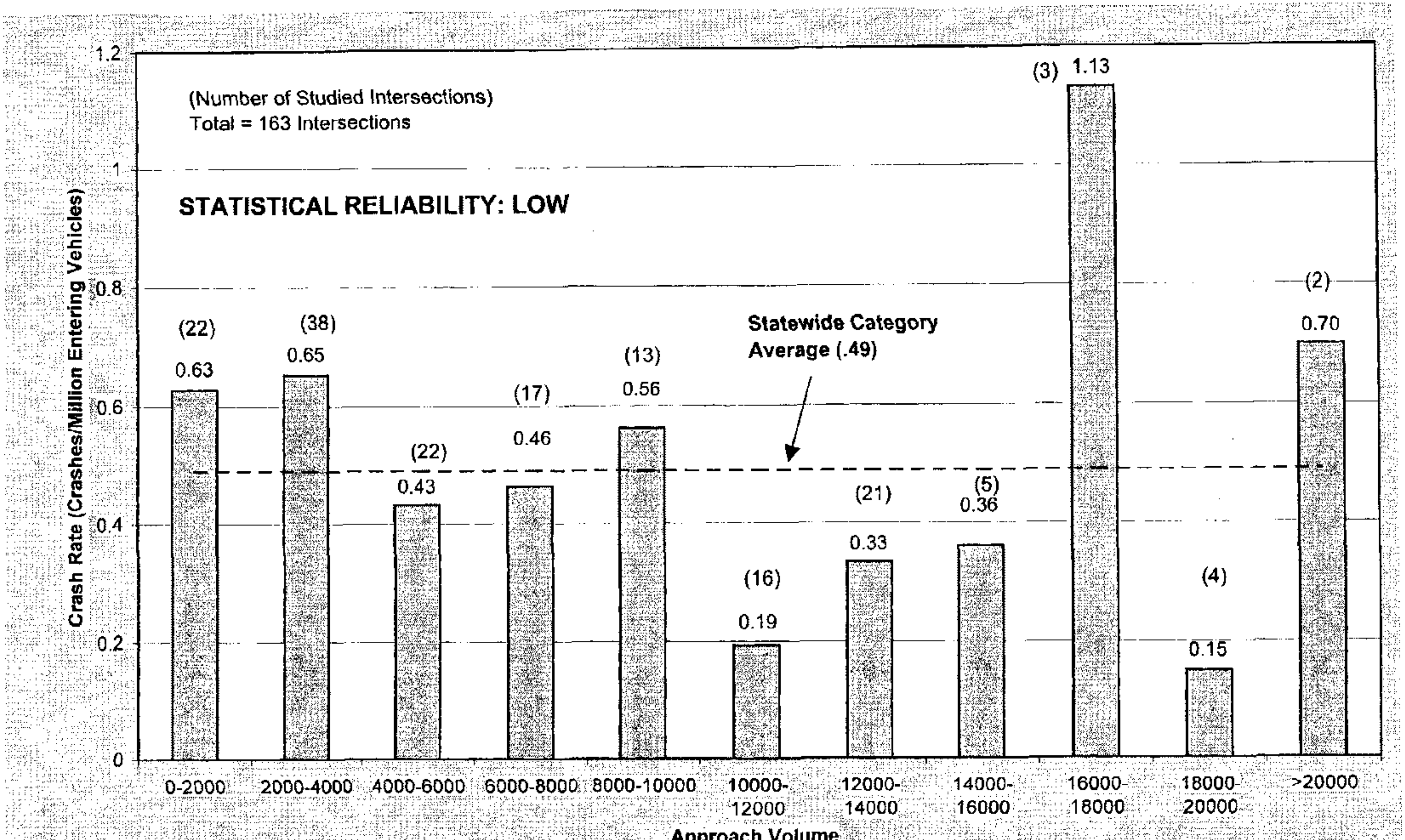


Figure 5.4

Average Crash Rate for Three-Legged Intersections with Bypass Lane by Approach Volume

System-Wide Comparative Analysis

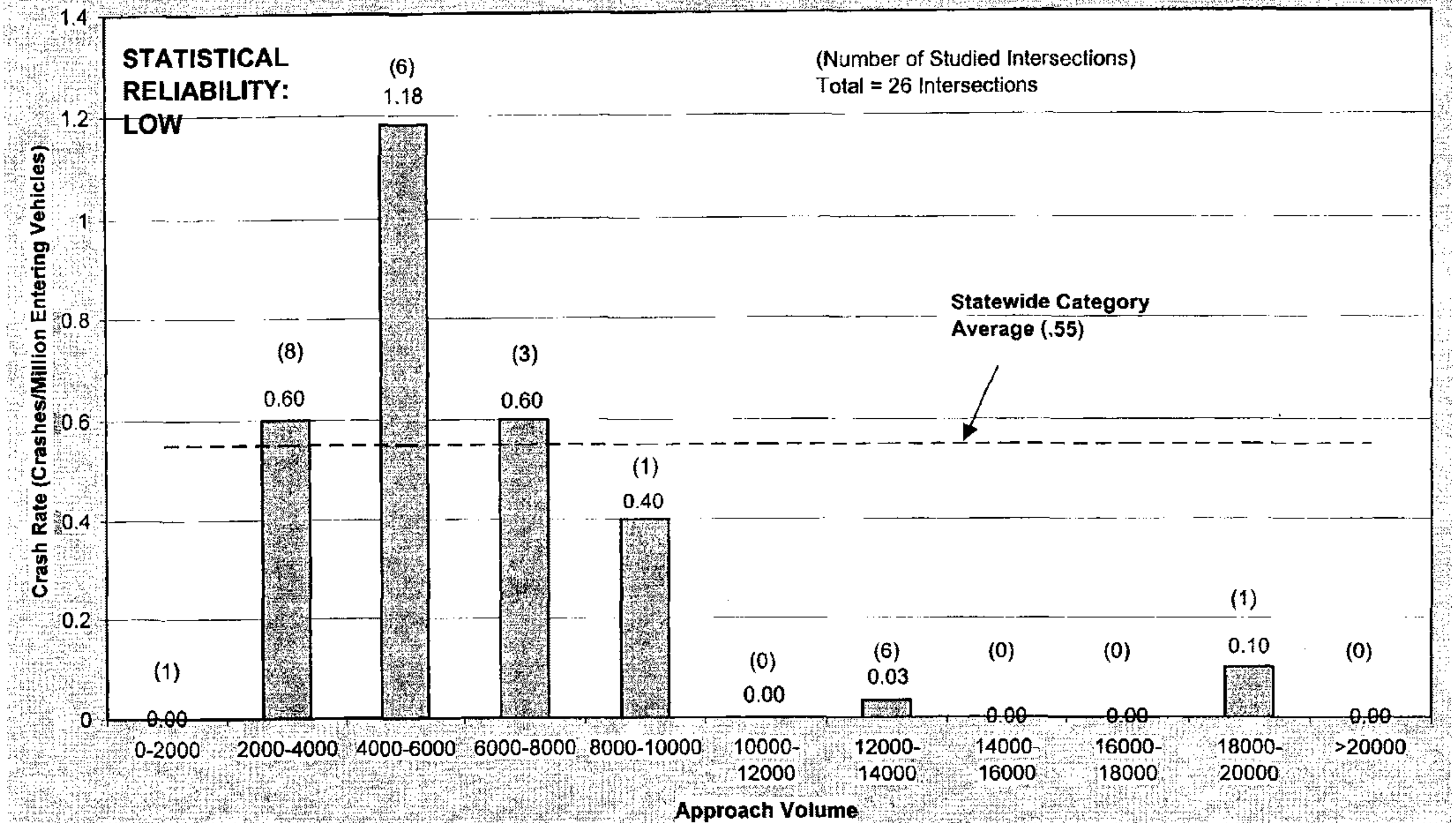


Figure 5.5

Average Crash Rate for Three-Legged Intersections with Left Turn Lane by Approach Volume

System-Wide Comparative Analysis

8/1/2000

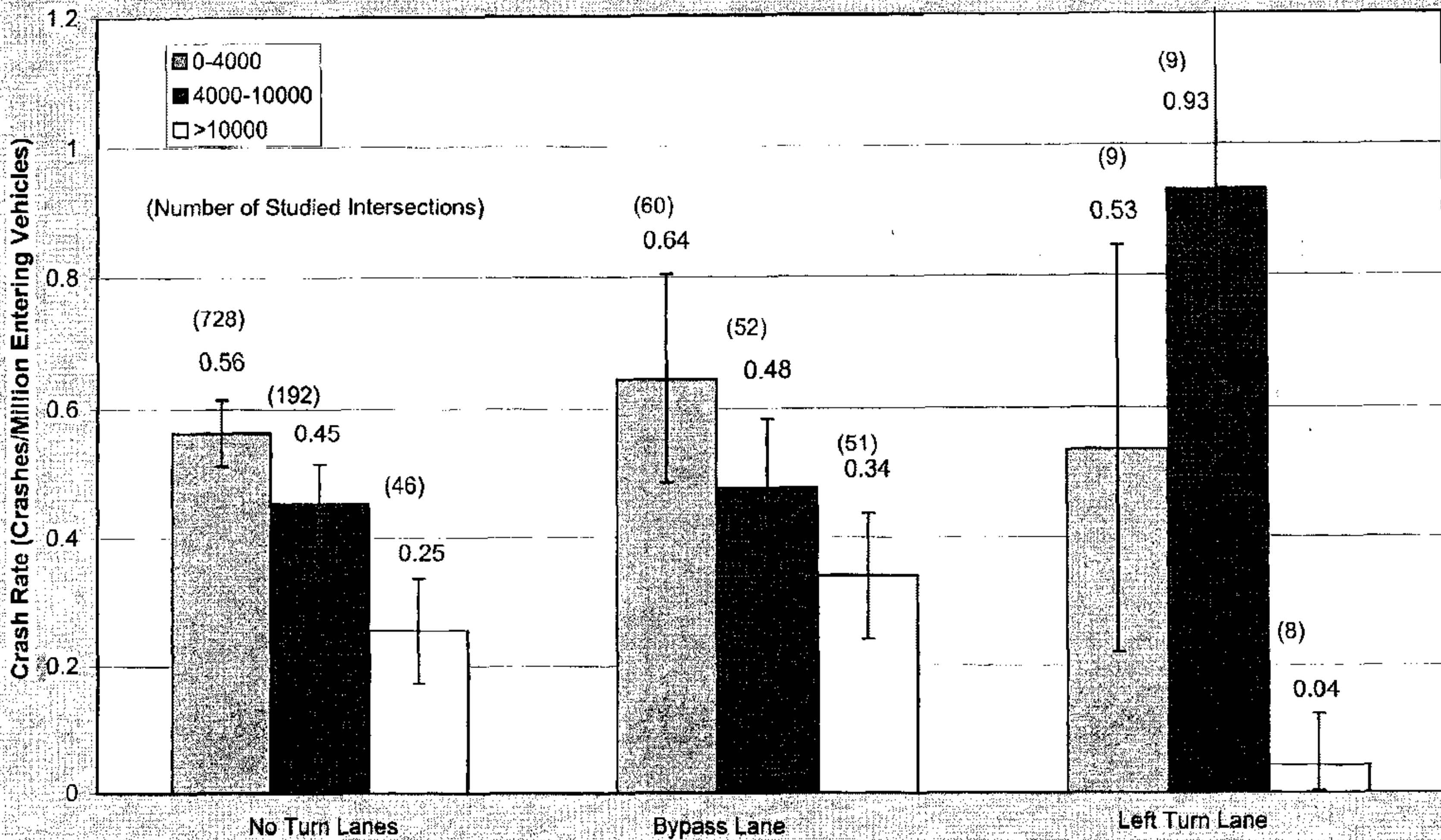


Figure 5.6

Average Crash Rate Grouped by Approch Volume for Three-Legged Intersections With Confidence Interval

System-Wide Comparative Analysis

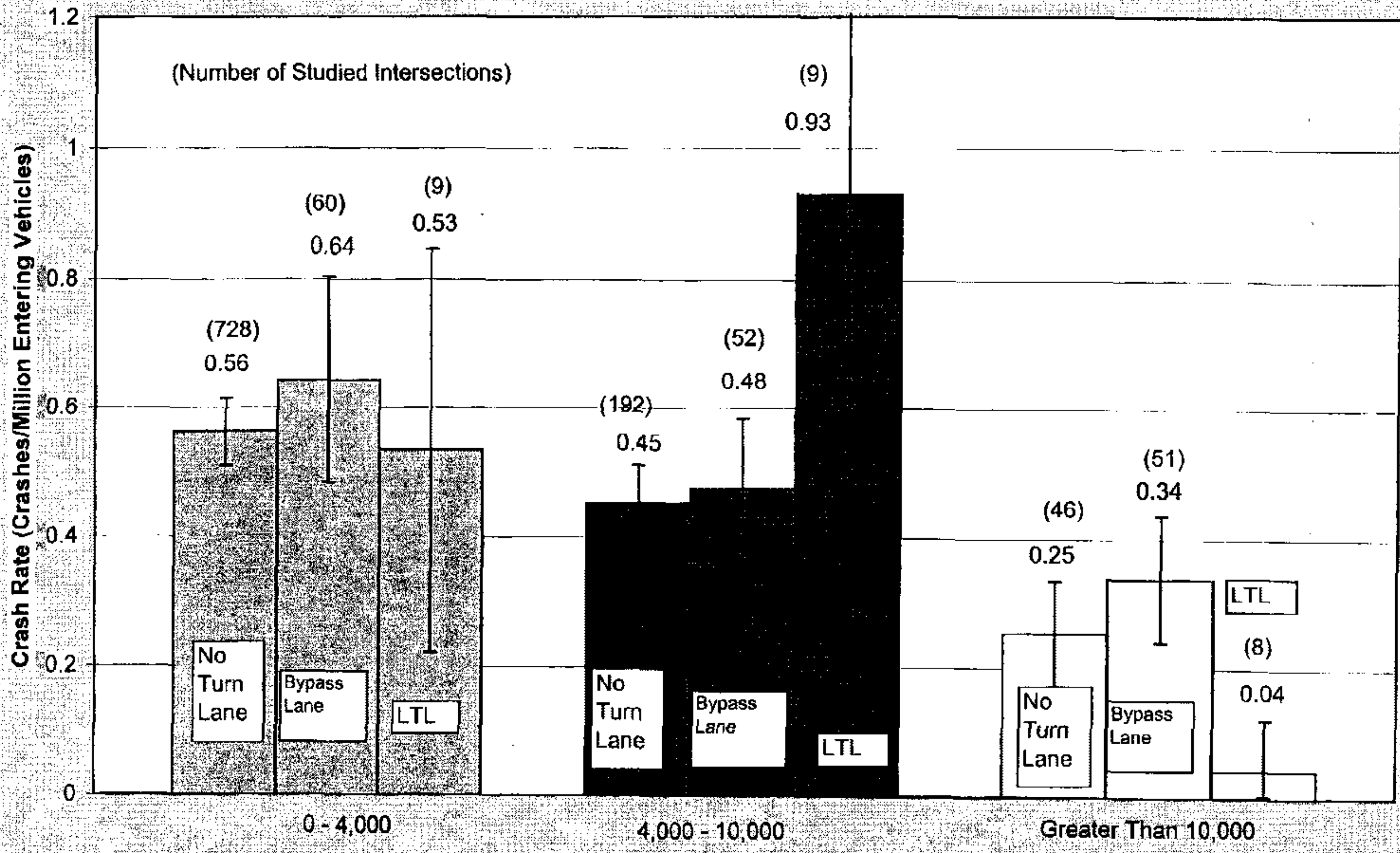


Figure 5.7

Average Crash Rates Listed by No Turn Lane / Bypass Lane / Left Turn Lane for Three-Legged Intersections

