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ANALYSIS OF OPERATIONS AND SAFETY OF Y-INTERSECTIONS

VOLUME I: TECHNICAL REPORT

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16. Abstract

Accident experience at unsignalized, two-way intersections, where the major road curves to the right and the side road continues on a tangent to the curve, was examined with the goal of determining whether this type of intersection has accident problems more severe than other types of three-legged intersections.

The study included a review of case studies of severe accidents at these sites, analysis of data from a Y-intersection improvement program from Washtenaw County, Michigan, and analysis of accident data from three-legged intersections on the Michigan state trunkline. Field observations were made at 53 sites. A survey was conducted of state Departments of Transportation concerning their experiences with this type of intersection.

The analyses show that this special type of Y-intersection does not pose a unique risk relative to other three-legged intersections. Its accident patterns are similar to that of all curved Y-intersections. The criteria used for selecting curved Y-sites for safety improvements are sufficient for identifying problem sites among the special Y-intersections also.

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Many members of the University of Michigan Transportation Research Institute staff contributed to this project. Dr. Paul E. Green developed the method of Bayesian estimation of rates, used in the statistical modelling of this research, as part of his Ph.D. dissertation. He also performed the statistical tests required in the analyses. Cecil Lockard and Raymond Masters performed the field studies, and Professor Leland Quackenbush carried out the interviews of the State Departments of Transportation. Dr. Kenneth Campbell served as project director and offered his insights throughout the project. We gratefully acknowledge their contributions.

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CHAPTER 1
ANALYSIS OF OPERATIONS AND SAFETY OF Y-INTERSECTIONS

Introduction

This research examines the accident experience on a particular configuration of the Y-intersection, where a two-way main road curves to the right and the crossroad continues on a tangent from the curve as shown in Figure 1-1. In this report, this particular kind of intersection is referred to as a special right Y-intersection. The mirror image of this configuration, where the main road curves to the left and the crossroad continues on a tangent to the curve, is referred to as a special left Y-intersection.

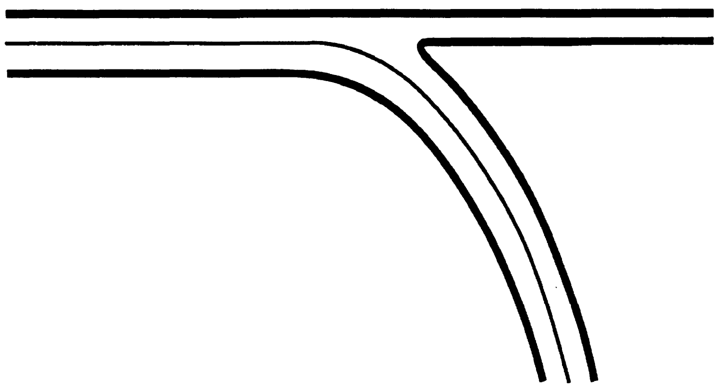


Figure 1-1 - Y-Intersection with Main Road Curving Right and Crossroad on a Tangent

Special right and left Y-intersections were not designed deliberately but are a consequence of the pattern of the original section roads of Michigan that followed the land surveys. Over time, the main roads were built to favor the major traffic flows. This particular type of Y-intersection was often due to abrupt changes in alignments required to follow the section roads. Many of these Y-intersections still exist today. Most sites are in rural areas, but there are some in urban areas. While most are on local roads, some can be found on the Michigan state trunkline road system.

There are obvious problems with intersections of this configuration. A vehicle turning left from the main highway to the crossroad at locations where the main road curves to the right has to travel a considerable distance in the opposing traffic lane, thus increasing the opportunity for a collision with an oncoming vehicle. A driver intending to go straight ahead onto the crossroad might not perceive that he/she must yield to traffic. A driver unfamiliar with the intersection could be drawn to the crossroad, especially under low-light conditions, and cross the opposing lane unintentionally. A vehicle on the crossroad attempting to turn left onto the main road must perform a difficult maneuver and may have a sight-distance problem in observing traffic approaching from the left.

Whether the scenarios described above translate into an abnormally high accident frequency has never been systematically studied. Before remedial action can be taken, it is necessary to determine if an accident problem exists and to understand the nature of the problem in terms of accident types and circumstances.