System-Wide Comparative Analysis

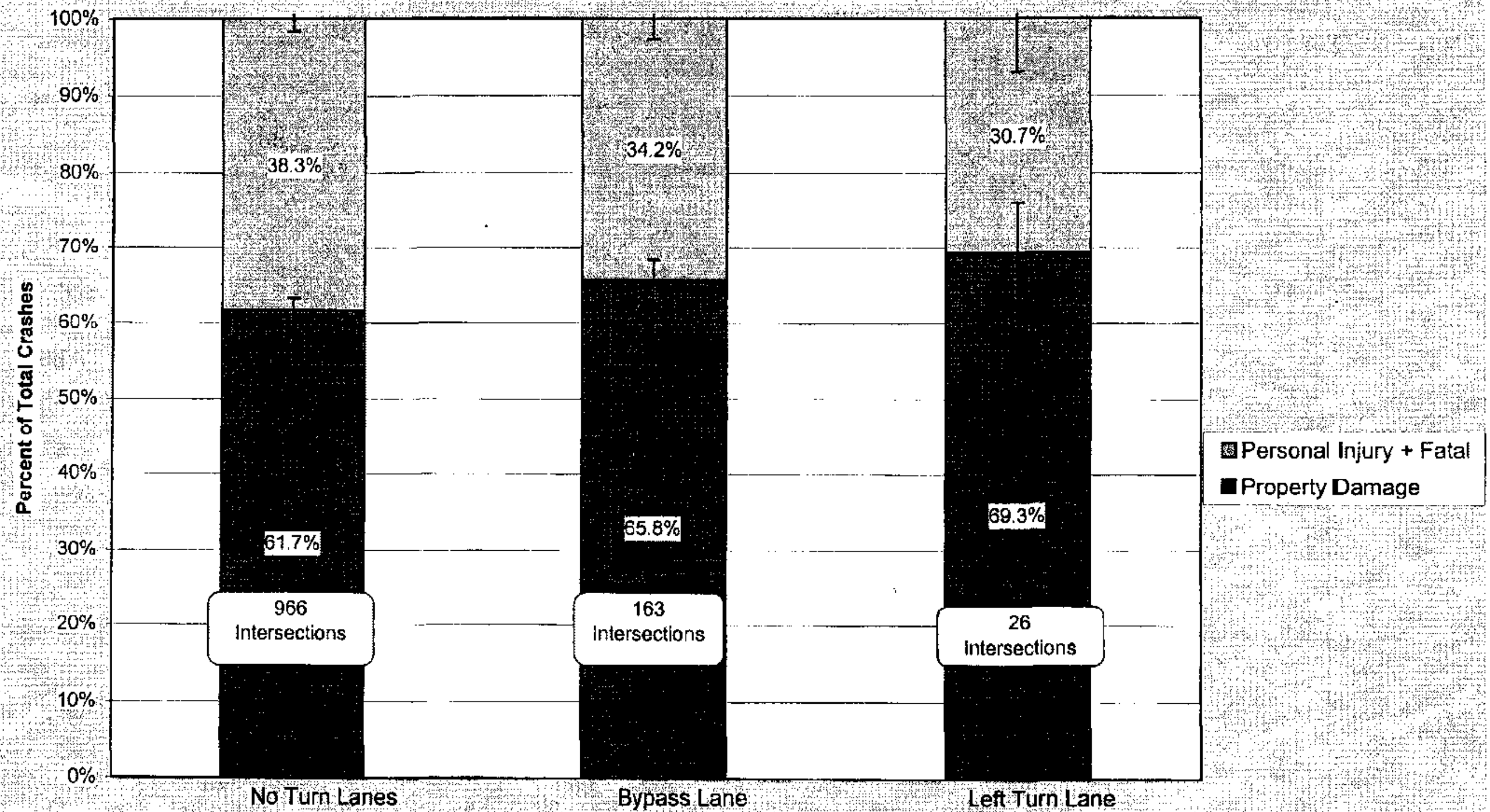


Figure 5.8

Average Crash Severity for Three-Legged Intersections

System-Wide Comparative Analysis

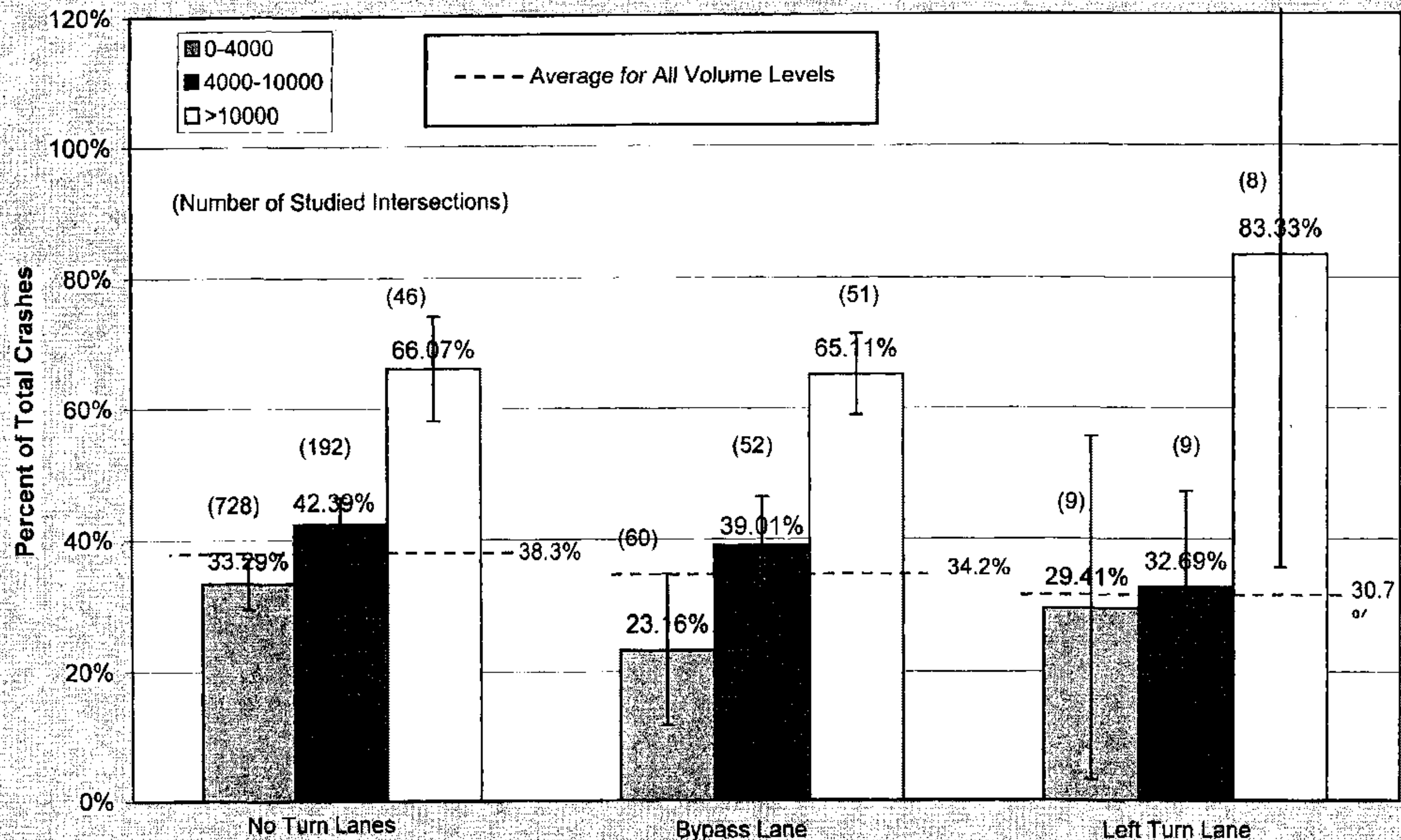


Figure 5.9

Percentage of Injury and Fatal Crashes Grouped by Approach Volume for Three-Legged Intersections

State-Wide Comparative Analysis

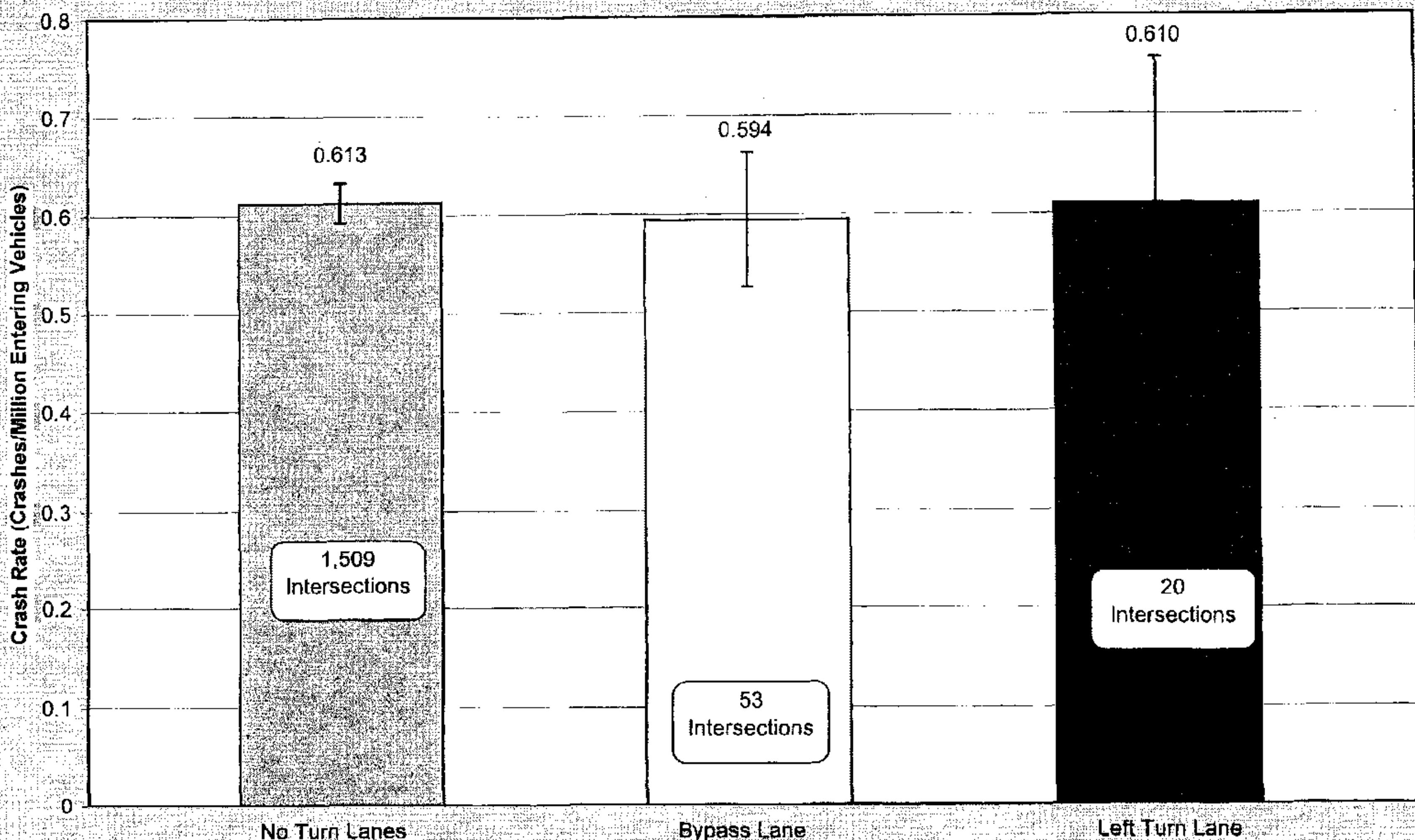


Figure 5.10

Average Crash Rate for Four-Legged Intersections

System-Wide Comparative Analysis

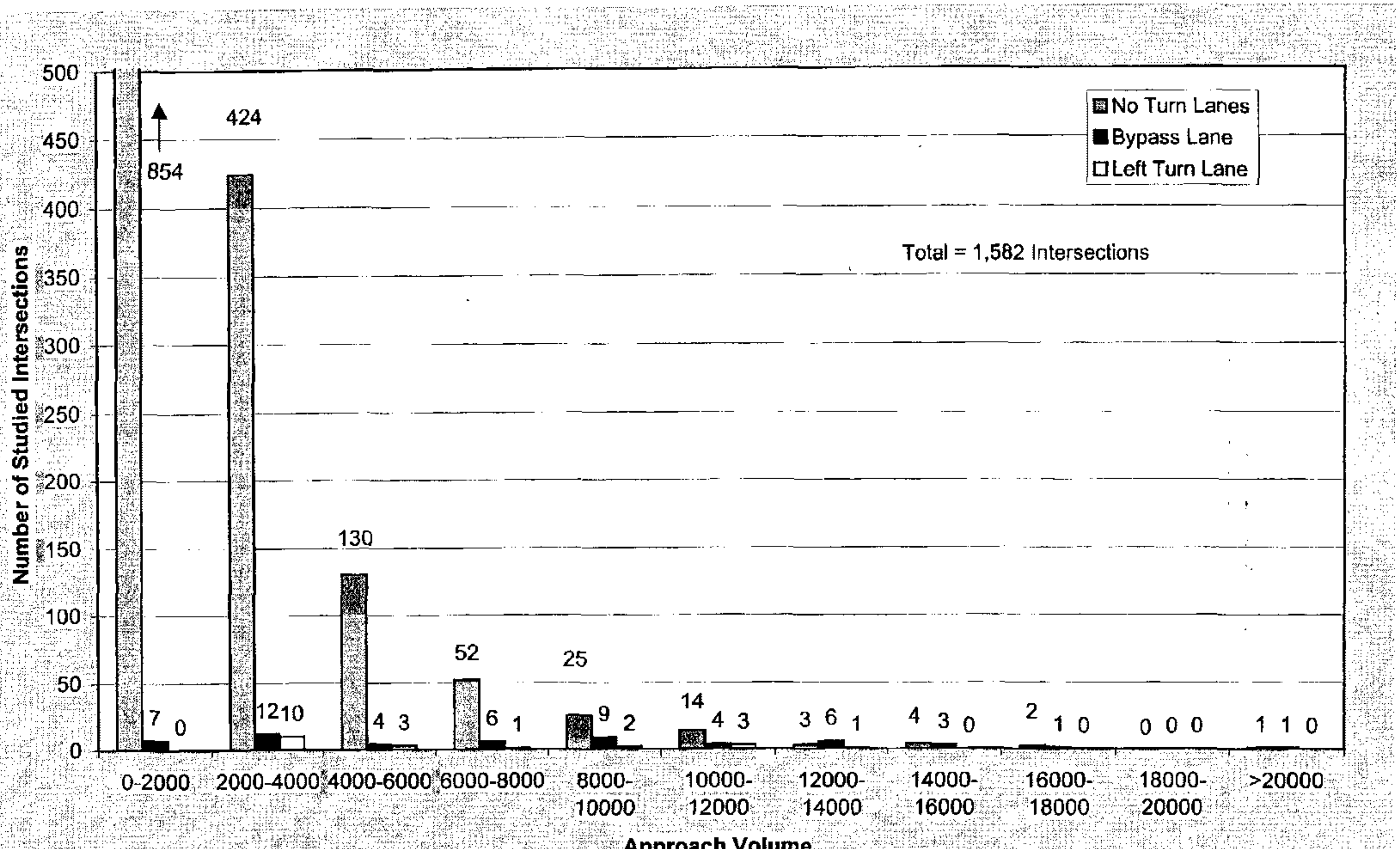


Figure 5.11

Number of Four-Legged Intersections Studied by Approach Volume

System-Wide Comparative Analysis

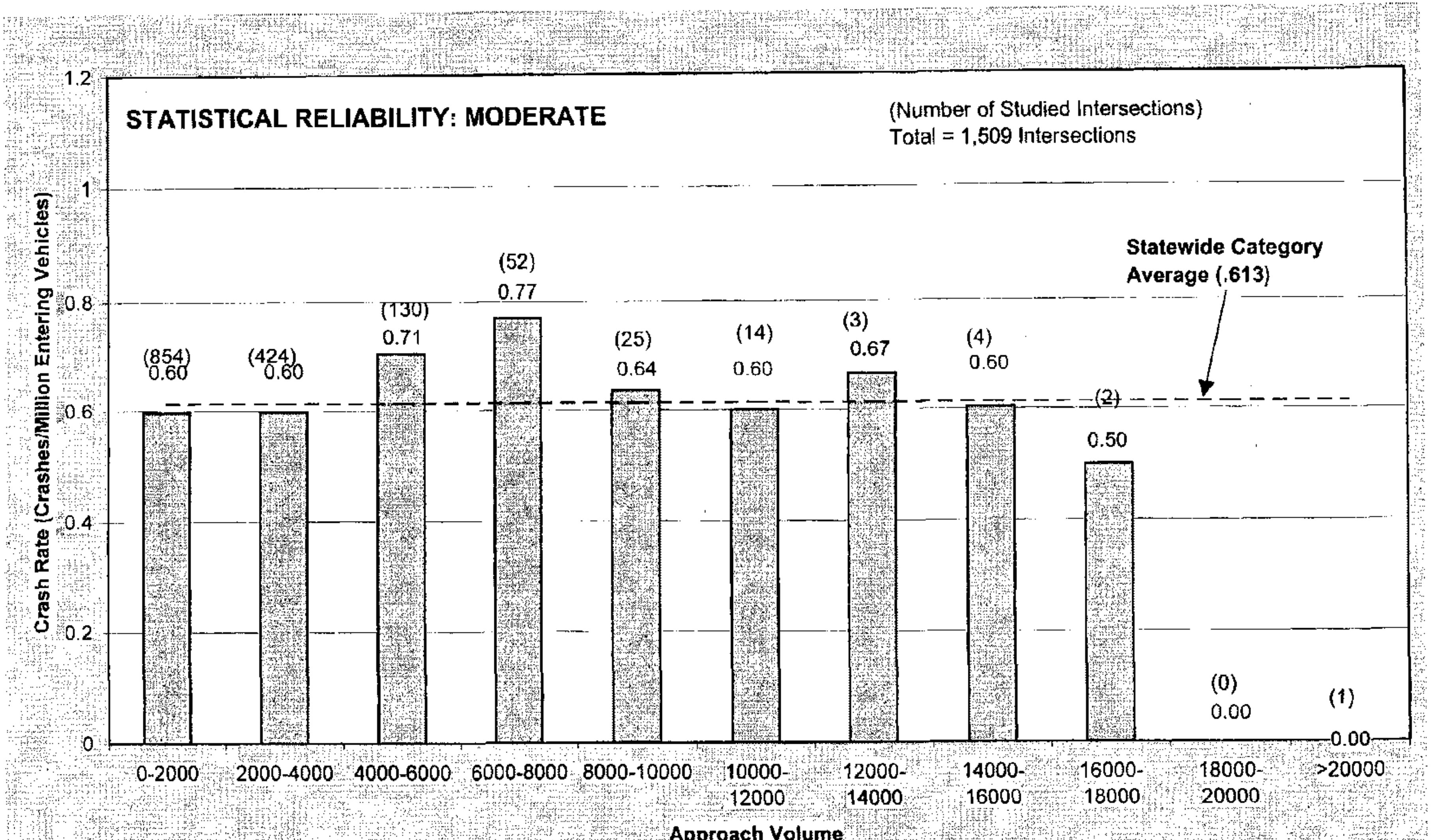


Figure 5.12

Average Crash Rate for Four-Legged Intersections With No Turn Lanes by Approach Volume

System-Wide Comparative Analysis

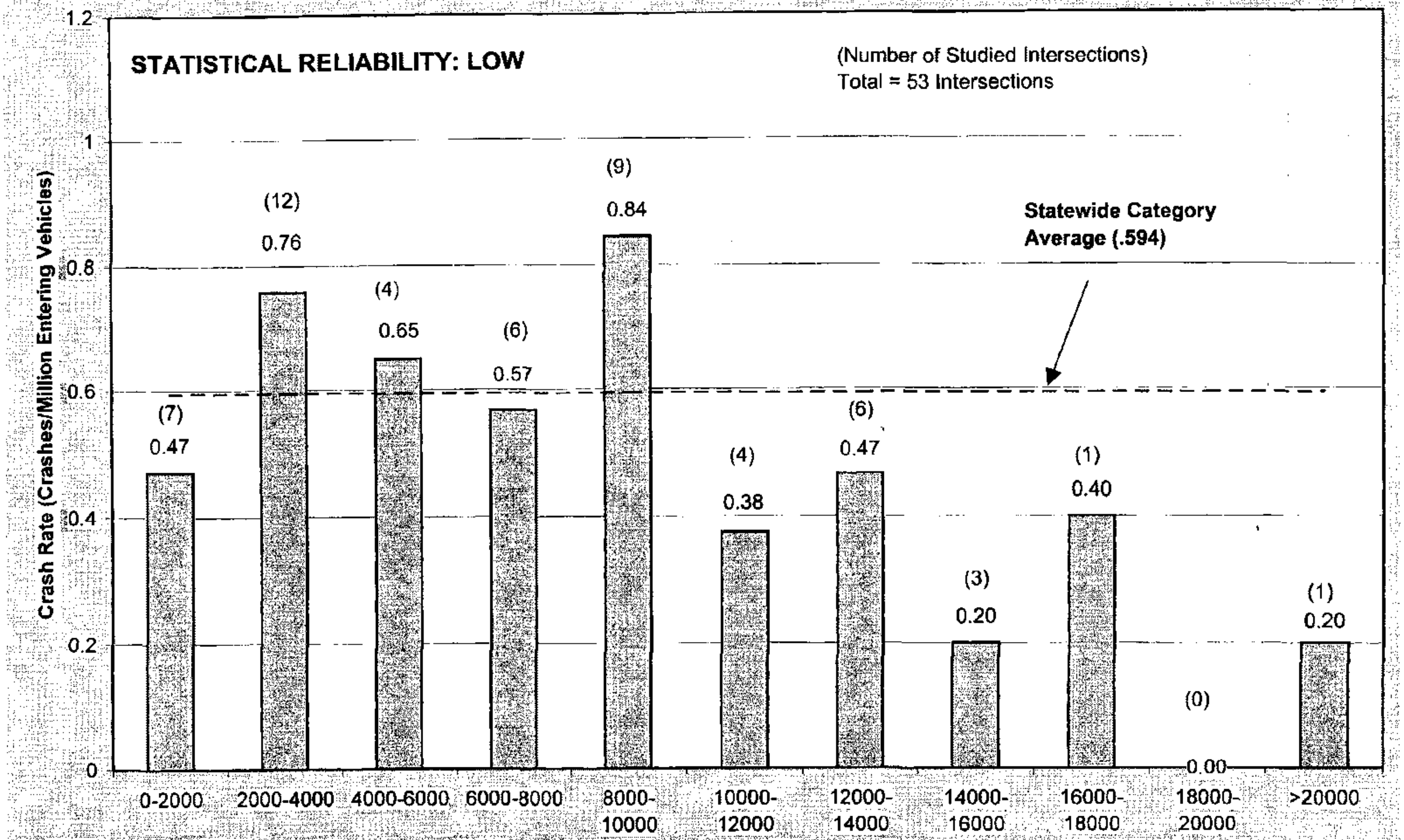


Figure 5.13

Average Crash Rate for Four-Legged Intersections With Bypass Lane by Approach Volume

System-Wide Comparative Analysis

8/1/2000

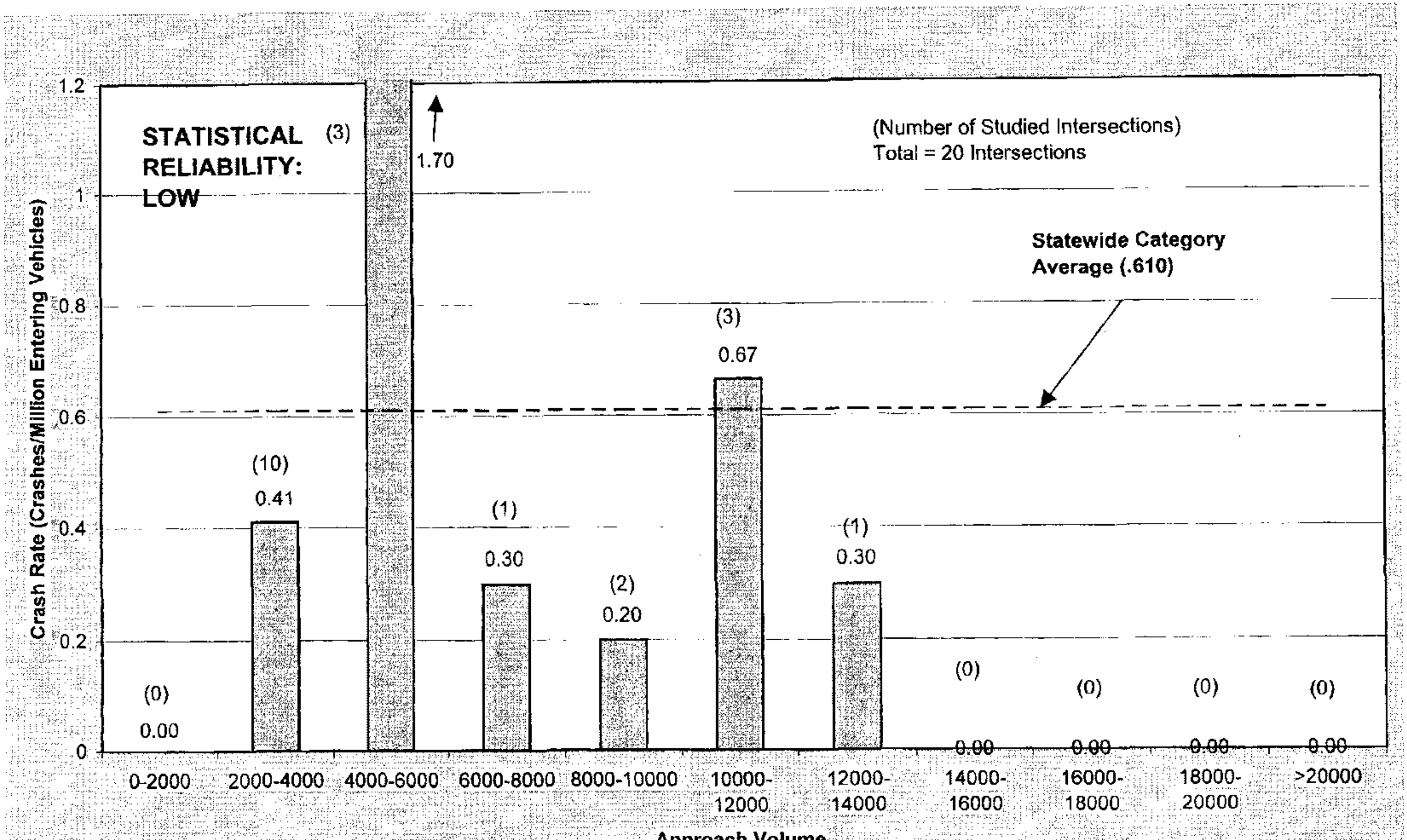


Figure 5.14

Average Crash Rate for Four-Legged Intersections With Left Turn Lane by Approach Volume

System-Wide Comparative Analysis

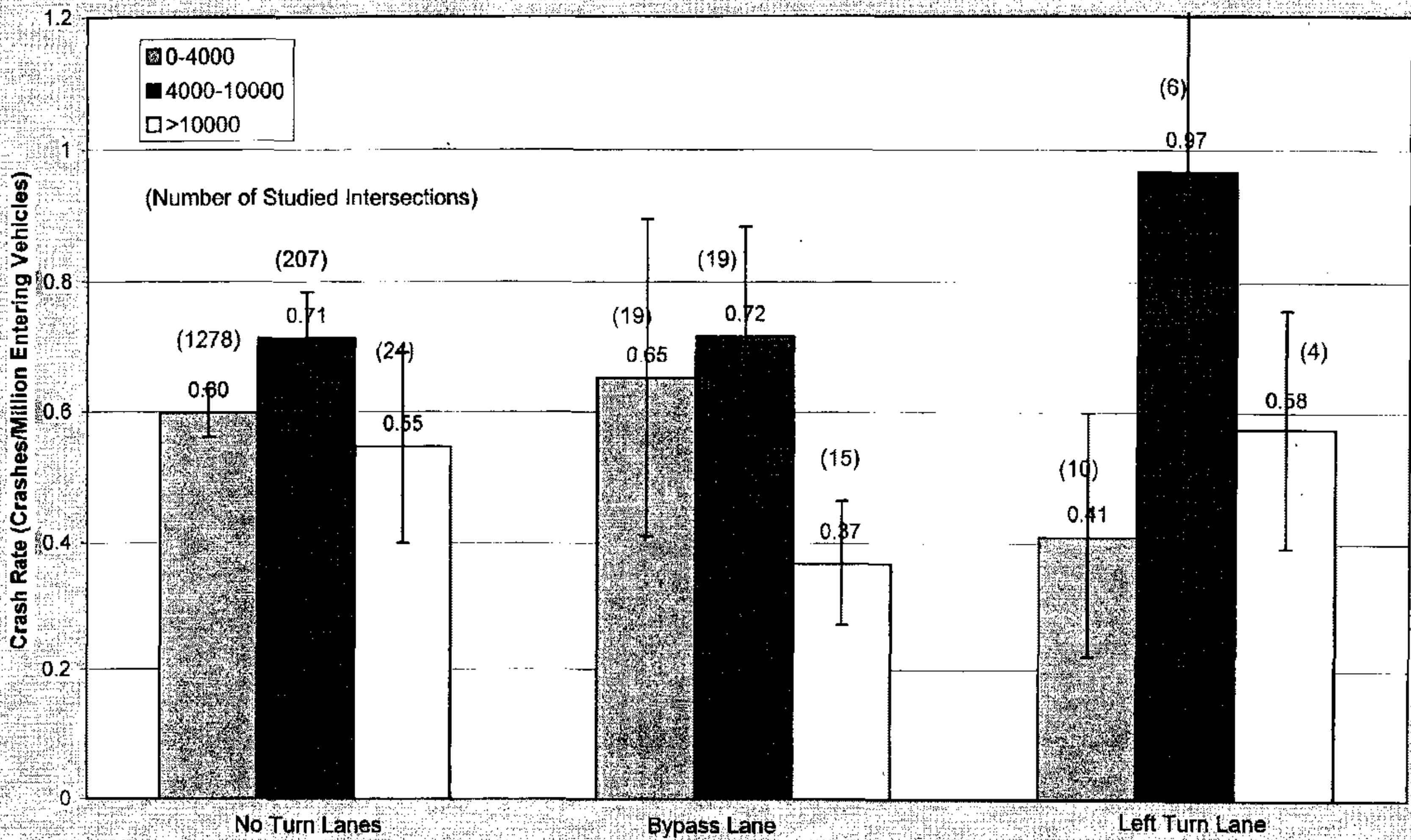


Figure 5.15

Average Crash Rate Grouped by Approach Volume for Four-Legged Intersections

System-Wide Comparative Analysis

8/1/2000

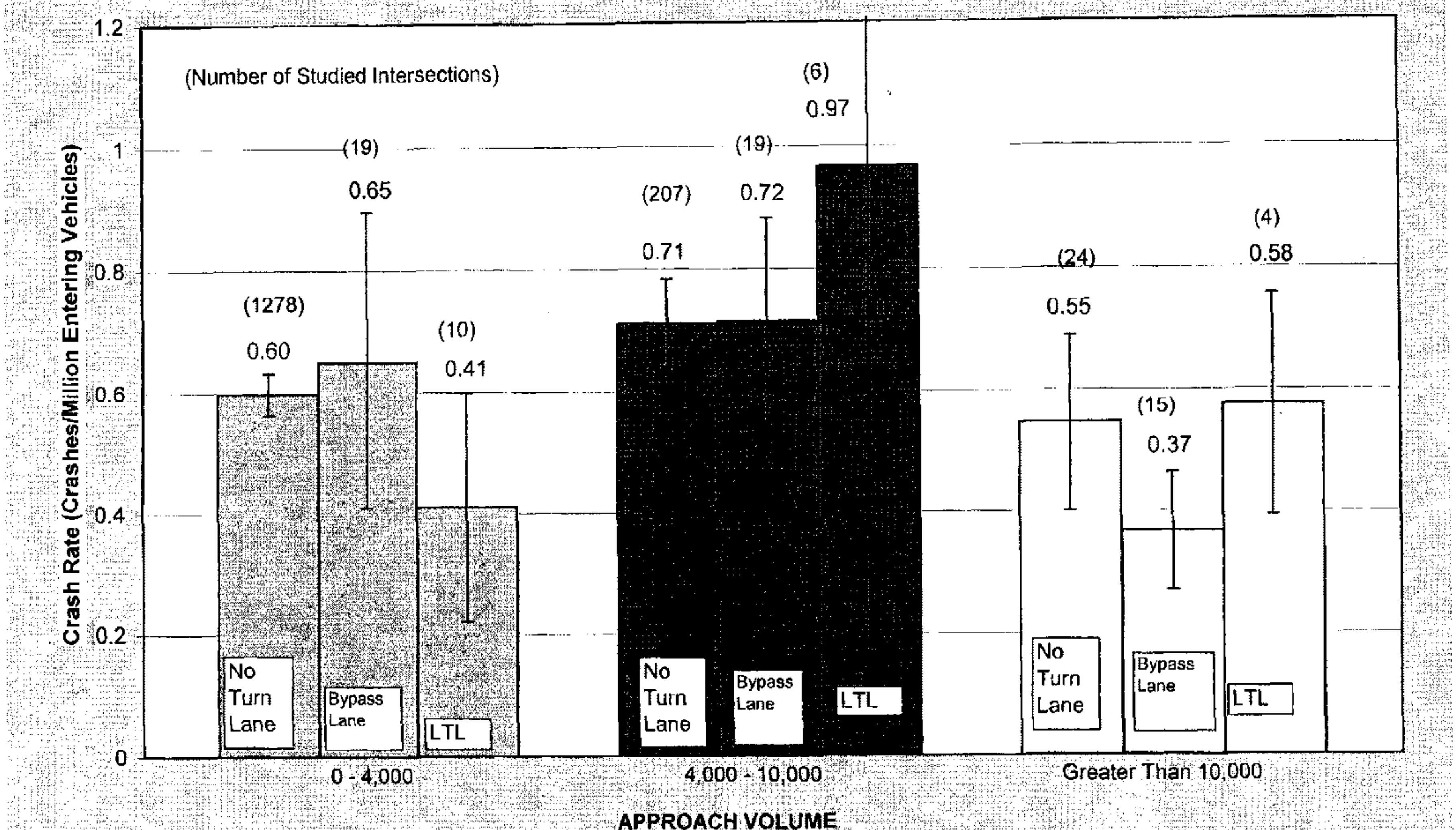


Figure 5.16

Average Crash Rates Listed by No Turn Lane / Bypass Lane / Left Turn Lane for Four-Legged Intersections

System-Wide Comparative Analysis

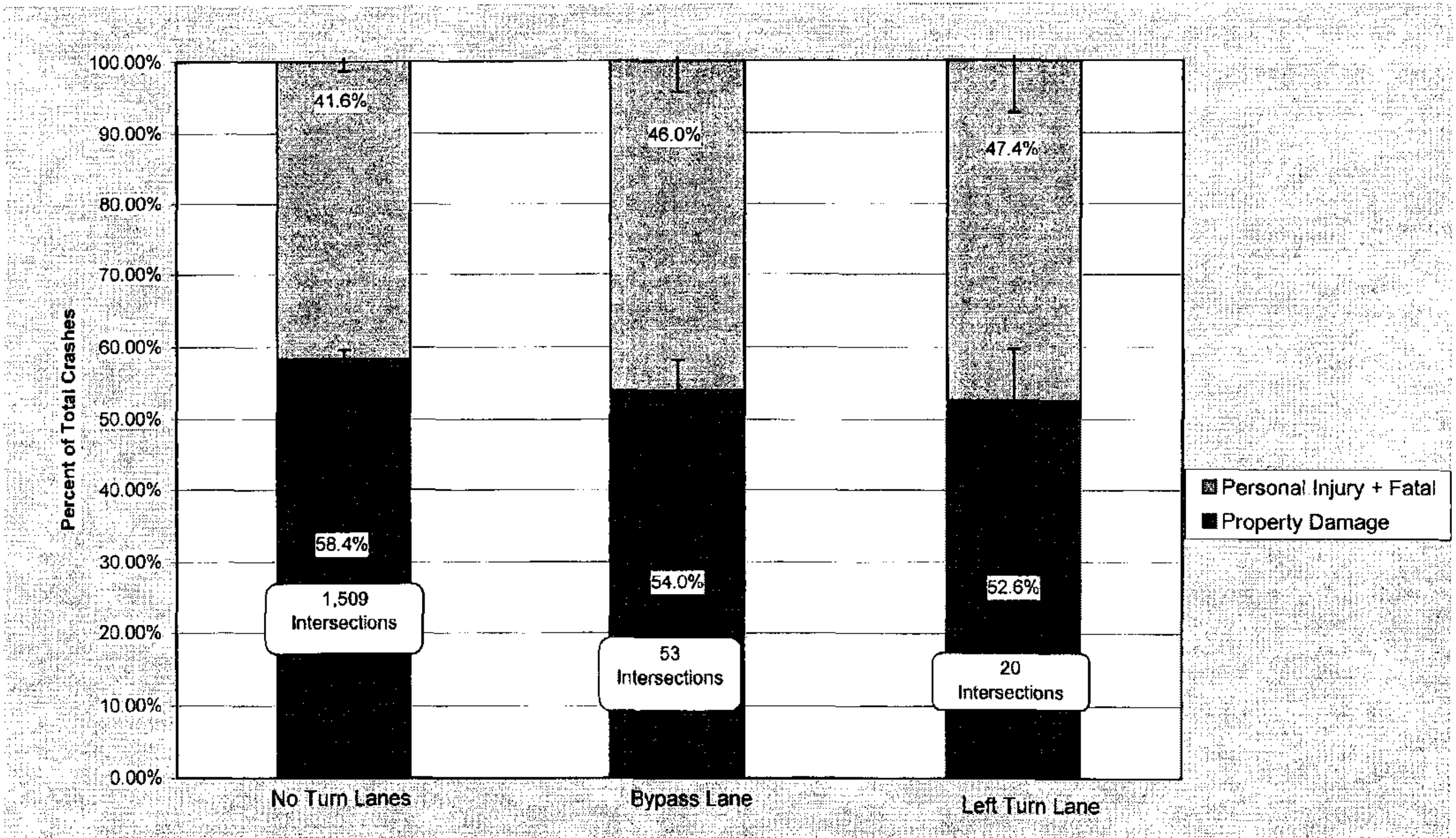


Figure 5.17

Average Crash Severity for Four-Legged Intersections

System-Wide Comparative Analysis

8/1/2000

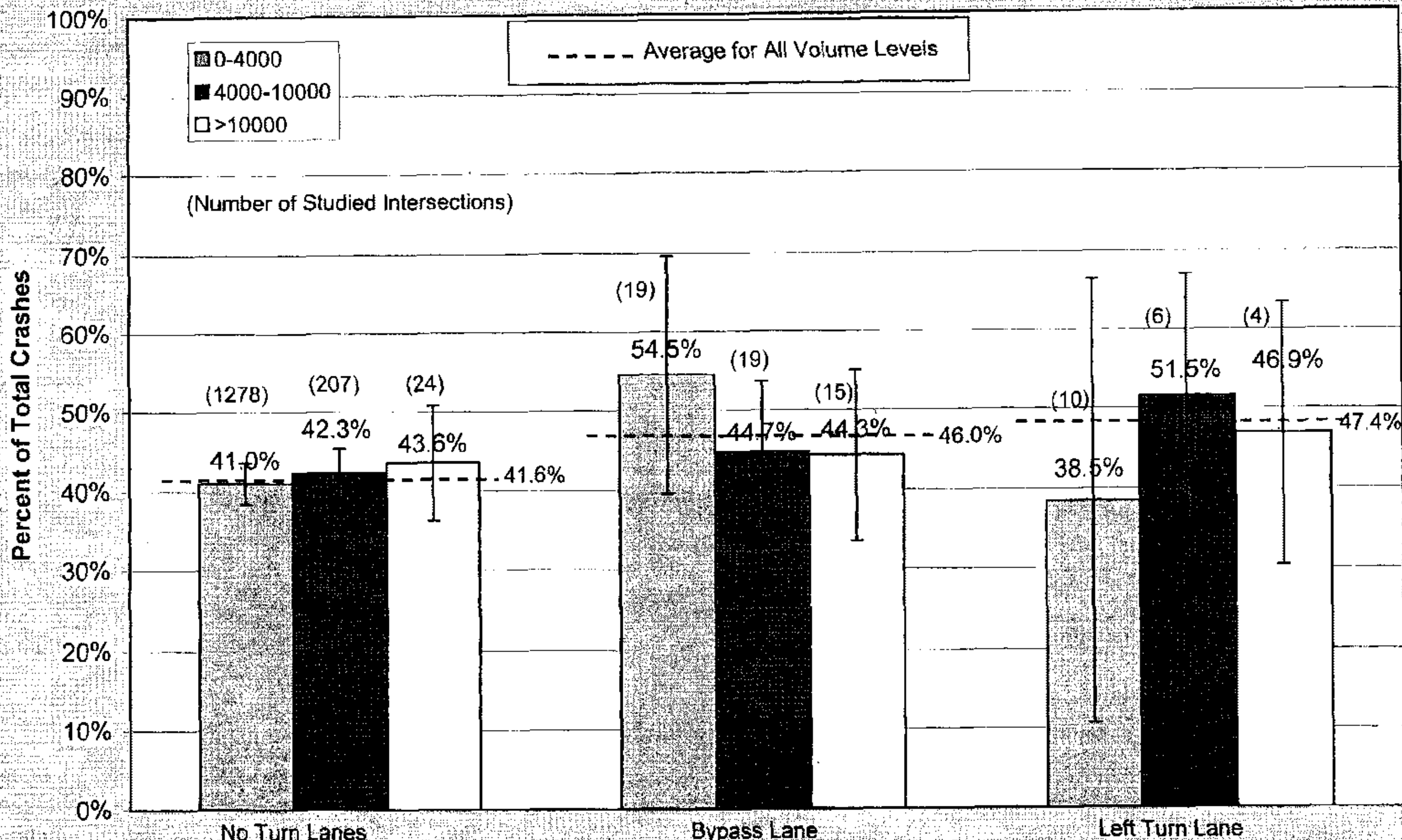


Figure 5.18

Percentage of Personal Injury Plus Fatal Crashes Grouped by Approach Volume for Four-Legged Intersections