This research addressed this problem mainly through the comparison of the accident experience at special right Y-intersections with that of other types of Y-intersections and that of Y-intersections with T-intersections using geometric and accident data from the Michigan trunkline system. Before the analysis of the trunkline data was undertaken, case studies of severe accidents at special right Y-intersections were examined to formulate questions and develop hypotheses. The literature was reviewed from the perspective of accident studies and human factors, and a survey of 25 State Departments of Transportation concerning their practices and policies toward these special configurations of Y-intersections was conducted. An information file collected by the Washtenaw County Road Commission for their Y-intersection improvement program was reviewed and analyzed. The research also included field observations at 53 special Y-sites throughout the state.

The report is organized as follows. The following chapter presents the analysis of the case studies of severe accidents at special right Y-sites, a review of the literature, and a review of policies and practices at other states concerning special Y-intersections. Chapter 3 presents the analysis of the Washtenaw County Y-intersection data. Chapter 4 contains the analysis of the Michigan Trunkline data file. The first section of Chapter 4 describes the development of the sample file used in the analysis. The comparison of Y- versus T-intersections is in section 2. The accident experiences of different categories of Y-intersections are compared in section 3. Chapter 5 contains further analyses of special Y-intersections and contains summaries of the field observations of the special Y-sites. Chapter 6 presents the findings of this research and interprets their implications for a treatment and countermeasure program for special Y-intersections.

CHAPTER 2
REVIEW OF EXPERIENCE, LITERATURE, AND COUNTERMEASURES

2.1 LITIGATION CASE REVIEW

Introduction

This research commenced with the examination of a set of case studies of severe accidents at special Y-intersections. Case studies are unique and their analysis can never lead to global conclusions. However, they serve a useful role in an investigation of the phenomenon in question. By carefully examining the in-depth information of a few cases, a researcher can gain enough insight to be able to ask relevant questions, formulate hypotheses, and design an experiment or statistical analysis to reach supportable conclusions.

The source of case studies for accidents at special right Y-intersections was the litigation files from cases involving the Michigan Department of Transportation (MDOT). The files contain detailed information about individual accidents that occurred at the sites. While not all case files have the same level of detail, most have information about conditions at the time of the accident, the police reports, witnesses' statements, information on the drivers involved, and expert witness testimony.

In examining the set of litigation files developed for accidents that occurred at special right Y-intersections, our objectives are to:

Identify any commonalities in the circumstances under which these severe accidents occurred at these sites.

Develop a set of questions about accidents at this Y-configuration that can be addressed in a cross-sectional statistical analysis of accident data.

Procedure

The MDOT selected ten cases from their litigation files that involved accidents at special Y-intersections. We were allowed to examine the files at the MDOT office and to take notes. No material was to be removed or copied.

Ten cases were reviewed. While all ten involved accidents at special Y-intersections, two cases were not directly applicable, and one involved a case where the main road curved to the left rather than the right. That case involved a single-vehicle/cyclist accident that occurred at a Y-intersection where the main road curved to the left. Because this type of accident could have also occurred at a Y-intersection where the main road curves to the right, it is included in the review.

A brief summary of the eight cases reviewed is presented below. Since some of the cases are not closed at the time of this writing, references to the names of persons involved, year of occurrence, townships, and counties will not be made here.

Summary of the Case Studies

Case 1
US-10 and Wever Road
June 21
8:24 p.m.

US-10 runs in a general east-west direction at the accident site. It has two lanes, divided by a standard yellow centerline, striped for no passing. The pavement edges are delineated with white edgelines.

US-10 curves in a gentle south and east direction. The curve is 2.5 degrees and is 1,532 ft. long. The surface is bituminous. The speed limit is 55 mph, and speed studies show that this is close to the 85th percentile speed. The sight distance at this site is good.

The angle at which Wever Road, a county primary road, intersects with US-10 is not known but it is much less than 45 degrees. Traffic moving east on US-10 can access Wever Road but has to cross the westbound lane of traffic of US-10 to get there. Traffic from Wever to US-10 is controlled by a single stop sign. Figure 2-1 shows a sketch of the site.