State-Wide Comparative Crash Analysis

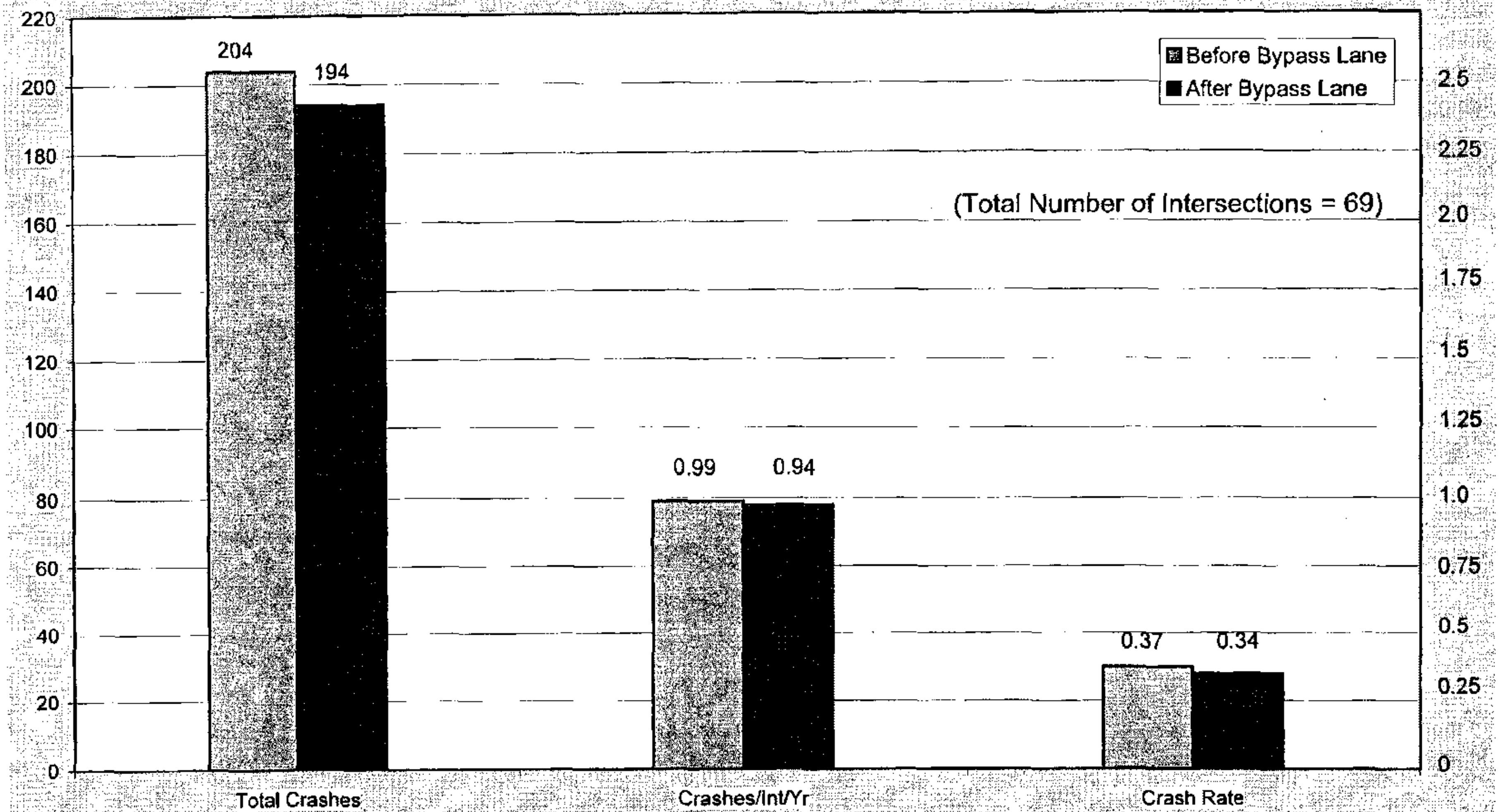


Figure 5.19

Total Number of Crashes, Number of Crashes per Intersection per Year, and Crash Rate

Before vs. After Crash Analysis

8/1/2000

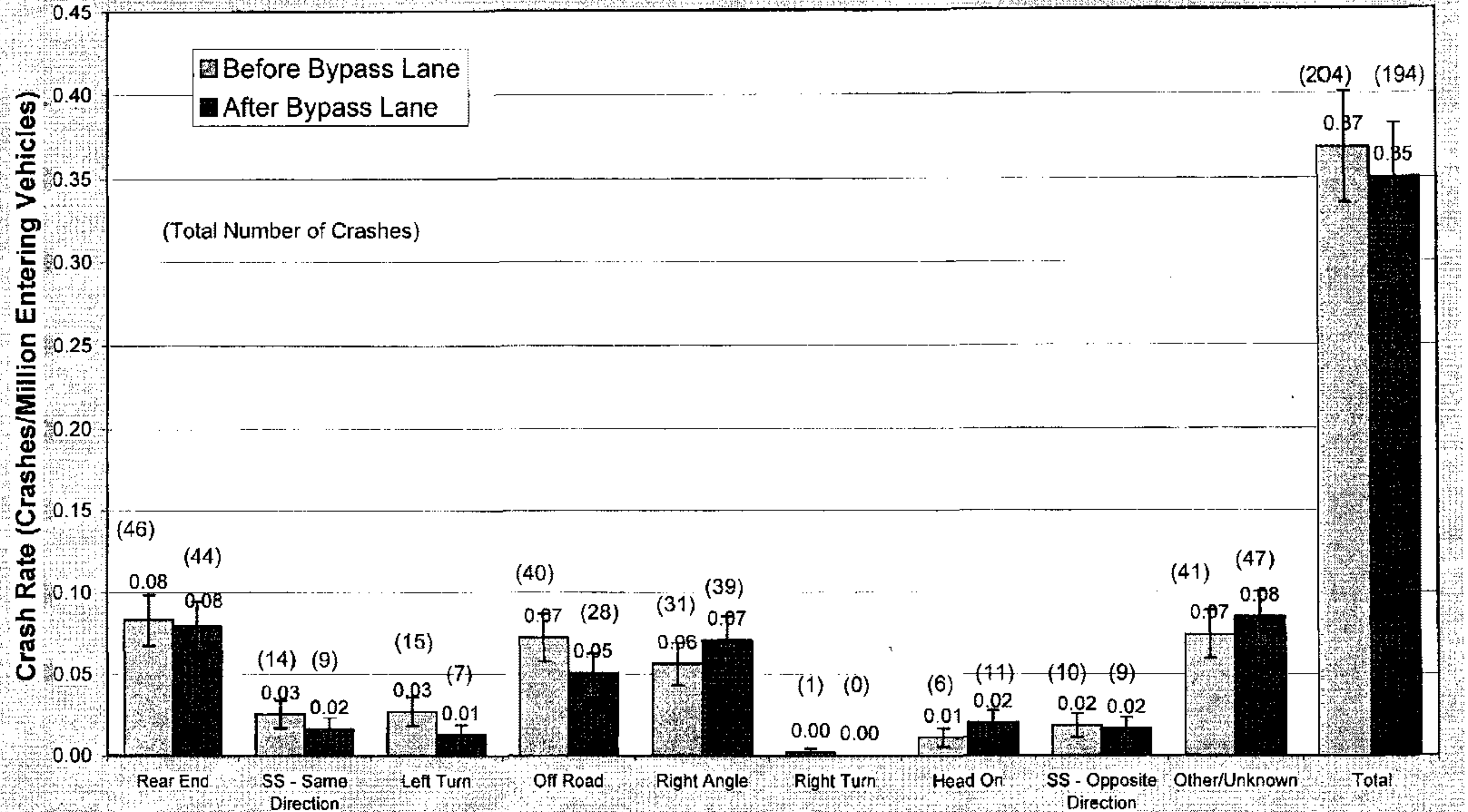


Figure 5.20

Distribution of Crash Types - Based on Crash Rates
(90% Confidence Interval)

Before vs. After Crash Analysis

8/1/2000

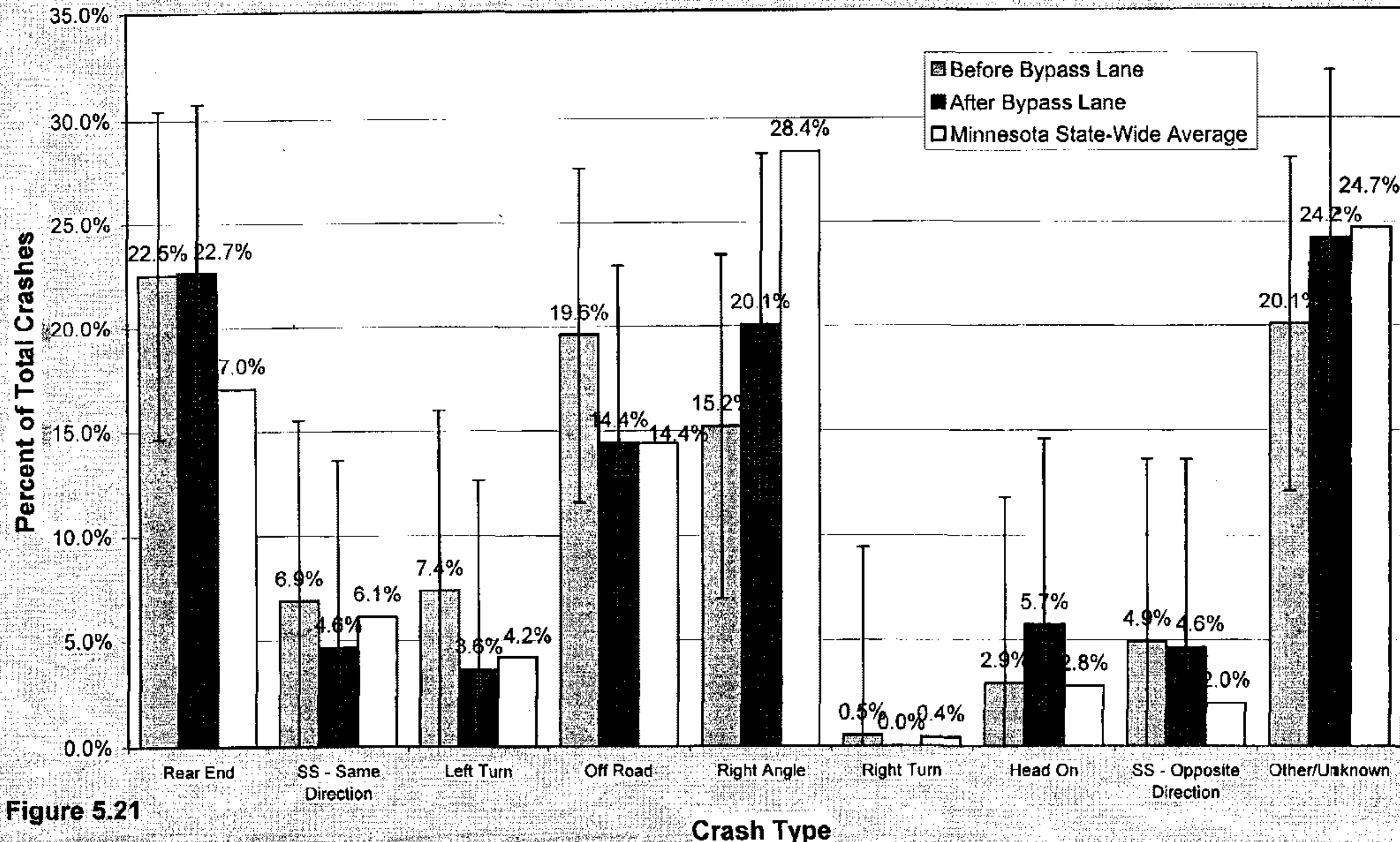


Figure 5.21

Distribution of Crashes - Based on Crash Percentage

Before vs. After Crash Analysis

8/1/2000

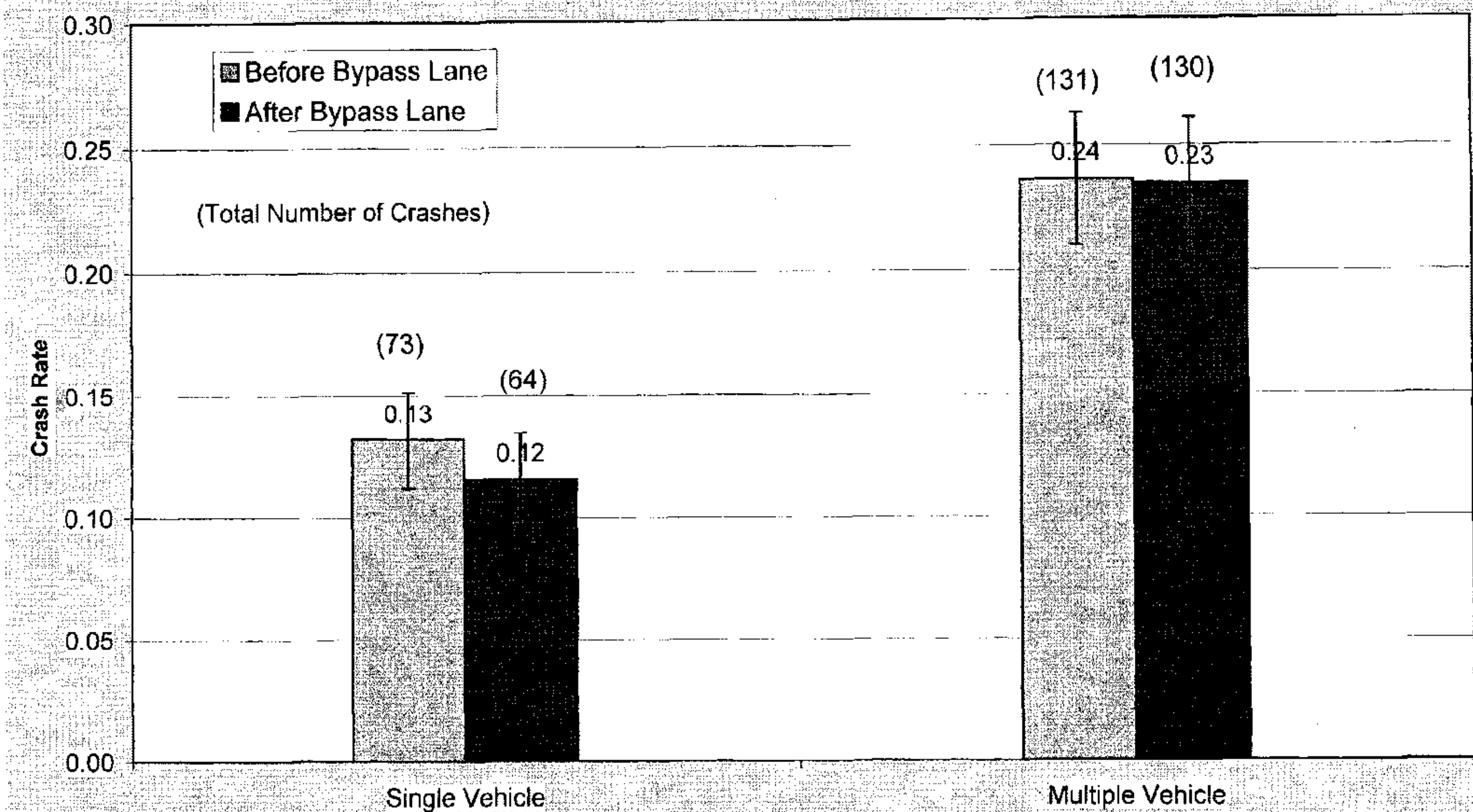


Figure 5.22

Single Vehicle versus Multiple Vehicle Crashes - Rates
(90% Confidence Interval)

Before vs. After Crash Analysis

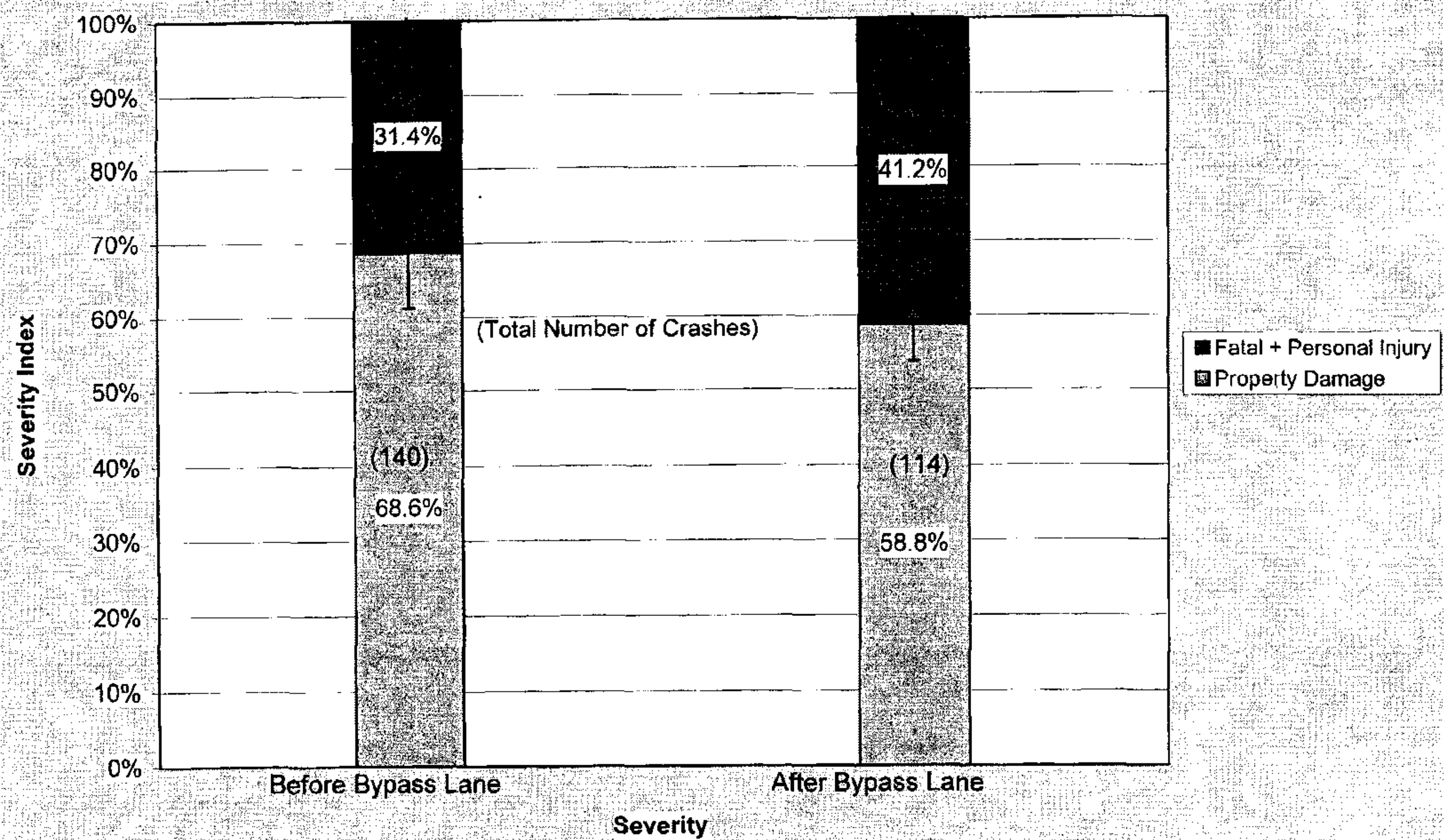


Figure 5.23
Crash Severity

Before vs. After Crash Analysis

6.0 Traffic Operations Analysis

The purpose of this chapter is to document the traffic operations analysis of three-legged and four-legged intersections and to determine if there is a difference in the quality of flow or level of service (LOS) for the three intersection design at various combinations of mainline and cross street traffic volumes.

The objective of the operations analysis is to determine if logical threshold volumes can be identified, based on level of service and intersection delay, that could become the basis for recommending one of three particular intersection treatments:

- Condition 1: Mainline volume less than X,XXX vehicles per day – No turn lanes required
- Condition 2: Mainline volume between X,XXX and Y,YYY vehicles per day – Combined right turn / bypass lane recommended
- Condition 3: Mainline volume greater than Y,YYY vehicles per day – Separate left and right turn lanes recommended

The two types of modeling software that were used for this operations analysis were:

- Highway Capacity Software (HCS) – for unsignalized intersections
- CORSIM 1.03

6.1 Inputs / Outputs of Modeling Software

Table 6.1 lists the inputs, outputs, and alternate applicability for both models. Some of the inputs and outputs include:

Inputs

- Lane designations, geometry, and turn bay lengths
- Peak hour volumes and factor.
- Driver characteristics (gap) and speed

Outputs

- Intersection, approach, and main street left turn delay and level of service
- Queue lengths and travel speed

The specific roadway geometry and peak hour turning movement volumes used in the analysis are documented in Table 6.2. The traffic volumes selected for analysis included the following:

- 600 vehicles per hour on each major street approach (20% left turns, 70% through, and 10% right turns) combined with 150 vehicles on each minor street approach (25% left turns, 50% through, 25% right turns).

- 400 vehicles per hour on each major street approach combined with 100 vehicles on each minor street approach.

These hourly volumes roughly approximate 5000 to 8000 vehicles per day on the major street and 1200 to 2000 vehicles per day on the minor street. These volumes were selected because they were thought to represent the worst case conditions on typical rural trunk highways and because they covered the range of volumes identified in the figures documenting warrants for left turn treatments in the Road Design Manual (Figure 5-3.01 A, B, C, and D).

The HCS model was used initially because it is considered to be the standard software for traffic engineering studies. However, for the HCS model, some of the input and output information could not be included because of the limited capability of the software. Also, it was determined that the HCS model could not distinguish between a left turn lane and a bypass lane. As a result of the limitations of the HCS model, the analysis was continued using CORSIM, a more powerful microscopic traffic operations model. The CORSIM model incorporates all inputs and outputs chosen for this analysis and theoretically has the capability to distinguish between a left turn lane and a bypass lane.

6.2 Results of Operation Analysis

The results of the operations analysis provided by each model are shown in Table 6.3. At the lower traffic volumes (Table 6.3.b), both the HCS and CORSIM model report a consistent LOS A for the six different intersection. However, at the higher volume level (Table 6.3.a), the output from the two models is very different for the four-legged intersections. The HCS model indicates a LOS C or D and CORSIM suggests a much better quality of traffic flow with a LOS A operation. Experience with the unsignalized components of both models suggests that the CORSIM model is probably providing the more accurate results.

6.3 Summary

The results of the traffic operations analysis suggests that at even fairly high combinations of main line and cross-street traffic volumes, the presence of either bypass lanes or left turn lanes does not significantly effect the overall quality of traffic flow. The output from the computer models indicates a LOS A condition for each of the six geometric design alternatives for both assumed traffic volume scenarios. In addition, providing left turn lanes at rural intersections could be expected to reduce an already low level of intersection delay by less than 5 percent.

The results of the analysis also suggest that there is no objective data to support the recommended left turn treatment warrants documented in Chapter 5 of the Mn/DOT Road Design Manual.

Table 6.1
Model Overview

	HCS-Unsignalized	CORSIM
INPUTS:		
Lane Designations	X	X
Lane Geometry and Turn Bay Length		X
Peak Hour Volumes for all Movements	X	X
Peak Hour Factor	X	X
Percentage of Trucks	X	X
Driver Characteristics (Gap Acceptance)	X	X
Speed		X
OUTPUTS:		
Intersection Delay and LOS	X	X
Approach Delay and LOS	X	X
Main Street Lefturn Delay and LOS	X	X
Queue Lengths	X	X
Fuel Consumption		X
Travel Speed		X
ALTERNATE APPLICABILITY:		
1A (4-leg no LT Lane)	X	X
1B (3-leg no LT Lane)	X	X
2A (4-leg with ByPass)		X
2B (3-leg with ByPass)		X
3A (4-leg with LT Lane)	X	X
3B (4-leg with LT Lane)	X	X

Table 6.2
Model Inputs for Operations Analysis

Geometry - Number of Lanes

Design Category	Major Street						Minor Street					
	Approach 1			Approach 2			Approach 3			Approach 4		
	Left	Thru	Right	Left	Thru	Right	Left	Thru	Right	Left	Thru	Right
No Turn Lanes	0	1	0	0	1	0	0	1	0	0	1	0
Bypass Lanes	0	1	1	0	1	1	0	1	0	0	1	0
Left Turn Lanes	1	1	1	1	1	1	0	1	0	0	1	0

Turning Movement Volumes

Volume Category	Major Street						Minor Street					
	Approach 1			Approach 2			Approach 3			Approach 4		
	Left	Thru	Right	Left	Thru	Right	Left	Thru	Right	Left	Thru	Right
	20%	70%	10%	20%	70%	10%	25%	50%	25%	25%	50%	25%
A. 600/150*	120	420	60	120	420	60	37	75	38	37	75	38
B. 400/100*	80	280	40	80	280	40	25	50	25	25	50	25

Note*
A. 600 vehicles per hour on each major street approach / 150 vehicles per hour on each minor street approach
B. 400 vehicles per hour on each major street approach / 100 vehicles per hour on each minor street approach

Table 6.3
Intersection Level of Service

TABLE 6.3.a
Mainline Approaches 600vph (20-70-10 split)
Cross Street Approaches 150vph (25-50-25 split)

	HCS-Unsignalized	CORSIM
1A (4-leg no LT Lane)	D	A
1B (3-leg no LT Lane)	A	A
2A (4-leg with ByPass)	N.A.*	A
2B (3-leg with ByPass)	N.A.*	A
3A (4-leg with LT Lane)	C	A
3B (3-leg with LT Lane)	A	A

TABLE 6.3.b
Mainline Approaches 400vph (20-70-10 split)
Cross Street Approaches 100vph (25-50-25 split)

	HCS-Unsignalized	CORSIM
1A (4-leg no LT Lane)	A	A
1B (3-leg no LT Lane)	A	A
2A (4-leg with ByPass)	N.A.*	A
2B (3-leg with ByPass)	N.A.*	A
3A (4-leg with LT Lane)	A	A
3B (3-leg with LT Lane)	A	A

* The HCS software is not able to analyze bypass lanes

7.0 Design Analysis

The purpose of this chapter is to document and analyze Mn/DOT's current practices relating to the design of bypass and left turn lanes, including the following items:

- Design guidelines for both bypass lanes and separate right and left turn lanes (width, length, tapers, etc.)
- Current traffic control guidelines (signs and pavement markings)
- Estimated construction costs
- Current warrants for installation

In addition, a summary discussion is provided that takes into account the conclusions of the previous sections (Literature Search, Survey of Practice, Legal Issues, Safety Analysis, and Traffic Operations Analysis) and presents a series of recommended policy and design guideline revisions.

7.1 Design Guidelines

The current design guidelines for bypass lanes and separate left and right turn lanes are taken from State of Minnesota Department of Transportation Road Design Manual Part I. All lane widths are 3.6 meters except for left turn lanes which are 4.0 meters, and all dimensions are in metric units.

7.1.1 Bypass Lane

The recommended design features for bypass lanes, illustrated in Figures 7.1 and 7.2 from the Mn/DOT Road Design Manual, show the design guidelines for both three-legged and four-legged intersections. The key elements of the design include a 90-meter storage length for the right turn or right/through lane and the use of a 54-meter taper length (15:1) to move through traffic around left turning vehicles. The use of these dimensions allows through traffic to move around left turning vehicles at speeds up to approximately 70 percent of typical rural operating speeds. The total length of a bypass lane at three-legged and four-legged intersections is approximately 250 meters and 296 meters, respectively.

7.1.2 Full Left Turn Lane

The recommended design features for left turn lanes are illustrated in Figures 7.3 and 7.4 for both three-legged and four-legged intersections. The key elements of the design are the use of reverse 3500-meter radius curves to separate the through lanes in order to provide recommended 90-meters of left turn storage. Based on these dimensions, through traffic is moved around left turning vehicles at speeds equal to or greater than 100 percent of typical rural operation speeds. The total length of a full left turn lane is approximately 740 meters for both three-legged and four-legged intersections.

7.1.3 Alternative Minimum Left Turn Lane

Mn/DOT guidelines allow the use of an alternative minimum length left turn lane design where speeds are 70 km/h (45 mph) or less. Figures 7.5 and 7.6 illustrate the design guidelines for three and four-legged intersections. The key elements of this design include the use of 90-meter left turn lanes and a 1:50 taper to move through traffic around left turning vehicles at speeds in the range of 90 to 100 percent of typical rural operating speeds. The total length needed for the construction of a alternative minimum left turn lane at a three-legged and four-legged intersections is approximately 390 meters.

7.1.4 Alternative Left Turn / Bypass Lane Designs

A review of the literature suggests there are (at least) two additional left turn/bypass lane designs that are currently being used by various transportation agencies along rural roadways in North America. The first is a hybrid left turn – bypass lane that is used extensively in Canada. The second involves simply using wide paved shoulders in the vicinity of key public roadway intersections.

1. Hybrid Left Turn / Bypass Lane at Four-Legged Intersections

   A hybrid left turn/bypass lane involves the development of an exclusive left turn lane using the basic dimensions of a left turn/bypass lane. The use of a 1:15 taper and 90-meter turn lanes suggest that through traffic would be moved around left turning vehicles at speeds up to approximately 70 percent of typical rural operating speeds. Figure 7.7 shows the design features for a hybrid left turn/bypass lane. The total length needed for the construction of this alternative is approximately 285 meters.

2. Full Shoulder

   Figures 7.8 and 7.9 show the design features for utilizing full width shoulders at three-legged and four-legged intersections in order to accommodate both right turn and bypass maneuvers at low volume intersections. The total length needed for the construction of a full shoulder ranges from approximately 186 to 230 meters for three-legged and four-legged intersections, respectively.

Figures 7.10 and 7.11 provide a comparison of the different design alternatives for three and four-legged intersections.

7.2 Current Traffic Control Guidelines

7.2.1 Signing

The current traffic control signing guidelines for left and right turn lanes are found in the Manual on Uniform Traffic Control Device (MUTCD). There are no guidelines in the MUTCD for signage of bypass lanes. Therefore, Mn/DOT's typical practice of providing no additional signs is consistent with the MUTCD.

7.2.2 Pavement Markings

The current traffic control pavement markings for left and right turn lanes are also found in the MUTCD. There are no specific guidelines for markings of bypass lanes in the MUTCD. However, Mn/DOT has developed a recommended practice for marking bypass lanes at both three and four-legged intersections, which is illustrated in Figure 7.12.

7.3 Estimated Construction Costs

Estimated construction costs were developed for the different types of intersection designs. The estimates are based on accounting for excavation, surfacing, pavement markings, traffic control, and a 20 percent contingency. The key assumptions are noted in Table 7.1. It should be noted that Mn/DOT personnel have reviewed these cost estimates and appropriate adjustments have been made. The estimated construction costs for three and four-legged intersections are documented in the following paragraphs.

7.3.1 Three-Legged Intersection

The estimated construction costs for each design alternative at three-legged intersections are documented in Table 7.2 and are summarized below:

1. Full Left Turn Lane $200,000
2. Alternative Minimum Left Turn Lane $166,000
3. Bypass Lane $50,000
4. Full Shoulder $26,000

7.3.2 Four-Legged Intersection

The estimated construction costs for each design alternative at four-legged intersections are documented in Table 7.3 and summarized below:

1. Full Left Turn Lane $215,000
2. Alternative Minimum Left Turn Lane $165,000
3. Bypass Lane $59,000
4. Hybrid Left Turn/Bypass Lane $85,000
5. Full Shoulder $52,000

7.4 Warrants for Installation

The warrants for installation of right turn lanes, left turn lanes, and bypass lanes at rural intersections on two-lane highways are documented in Section 5.3 of the Mn/DOT Road Design Manual. The specific recommendations are identified in the following paragraphs.

7.4.1 Right Turn Lanes

Right turn lanes should be considered when the projected average daily traffic (ADT) is greater than 1500, the design speed is greater than 70 kilometers per hour, and the following:

a. at all public road access points

b. if industrial, commercial, or substantial trip-generating land use is to be served, or
c. if the access serves more than ten residential units

The need for a right turn lane should also be based on a consideration of the number of right turns.

7.4.2 Left Turn Lanes

Left turn lanes should be provided when the access is to a public road, an industrial tract, or a commercial center and one of the following criteria are met:

a. Crash records confirm an excessive hazard (an average of more than three crashes per year involving left-turning vehicles).

b. The criteria for left-turn lane warrants in Figures 5-3.01B, C, and D (found in the Mn/DOT Road Design Manual) are satisfied.

7.4.3 Bypass Lanes

When the criteria for the left-turn lane warrants are not satisfied, a bypass lane may be considered. At four-legged intersections, the bypass lane combined with a right turn lane should only be used where the crossroad volumes are low. For this condition, an evaluation assessing the likelihood of all three movements (left turn, right turn, and through movements) occurring simultaneously must be made to determine if this is acceptable or if separate left-turn and right-turn lanes are justified.

The bypass lane is provided as a convenience or emergency measure and designed for lower speed maneuvering. This design is not recommended for indiscriminate use. It should be taken under consideration that the pavement markings for the bypass lane will infringe on the availability of the passing zone.

A review of Mn/DOT's policies relative to the use of turning lanes on two-lane highways indicates that a great deal of discretion is left to the individual designer. Some guidance is provided relative to each of the following issues:

1. Speed - Right turn lanes should be considered when speeds are greater than 70 km/h (45 mph). It's is expected that this condition would be met in virtually all rural highways.

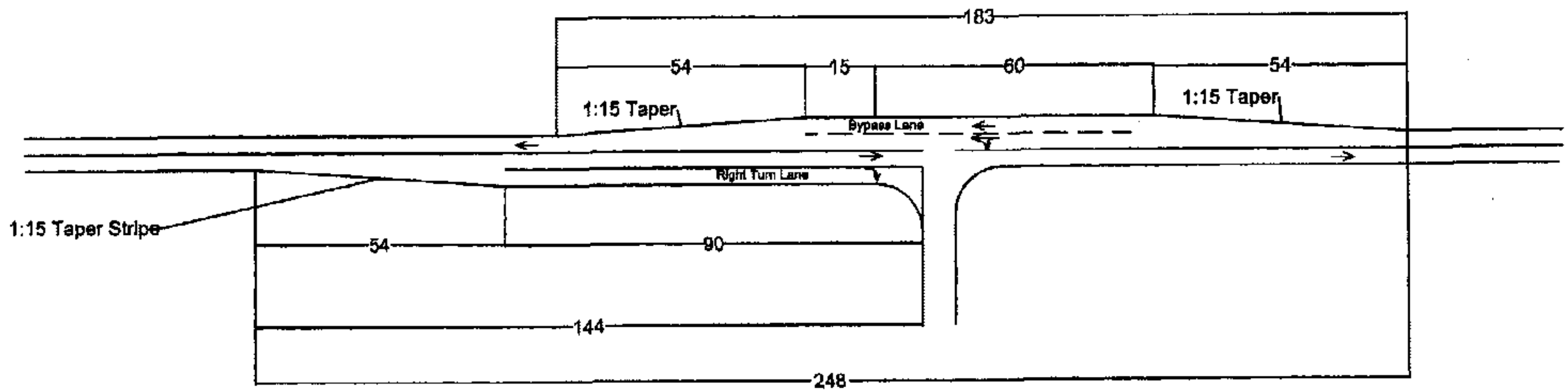
2. Volume - Right turn lanes should be considered when forecast volumes exceed 1500 vehicles per day. It is expected that this condition would be met on virtually all rural highways.