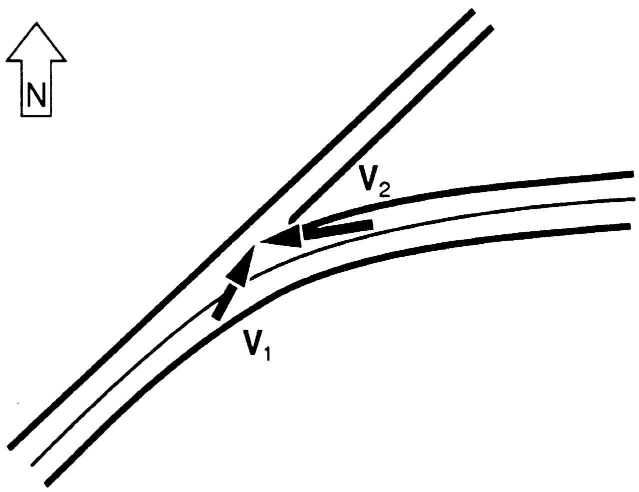


Figure 2-1 - Site of Case 1

The accident history for the 11 years prior to the accident was not remarkable. In 11 years there were 12 accidents, with a total of eight injuries. Four of the accidents were head-on left, with only one severe injury.

The case accident, a two-vehicle head-on collision, occurred on June 21 at 8:24 p.m. at the intersection of US-10 and Wever Rd. The weather was clear. The road was dry. June 21 is the longest day of the year, so 8:24 p.m. was still daylight.

Vehicle 1 was driven by a 19-year-old female, who had just left work in Ludington. She was travelling eastbound on US-10 with the intention to turn onto Wever Road. Vehicle 2, travelling westbound on US-10 at around 60 mph, was driven by a 33-year-old male. His two young sons were in the back seat. They were on their way toward Ludington on a vacation.

As the vehicles were converging on the intersection, vehicle 1 started to cross the centerline and move into the westbound lane somewhat ahead of the intersection. Vehicle 1 did not yield the right-of-way to vehicle 2, but continued toward Wever Road, hitting vehicle 2 at about 40 mph, nearly head-on. The driver of vehicle 2 and one of the passengers were killed. The second passenger was seriously injured. The driver of vehicle 1 sustained type B injuries. The vehicles were totalled.

There was no evidence that defects in either vehicle contributed to the accident. Tests showed that neither driver had ingested controlled substances or alcohol before the accident.

The road was found to be marked in accordance with the Manual of Uniform Traffic Control Devices (MUTCD) (1). The signs were in good condition, and the pavement markings were adequate and in good condition.

There was no curve-ahead, advance-warning sign in advance of the curve since the curve is only a 2.5 degree curve. Wever Road is light colored and narrow and does not look like a continuation of the highway.

Case 2
M-19 and Kinney Road
January 2
4:53 p.m.

M-19 in the area of the accident is a two-lane bituminous highway in the north/south direction. Lanes are 12 feet wide with 3-foot bituminous shoulders and an additional 6- to 7-foot gravel shoulder. The roadway is divided by a standard double yellow centerline, and the pavement edges are marked with white edgelines.

At the scene of the accident, M-19 curves to the southwest approximately 1 mile before continuing southward. In essence, Route M-19 follows Kinney Road to the curve, moves over one mile to Memphis Road, and then continues south on Memphis Road.

Kinney Road continues on the tangent to form a Y-intersection with M-19. At this point Kinney becomes a gravel road. Telephone poles continue down Kinney. A sketch of the intersection is shown in Figure 2-2.

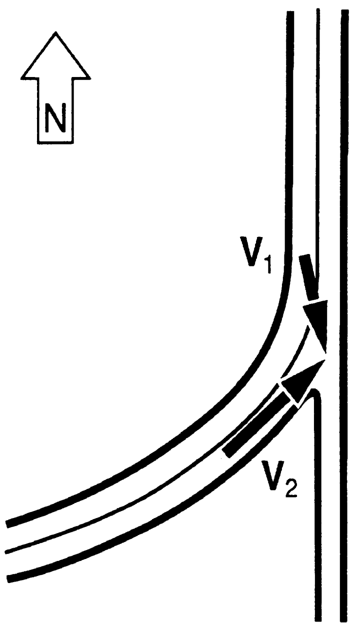


Figure 2-2 - Site of Case 2

A two-car collision occurred on M-19 just north of its intersection with Kinney on January 2 at 4:53 p.m.

Vehicle 1 was travelling southbound on M-19. The driver was familiar with the area and liked to drive this route looking for wildlife. There was testimony that he was troubled and having difficulties with his job.

Vehicle 2 was traveling northeast on M-19. As the vehicles approached the intersection, vehicle 1 continued on the tangent onto Kinney Road and hit vehicle 2. The driver of vehicle 1 was killed. The driver of vehicle 2 said that he expected vehicle 1 to continue on the curve on M-19, but instead it went onto Kinney.