3. Crashes - Left turn lanes should be considered when there are three or more crashes involving left turning vehicles. A review of the statewide data suggests that fewer than 3 percent of rural intersections experience a total of 3 or more crashes per year, and it is estimated that fewer than 0.5 percent of the rural intersections experience 3 or more crashes involving left turning vehicles on an annual basis.

4. Traffic Operations - Left turn lanes should be considered when combinations of through and left turning volumes exceed thresholds identified in Figures 5-3.01 A-D in the Road Design Manual. However, it should be noted that the traffic operations analysis suggested that there is no objective data to support guidance provided in these figures.

5. Design Consistency - Turn lanes should be considered at every intersection along a segment of highway if most intersections warrant the installation.

A final review of this information indicates that the warrants provide very little actual guidance because the speed and volume warrants are so low that they would likely be met at practically all intersections. In addition, the crash warrant is so high that it would likely not be met at any intersection and the traffic operations warrants cannot be supported based on the output from the computer modeling effort. As a result, the warrants provide designers with a great deal of discretion relative to the use of turn lanes and this may at least partially explain what appears to be an inconsistent use of turn lanes from one district to another, even along the same trunk highway.



(Dimensions are in Metric Units)

Figure 7.1
Bypass Lane

Source: MnDOT Road Design Manual

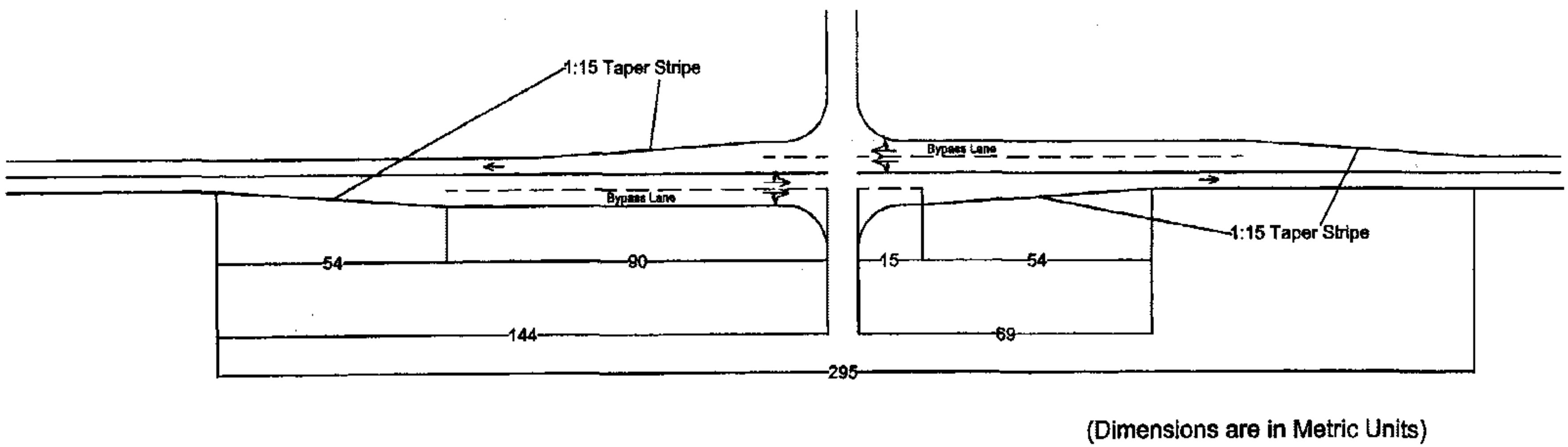
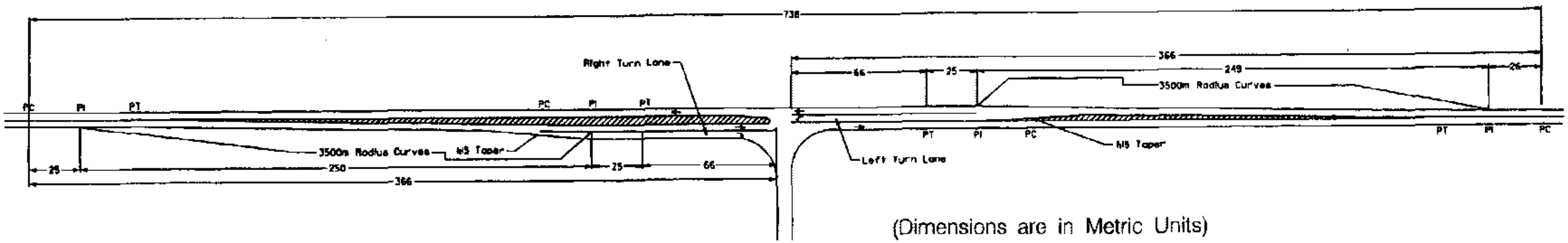


Figure 7.2
Bypass Lane
Four-Legged Intersection

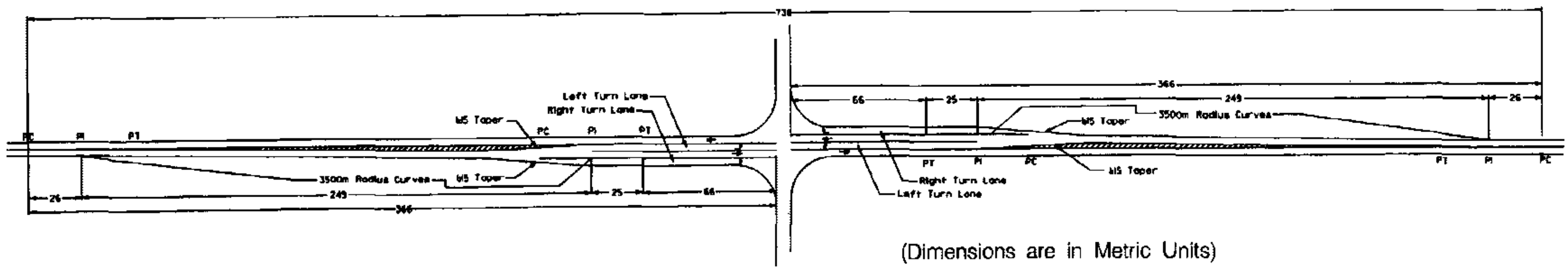
Source: MnDOT Road Design Manual
Figure 5-3.01F



(Dimensions are in Metric Units)

Figure 7.3
Full Left Turn Lane
Three–Legged Intersection

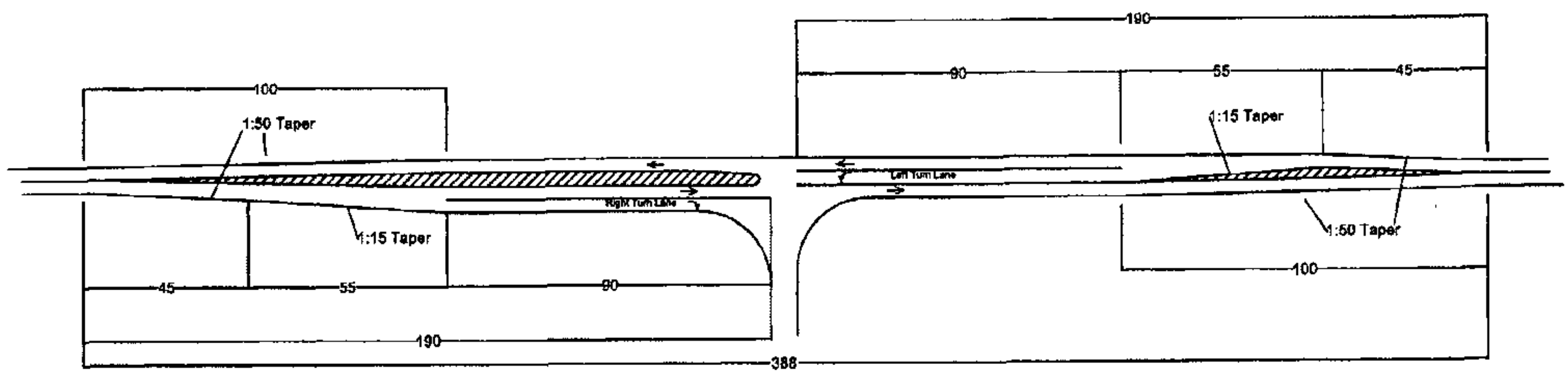
Source: MnDOT Road Design Manual
Figure 5–2.06C (100 KPH Assumed)



(Dimensions are in Metric Units)

Figure 7.4
Full Left Turn Lane
Four–Legged Intersection

Source: MnDOT Road Design Manual
Figure 5–2.06C (100 KPH Assumed)

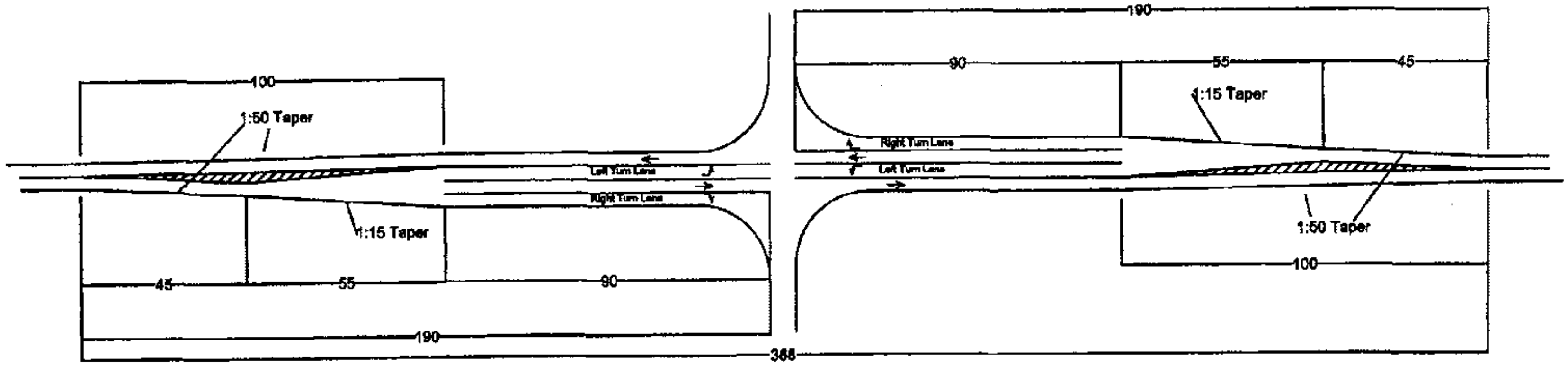


Note 1: There are 2 tapers - 50:1 to move traffic in the through lane and 1:15 to move traffic into the right turn lane

Note 2: For speeds 70 km/h and less

(Dimensions are in Metric Units)

Figure 7.5
Alternative Minimum Left Turn Lane
Three-Legged Intersection



Note 1: There are 2 tapers - 1:50 to move through traffic and 1:15 *to move traffic into* right turn lane

Note 2: For speeds 70 km/h and less

(Dimensions are in Metric Units)

Figure 7.6
Alternative Minimum Left Turn Lane
Four-Legged Intersection

Source: MnDOT Road Design Manual
Figure 5-2.06C

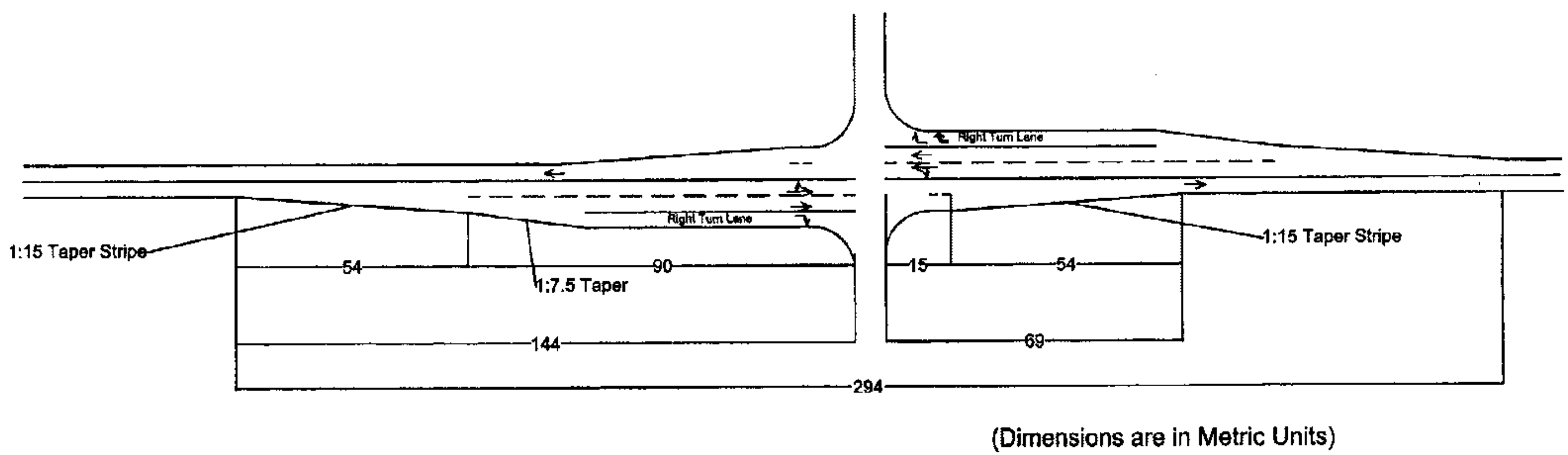
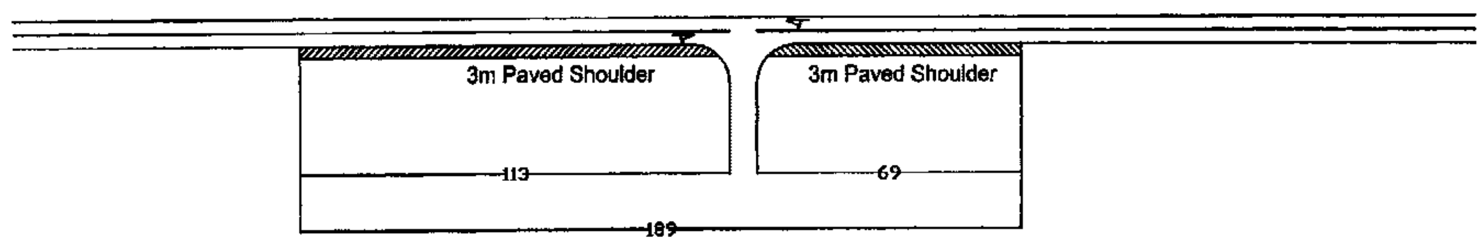
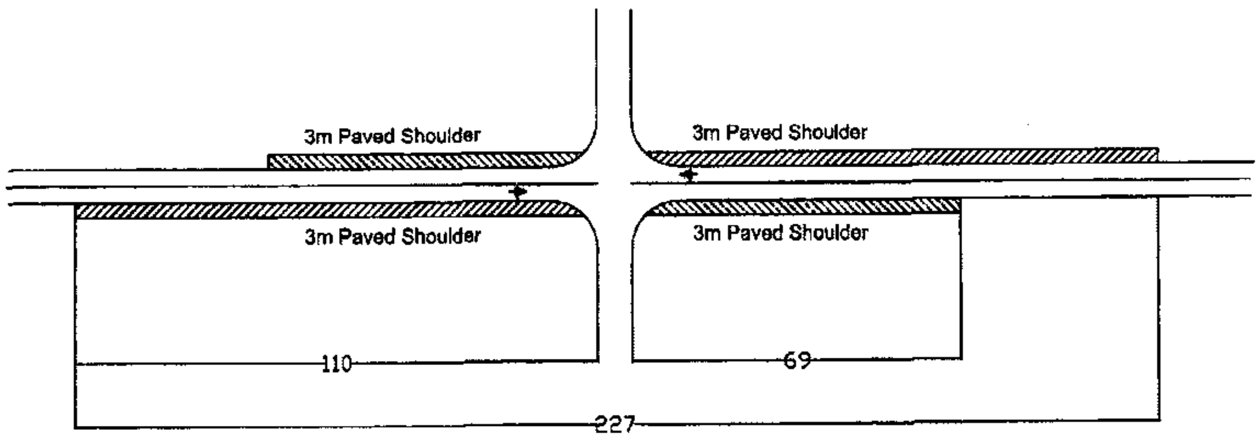


Figure 7.7
Hybrid Left Turn/Bypass Lane
Four-Legged Intersection



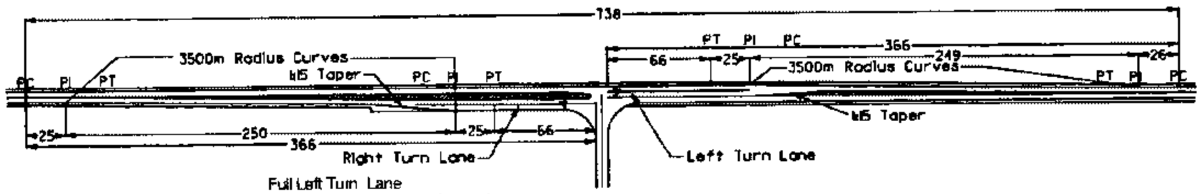
(Dimensions are in Metric Units)

Figure 7.8
Full Shoulder
Three-Legged Intersection

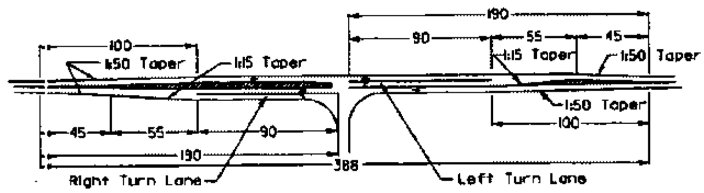


(Dimensions are in Metric Units)

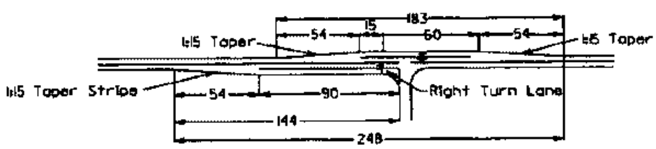
Figure 7.9
Full Shoulder
Four-Legged Intersection



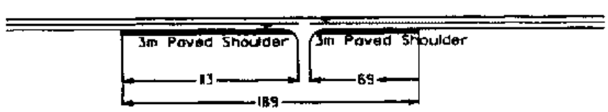
Full Left Turn Lane
MnDOT Road Design Manual
Figure 5-2.06C (100 KPH Assumed)



Alternative Minimum Left Turn Lane
MnDOT Road Design Manual
Figure 5-2.06C



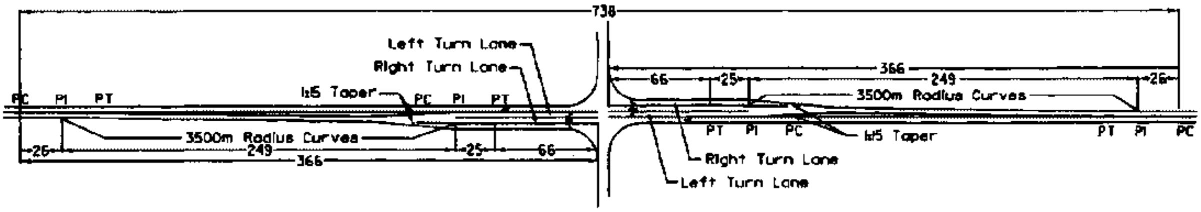
Bypass Lane
MnDOT Road Design Manual
Figure 5-3.01E



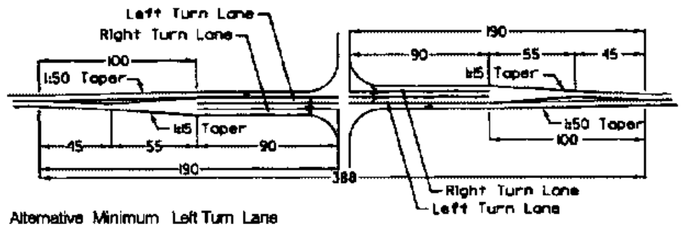
Full Shoulder

(Dimensions are in Metric Units)

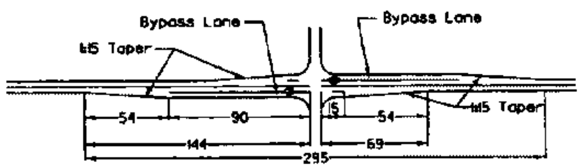
Figure 7.10
Three-Legged Intersection
Alternatives



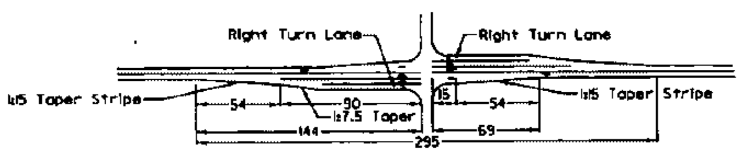
Full Left Turn Lane
MnDOT Road Design Manual
Figure 5-2.06C (100 KPH Assumed)



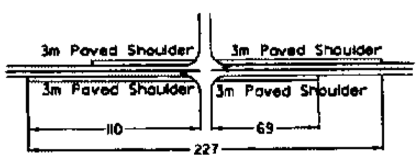
Alternative Minimum Left Turn Lane
MnDOT Road Design Manual
Figure 5-2.06C



Bypass Lane
MnDOT Road Design Manual
Figure 5-3.01F



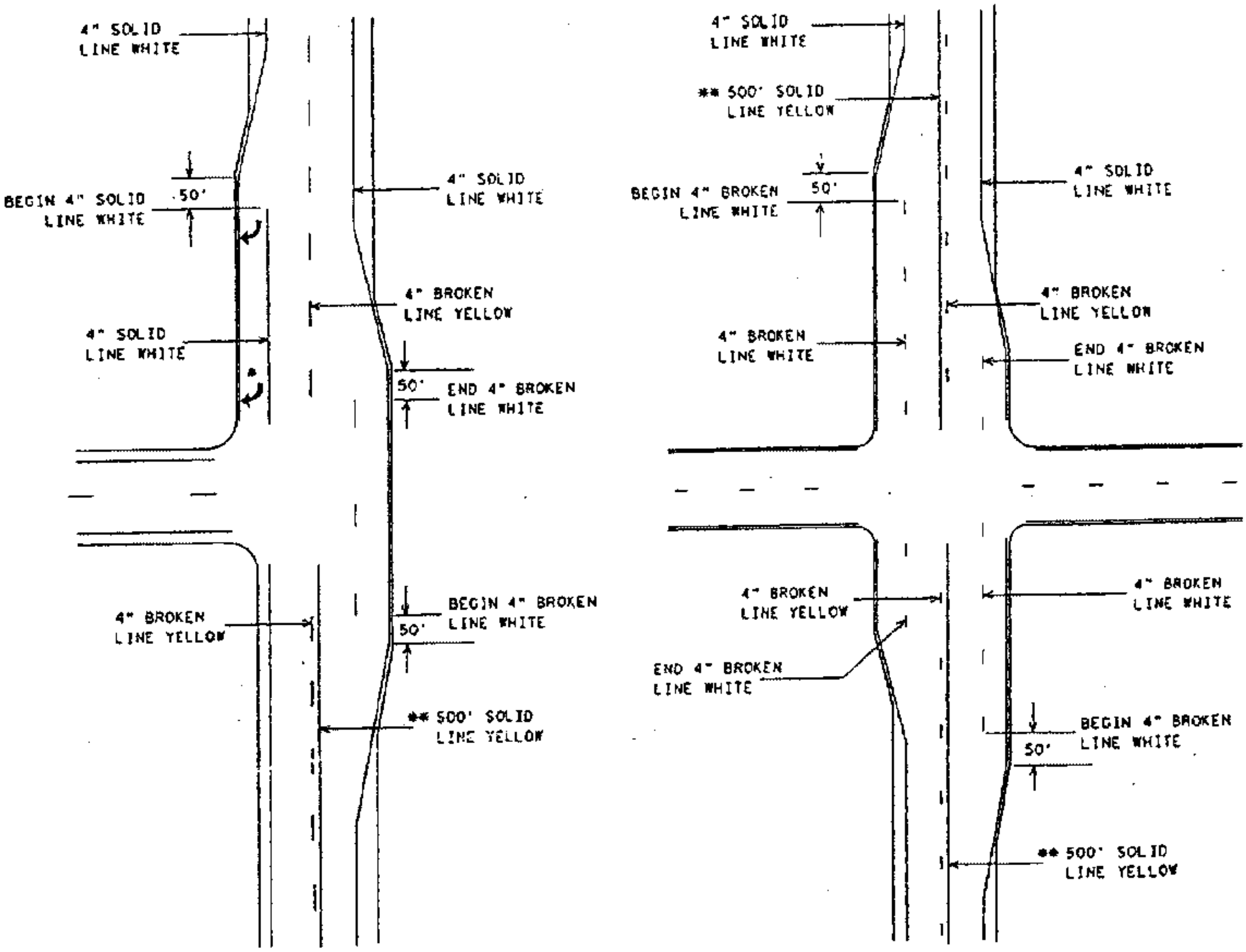
Hybrid Bypass Lane



Full Shoulder

(Dimensions are in Metric Units)

Figure 7.11
Four – Legged Intersection Alternatives



NOTE: CROSSROAD LAYOUT IS TO BE USED ONLY FOR MAINTENANCE OF EXISTING INSTALLATIONS.

* SEE FIGURE 7.11 FOR PLACEMENT OF ARROWS.

** IF THE DISTANCE BETWEEN THE BEGINNING OF THE SOLID LINE YELLOW IS LESS THAN THE DISTANCES IN THE CHART BELOW FROM THE END OF A PRECEEDING SOLID LINE YELLOW IN THE SAME LANE, THE SOLID LINE SHALL BE EXTENDED BETWEEN THEM.

35 MPH SPEED LIMIT OR LESS	500'
40-50 MPH SPEED LIMIT	650'
55 MPH SPEED LIMIT	800'

Text Ref.: 7-4.05.10

July 1, 1994	PAVEMENT MARKING DETAILS BYPASS LANES	FIGURE 7.12

Table 7.1
Assumptions for Cost Estimates

- Existing Conditions (rural)

  - Two-way traffic with 2.4 meter shoulder and 3.6 meter lanes

- Proposed Section for Widening

  - 200 mm (8") bituminous pavement
  - 150 mm (6") class 5 aggregate base
  - 610 mm (24") select granular bedding

  * on compacted suitable soils

- Grading and Bituminous

  1. Three-Legged Alternatives

     a. Alt. 1 - Bituminous removal and grading in two sides
        Mill and overlay on the other side
     b. Alt. 2 - Remove bituminous shoulders and grading in three sides
        Mill and overlay 7.2 meters
     c. Alt. 3 - Remove bituminous shoulders and grading two of the three sides
        Mill and overlay needed
     d. Alt. 4 - Remove bituminous shoulder south-side only
        No mill and overlay needed

  2. Four-Legged Alternatives

     a. Alt. 1 - Bituminous removal and grading in two of four quadrants
        Mill and overlay the other two quadrants
     b. Alt. 2 - Remove bituminous shoulders and grading in four quadrants
        Mill and overlay 7.2 meters
     c. Alt. 3 - Bituminous removal and grading in all four quadrants
        No mill and overlay needed
     d. Alt. 4 - Bituminous removal and grading in all four quadrants
        No mill and overlay needed
     e. Alt. 5 - Strengthen shoulder in all four quadrants
        No mill and overlay needed

Table 7.2
Three-Legged Intersection Alternatives
Cost Estimate

Item No.	Items	Unit	Unit Price	Alt 1 Quantity	Alt 1 Cost	Alt 2 Quantity	Alt 2 Cost	Alt 3 Quantity	Alt 3 Cost	Alt 4 Quantity	Alt 4 Cost
2104.503	Remove Bituminous Pavement	m2	$ 2.50	1640	$ 4,100.00	1865	$ 4,662.50	1035	$ 2,587.50	335	$ 837.50
2104.513	Sawing Bituminous Pvm't (Full Depth)	m	$ 10.00	735	$ 7,350.00	780	$ 7,800.00	435	$ 4,350.00	140	$ 1,400.00
2105.501	Common Excavation (1)	m3	$ 6.50	3545	$ 23,042.50	1610	$ 10,465.00	985	$ 6,402.50	555	$ 3,607.50
2105.522	Select Granular Borrow (CV)	m3	$ 10.50	2075	$ 21,787.50	1970	$ 20,685.00	565	$ 5,932.50	315	$ 3,307.50
2211.503	Aggregate Base (CV) Cl. 5 (2)	m3	$ 20.00	515	$ 10,300.00	490	$ 9,800.00	140	$ 2,800.00	80	$ 1,600.00
2232.501	Mill Bituminous Surface (50 mm)	m2	$ 1.00	6530	$ 6,530.00	2795	$ 2,795.00	0	$ -	0	$ -
2340.609	Bituminous Pavement (3)	t	$ 38.00	1620	$ 61,560.00	1545	$ 58,710.00	425	$ 16,150.00	240	$ 9,120.00
2340.609	Bituminous Overlay (4)	t	$ 38.00	500	$ 19,000.00	335	$ 12,730.00	0	$ -	0	$ -
2563.601	Traffic Control (5)	lump sum		1.0	$ 12,293.60	1.0	$ 10,211.80	1.0	$ 3,057.80	1.0	$ 1,589.80
2564.603	100 mm Solid Line -Epoxy (6)	m	$ 0.70	2250	$ 1,575.00	1125	$ 787.50	415	$ 290.50	140	$ 98.00
	Contingency @ 20% (7)				$ 33,507.72		$ 27,729.36		$ 8,314.16		$ 4,312.06
	ALTERNATIVE TOTAL COST				**$ 201,046.32**		**$ 166,376.16**		**$ 49,884.96**		**$ 25,872.36**

General Notes:

(1) Includes salvaging topsoil.
(2) Based on (6") 150 mm.
(3) Includes 31 base, 41 binder & 41 wear courses (8') 200 mm total depth.
(4) 50 mm (2") overlay on existing pavement, includes bit. fog seal.
(5) Based on 8% of the total construction cost.
(6) Includes gore area striping (600 mm wide) & white or yellow epoxy paint.
(7) Includes mobilization,erosion control,culvert extension & turf establishment.

Legend:

ALT 1 **FULL LEFT TURN LANE**
ALT2 **MINI LEFT TURN LANE**
ALT3 **BYPASS LANE**
ALT4 **FULL SHOULDER**

Note: Cost Estimates were reviewed by Mn/DOT personnel.

Table 7.3
Four-Legged Intersection Alternatives
Cost Estimate

Item No.	Items	Unit	Unit Price	Alt 1		Alt 2		Alt 3		Alt 4		Alt 5	
				Quantity	Cost	Quantity	Cost	Quantity	Cost	Quantity	Cost	Quantity	Cost
2104.503	Remove Bituminous Pavement	m2	$ 2.50	1640	$ 4,100.00	1825	$ 4,562.50	1060	$ 2,650.00	1060	$ 2,650.00	665	$ 1,662.50
2104.513	Sawing Bituminous Pvm't (Full Depth)	m	$ 10.00	680	$ 6,800.00	760	$ 7,600.00	440	$ 4,400.00	440	$ 4,400.00	280	$ 2,800.00
2105.501	Common Excavation (1)	m3	$ 6.50	3550	$ 23,075.00	2970	$ 19,305.00	1165	$ 7,572.50	1730	$ 11,245.00	1105	$ 7,182.50
2105.522	Select Granular Borrow (CV)	m3	$ 10.50	2075	$ 21,787.50	1750	$ 18,375.00	680	$ 7,140.00	1040	$ 10,920.00	630	$ 6,615.00
2211.503	Aggregate Base (CV) Cl. 5 (2)	m3	$ 20.00	515	$ 10,300.00	435	$ 8,700.00	170	$ 3,400.00	260	$ 5,200.00	155	$ 3,100.00
2232.501	Mill Bituminous Surface (50 mm)	m2	$ 1.00	6530	$ 6,530.00	2740	$ 2,740.00	0	$ -	0	$ -	0	$ -
2340.609	Bituminous Pavement (3)	t	$ 38.00	1620	$ 61,560.00	1375	$ 52,250.00	530	$ 20,140.00	815	$ 30,970.00	480	$ 18,240.00
2340.609	Bituminous Overlay (4)	t	$ 38.00	785	$ 29,830.00	330	$ 12,540.00	0	$ -	0	$ -	0	$ -
2563.601	Traffic Control (5)	lump sum		1.0	$ 13,118.60	1.0	$ 10,085.80	1.0	$ 3,624.20	1.0	$ 5,230.80	1.0	$ 3,168.00
2564.603	100 mm Solid Line -Epoxy (6)	m	$ 0.70	0	$ 2,250.00	1100	$ 770.00	400	$ 280.00	475	$ 332.50	435	$ 304.50
	Contingency @ 20% (7)				$ 35,870.22		$ 27,385.66		$ 9,841.34		$ 14,189.66		$ 8,614.50
	ALTERNATIVE TOTAL COST				**$ 215,221.32**		**$ 184,313.96**		**$ 59,048.04**		**$ 85,137.96**		**$ 51,687.00**

General Notes:

(1) Includes salvaging topsoil.
(2) Based on (6") 150 mm.
(3) Includes 31 base, 41 binder & 41 wear courses (8') 200 mm total depth.
(4) 50 mm (2") overlay on existing pavement, includes bit. fog seal.
(5) Based on 8% of the total construction cost.
(6) Includes gore area striping (600 mm wide) white or yellow epoxy paint.
(7)Includes mobilization,erosion control,culvert extension & turf establishment.

Legend:

ALT 1	**FULL LEFT TURN LANE**
ALT2	**MINI LEFT TURN LANE**
ALT3	**BYPASS LANE**
ALT4	**HYBRID BYPASS LANE**
ALT5	**FULL SHOULDER**

Note: Cost estimates were reviewed by Mn/DOT personnel

8.0 Conclusions and Recommendations

8.1 Conclusions

Literature Search

1. All of the published research addressed the issue of bypass lanes at three-legged intersections. There was no mention of the use of bypass lanes at four-legged intersections.

2. The literature concluded that bypass lanes reduced the assumed delay and crashes at three-legged intersections, but not as much as exclusive left-turn lanes. It was also noted that some states chose not to use any bypass lanes because of concerns regarding safety and driver expectation.

3. The search concluded that bypass lanes were a viable alternative to exclusive left turn lanes at three-legged intersections because they are less costly.

Survey of Usage

4. Most Minnesota cities and counties that responded to the questionnaire provided design features, signs or markings at bypass lanes that are not consistent with Mn/DOT guidelines.

5. Most city and county engineers (that responded to the survey) suggested that the use of bypass lanes at three-legged intersections was acceptable, but expressed concerns about safety issues at four-legged intersections.

Legal Issues

6. Minnesota law is very clear that passing on the right is only legal if the maneuver is carried out on the "main traveled portion" of the roadway. However, the definition of just what constitutes the "main traveled portion" of the roadway is subject to the interpretation of individual law enforcement officers and prosecutors.

Safety Issues

7. The results of the comparative crash analysis of over 2,700 intersections, including both three and four-legged intersections with no turn lanes, with bypass lanes and with exclusive left turn lanes was inconclusive. The slight differences in crash rates that were documented among the various intersection designs were not statistically significant. As a result, it is impossible to conclude that the use of either a bypass lane or a left-turn lane provides a greater degree of safety.

8. At lower volume levels (less than 4,000 vpd) the positive effects of left-turn lanes was noticeable. The three and four-legged intersections with left turn lanes had the lowest crash rates of any of the design categories. At higher volume levels, the crash rate data for the various design categories was not consistent. However, three-legged intersections with left-turn lanes and volumes over 10,000 vpd had the lowest crash rate of any of the design categories.

9. There appears to be a direct relationship between traffic volume and crash severity. Higher traffic volumes generally resulted in a higher percentage of fatal plus injury crashes in all design categories.

10. Intersections with left-turn lanes had the lowest percentage of rear end crashes and intersections with bypass lanes had the highest percentage. Intersections with no left-turn lanes had the highest percentage of left-turn crashes and intersections

with bypass lanes or left turn lanes had a similar, lower percentage of left-turn crashes.

11. The results of the comparative crash analysis have a low level of statistical reliability because of the small size of the sample of intersections in Mn/DOT's database for the bypass lane and left-turn lane categories. In addition, a review of the statewide distribution of intersections in the crash record database indicates a potential bias. Districts 1 and 4 (predominantly rural areas) account for fewer than 5 percent of the total number of intersections analyzed while the Metropolitan Division accounts for almost 20 percent of the intersections.

12. Because of the inconclusive results of the comparative analysis, a Before versus After analysis was conducted of 69 intersections where bypass lanes were constructed. The results of the analysis indicated a modest decrease in total crashes, average crash frequency and average crash rate. However, none of the differences were statistically significant. Two disturbing trends were also noticed. First, the severity index (percentage of injury plus fatal crashes) increased by over 30 percent following construction of the bypass lanes. Second, the average crash rate in the Before period was approximately 25 to 40 percent below the statewide average for similar intersections. This could explain why there was no decrease in crash frequency and also calls into question why these intersections were selected for additional treatment.

Traffic Operations Analysis

13. The results of the traffic operations analysis suggests that at even fairly high combinations of main line and cross-street traffic volumes, the presence of either bypass lanes or left-turn lanes does not have a significant quantifiable effect on the overall quality of traffic flow. The output from the computer models indicates a LOS A condition for each of the six geometric design alternatives for each of the assumed traffic volume scenarios.

14. The results of the operations analysis also suggests that there is no objective data to support the recommended left-turn treatment warrants documented in Chapter 5 of the Road Design Manual.

Design Analysis

15. Estimated construction costs were developed for each of the design categories. The costs ranged from approximately $50,000 for paved shoulders and bypass lanes to more than $200,000 for a full set of left-turn lanes.

16. Mn/DOT has written warrants for the deployment of left-turn and bypass lanes along two-lane rural roads that provide designers with a great deal of discretion. The warrants identify speed, volume, crash, and traffic operations conditions that indicate when auxiliary lanes should be provided. A review of this information suggests that the warrants provide very little actual guidance. The crash warrant is so high that it would likely be met at only a very small number of intersections. The traffic operations warrants cannot be supported based on the output from any computer modeling. The guidance for bypass lanes indicates that they should be considered when the criteria for left turn lanes are not satisfied. The final guideline addresses the issue of design continuity and suggests that turn lanes should be considered at all intersections along a segment of roadway if most intersections warrant their use. All of this results in providing individual designers with a great deal of discretion relative to the use of turn lanes and this may at least partially explain what appears to be an inconsistent use of turn lanes from one district to another, even along the same trunk highway.

8.2 Recommendations

1. The results of all of the various work tasks revealed no positive effects (other than minimizing construction costs) associated with the use of bypass lanes at *four-*

legged intersections. In general, the installation of bypass lanes did not reduce overall crash frequency, did not address the issue of rear end crashes, and tended to result in more severe crashes. Also, it can be demonstrated that the use of bypass lanes impairs the sight distance of left turning vehicles at four-legged intersections (Figure 8-1). Therefore, it is recommended that Mn/DOT consider revising their turn lane policies to at least reduce or eliminate the use of bypass lanes at four-legged intersections.

2. The results of the work tasks found some limited support for the use of bypass lanes at *three-legged intersections*. The literature search, the survey of usage and comments by Mn/DOT designers and traffic engineers indicated anecdotal evidence for safety and operational benefits associated with bypass lanes, particularly in low volume situations. However, a review of the crash data indicates that at lower traffic levels (less than 4000 vehicles per day) bypass lanes have the highest crash rate of any design category, the highest severity index, and the highest percentage of rear-end crashes. Also, this use of bypass lanes still results in left turn maneuvers from through lanes, a condition that is often considered to present a hazard on high-speed rural roadways. Therefore, it is also recommended that Mn/DOT consider further revising the turn lane policies to reduce or eliminate the use of bypass lanes at three-legged intersections.

3. The only documented advantage associated with the use of bypass lanes is the lower (than exclusive left-turn lanes) estimated construction cost. If Mn/DOT chooses to reduce or eliminate the use of bypass lanes, it is recommended that consideration be given to developing a shorter and therefore less costly exclusive left turn lane design. It is acknowledged that a shorter left turn lane design would provide a safe operating speed less than the prevailing travel speeds on two-lane rural roadways. However, this is exactly the case with the present bypass lane design. Developing a short left turn lane design would provide an opportunity to improve design consistency because all left turn improvements would result in left turn maneuvers only from an auxiliary lane.

4. In order to provide designers with more positive guidance regarding the use of turn lanes, it is recommended that Mn/DOT consider a prioritized approach based on the functional classification of the major roadway. One possible prioritized policy based on roadway function is documented in Table 8-1. The basic policy for situations where *major reconstruction* is being considered suggests the following:

   - Along principal arterials (where the primary function of the road is mobility), all public road intersections should have the standard design left turn lane.

   - Along minor arterials, intersection designs would range from full left turn lanes at other minor arterials; minimum design left turn lanes at lower volume collectors and local streets; and the use of paved shoulders at the lowest volume private driveways.

   - Along collector roadways, intersection designs would include the use of minimum design left turn lanes at other collectors and the use of paved shoulders at lower volume local streets and private driveways.

   - Along local streets, the primary turn lane treatment would be the use of paved shoulders.

   It should be noted that this suggested policy revision is not meant to infer that all in place bypass lanes should be immediately converted to some other design. It may be appropriate to perpetuate bypass lanes on maintenance/preservation projects or at constrained locations based on the individual designers engineering judgement. However, the policy does suggest that left turn lanes should be the first choice for rural intersection treatments (particularly when major investments in a corridor are being considered) and a prioritized approach that recognizes objectives for maximizing mobility and safety while acknowledging the reality of financial constraints.

5. It is recommended that Mn/DOT consider drafting legislation consistent with whatever turn lane policy is ultimately adopted that provides better definition of legal maneuvers, which could improve the consistency of enforcement.

6. Given the fact that it appears that bypass lanes will continue to be deployed for at least the near future, consideration should be given to developing policies and guidelines that would encourage a higher level of consistency in their design and ultimately in the motorists recognition and use of bypass lanes. Potential revisions include the greater use of standard design features and the development of a new strategy for signs and/or pavement markings to improve driver awareness.

7. The Office of Traffic Engineering should consider initiating a statewide effort to update the crash records files that are used extensively for both identification of hazardous locations and for safety related research. It is commonly acknowledged that these files are incomplete but it has always been assumed that the intersections in the files represent a random distribution both geographically and across the various design and intersection control categories. Several recent research projects, however, suggest that this assumption is not valid. Updating the files by either adding more or (better) all intersections in each District would improve the quality of the data and increase the statistical reliability of the results of any technical analysis of the data.

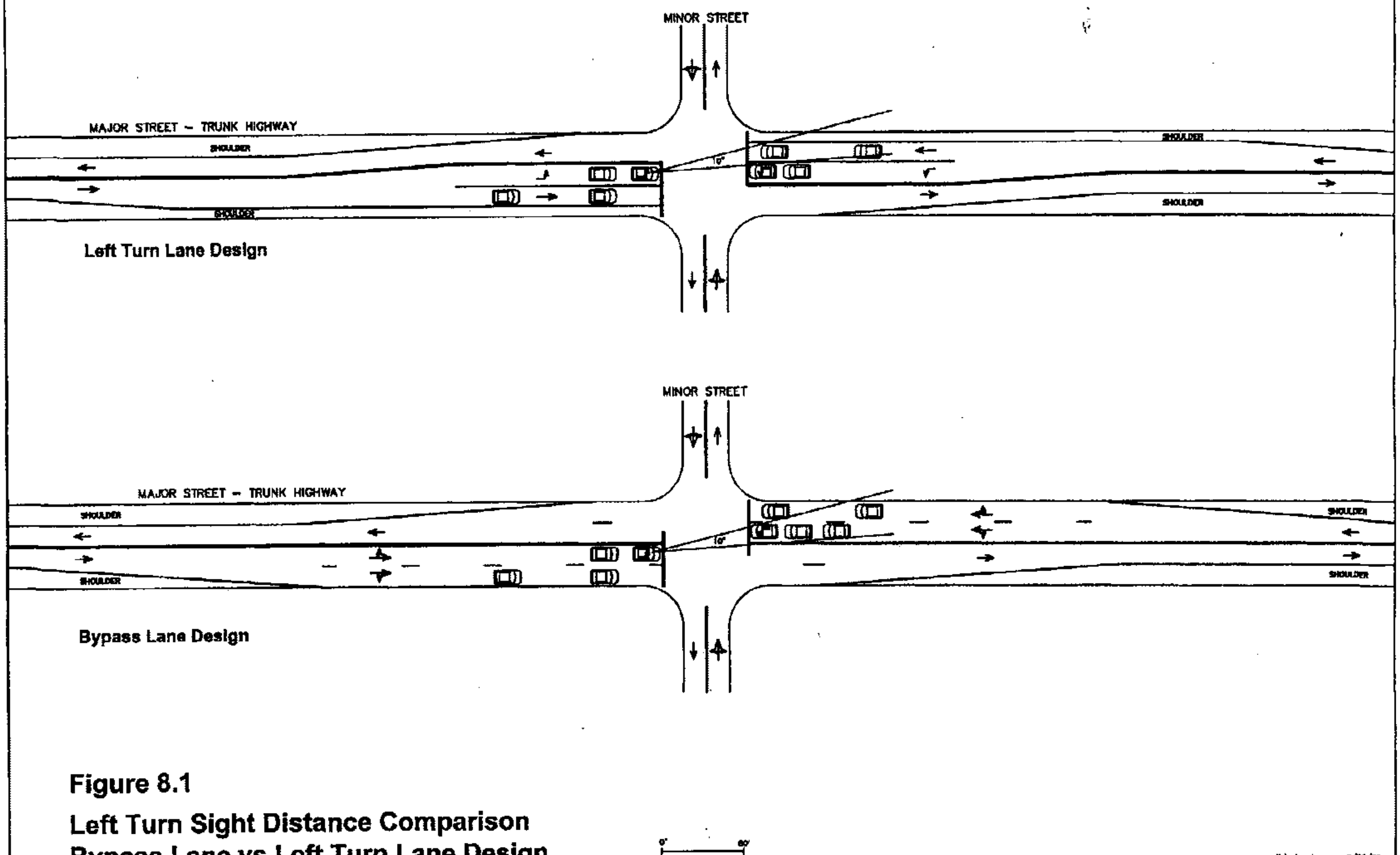


Figure 8.1
Left Turn Sight Distance Comparison
Bypass Lane vs Left Turn Lane Design

Table 8.1
Recommended Rural Intersection Design Policy

Major Street Functional Classification	Cross Street Functional Classification				
	Principal Arterial	**Minor Arterial**	**Collector**	**Local Street**	**Private Driveway**
Principal Arterial	LTL	LTL	LTL	LTL (N.R.)	N.A.
Minor Arterial	LTL	LTL	Min LTL	Min LTL	Paved Shoulder
Collector	LTL	Min LTL	Min LTL	Paved Shoulder	Paved Shoulder
Local Street	LTL (N.R.)	Min LTL	Paved Shoulder	Paved Shoulder	Paved Shoulder

Key:
LTL - Left Turn Lane
Min LTL - Minimum Left Turn Lane
N.A. - Not Allowed
(N.R.) - Intersections of local streets with Principal arterials are Not Recommended

Appendix A

Minnesota Department of Transportation
Survey Form

Minnesota Department of Transportation
Survey Form
Bypass Lanes at Unsignalized, 3 Legged Intersections

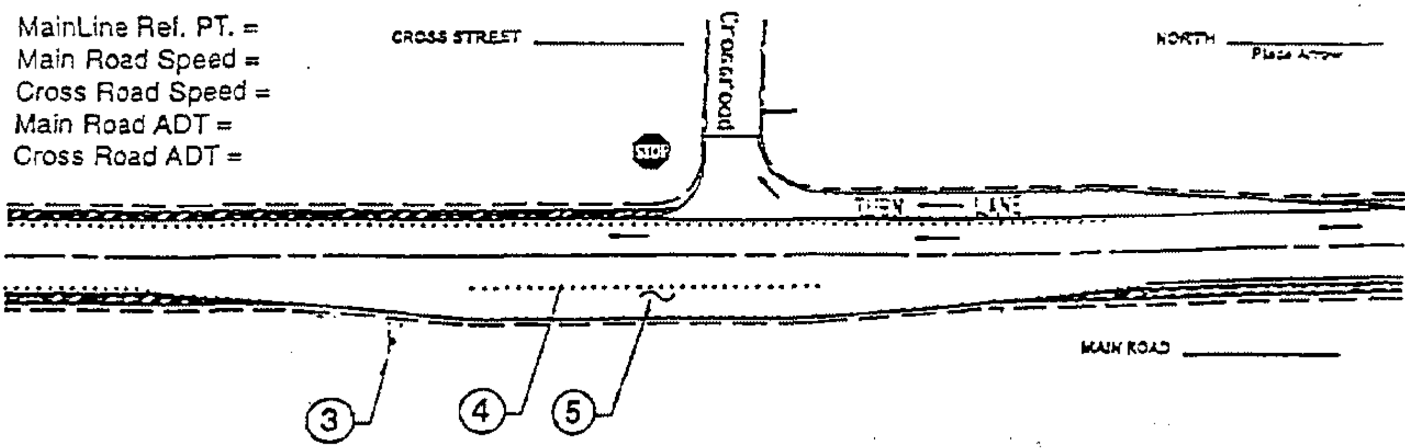
Agency: ______________________ Date: ______________________

Survey Completed By: ____
(please print) *Name* *Title*

Phone No. ______________________

Please fill in blanks below for 3-legged, unsignalized intersections with paved right-turn/bypass as shown below. Feel free to modify diagram to reflect your specific situation (please make cop for each situation):

MainLine Ref. PT. =
Main Road Speed =
Cross Road Speed =
Main Road ADT =
Cross Road ADT =



1.) Do you have any warrants for the use of bypass lanes?
If other, please attach a copy

a) Mn/DOT b) Other c) No

2.) Do you have any design guidelines for bypass lanes?
If other, please attach a copy

a) Mn/DOT b) Other c) No

Refer to the above figure for questions 3 through 5. Circle all that apply.

3) What kind of signing do you use?

a) pass with care b) road narrows c) none d) other ______________________
Please describe

4) What kind of pavement markings do you use?

a) solid white b) skip white c) other ______________________
Please describe

5) What kind of pavement messages do you use?

a) thru arrow b) "only" c) none d) other ______________________
Please describe

- OVER -

6) What kind of pavement thickness is used?

a) regular shoulder b) reinforced shoulder c) mainline design

d) other ______________________

Please describe

7) Has the bypass lane been in place since January 1, 1995?

a) yes b) no

(If no, how long has it been in place?)

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8) Do you have any observations or opinions about the safety or operation of By-pass Lanes?

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9) Do you want to receive a copy of the Final Report

a) yes b) no

Questions? Please Contact: Mike Gieseke
Phone (612) 582-1050
FAX (612) 582-1033

FOLD ON DOTTED LINE

Place Stamp Here

Mark Gieseke
Minnesota Department of Transportation
Office of Traffic Engineering
1500 W. County road B2, MS 725
Roseville, MN 55113

PLEASE TAPE SHUT, DO NOT USE STAPLES

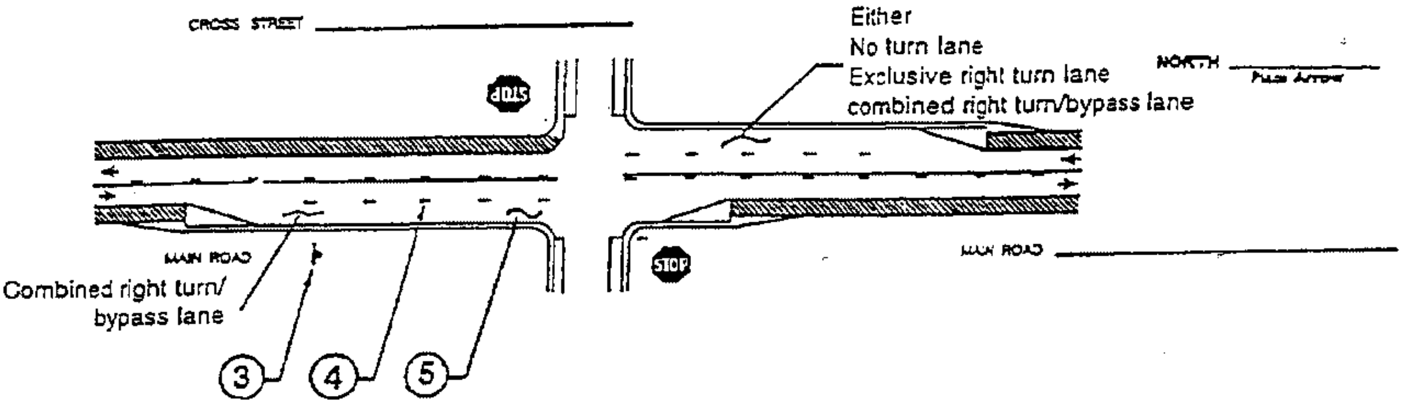
Minnesota Department of Transportation
Survey Form
Combination Right-Turn/Bypass Lanes at Unsignalized Intersections

Agency: ______________________ Date: ______________________

Survey Completed By: ______________________
(please print) Name Title

Phone No. ______________________

Please fill in blanks below for 4-legged, unsignalized intersections with paved right-turn/bypass l[a]
as shown below. Feel free to modify diagram to reflect your specific situation (please make cop[ies]
for each situation):



1.) Do you have any warrants for the use of combined right-turn/bypass lanes?
If other, please attach a copy

a) Mn/DOT b) Other c) No

2.) Do you have any design guidelines for combined right-turn/bypass lanes?
If other, please attach a copy

a) Mn/DOT b) Other c) No

Refer to the above Figure for questions 3 through 5. Circle all that apply

3) What kind of signing do you use?

a) right-turn b) right-turn only c) combined thru-right d) none

4) What kind of pavement markings do you use?

a) solid white b) skip white c) other ______________________
Please describe

5) What kind of pavement messages do you use?

a) right-turn arrow b) thru arrow c) combined thru-right arrow d) "only"

e) none f) other ______________________
Please describe

6) What kind of pavement thickness is used?

a) regular shoulder b) reinforced shoulder c) mainline design

d) other ______________________
Please describe

7) Has the intersection geometry or signing for the locations described in the previous survey been in place since January 1, 1995?

a) yes b) no
(If no, please describe changes)

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8) Do you have any observations or opinions about the safety or operation of By-pass Lanes?

____

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Do you want to receive a copy of the Final Report

a) yes b) no

Questions? Please Contact: Mike Gieseke
Phone (612) 582-1050
FAX (612) 582-1033

FOLD ON DOTTED LINE

Place
Stamp
Here

Mark Gieseke
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Roseville, MN 55113

PLEASE TAPE SHUT, DO NOT USE STAPLES

Office of Research Services
395 John Ireland Blvd., Mail Stop 330
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