The driver of vehicle 1 was found to have traces of marijuana in his blood.

Case 3
Grand River and Portland Road
November 13
4:35 p.m.

Grand River is an east-west bituminous road, which curves in a northerly direction where it intersects with Portland Road. Portland is also a two-lane bituminous-surfaced road. The intersection involved has a Y shape with the Y opening to the west. Grand River Road forms the upper arm and the leg of the Y. Portland Road forms the lower arm. Traffic is controlled by a stop sign for eastbound Portland traffic entering Grand River.

Figure 2-3 shows the intersection.

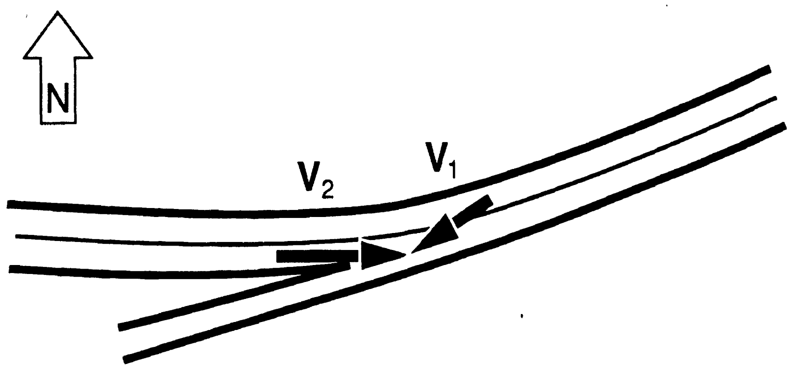


Figure 2-3 - Site of Case 3

On November 13, at 4:35 p.m. the weather was clear and the road was dry. Vehicle 1 was travelling westbound on Grand River. Vehicle 2 was travelling eastbound on Grand River. A witness who was waiting at the stop sign on eastbound Portland road said that vehicle 1 traveled into the eastbound lane and may have been attempting to turn onto Portland. The witness did not see a turn signal. Vehicle 1 hit vehicle 2 head-on in the eastbound lane of Grand River. The driver of vehicle 2 was killed. The driver of vehicle 1 claims he did not see vehicle 2 until he (driver of vehicle 1) was in the middle of the intersection.

No alcohol was found to be present.

Case 4
M-20 and McKinley Road
June 22
9:15 a.m.

M-20 is an east-west, two-lane, bituminous road. At the site of the accident, M-20 curves sharply north, continues northward for about a mile, then turns west. McKinley Road, an east-west, two-lane, gravel road, intersects with M-20 at the point where M-20 curves northward. A sketch of the intersection is shown in Figure 2-4.

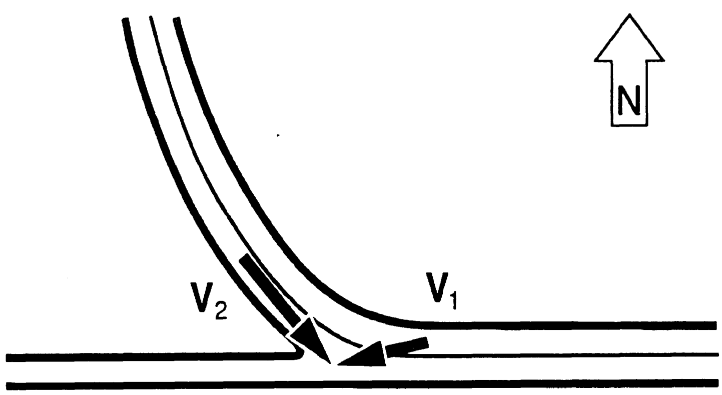


Figure 2-4 - Site of Case 4

Vehicle 1 was westbound on M-20 and attempted to enter McKinley Road. Vehicle 1 was observed to swerve to avoid an oncoming vehicle on eastbound M-20 and then to collide with vehicle 2, another oncoming eastbound vehicle on M-20.

The driver of vehicle 1, a 31-year-old woman was killed. The passengers, her two young children and a 20-year-old woman, sustained injuries. The adult passenger stated that the driver had driven this route many times and was familiar with it. She stated that the driver had just picked up her children from her ex-husband's home and may have been distracted by the children.

Another witness from a vehicle eastbound on M-20 stated that he saw vehicle 1 attempting to go straight onto McKinley and saw that it was not going to stop for the on-coming vehicle.

No alcohol was found to be present. The weather was clear and good. The road was dry. It was daylight.

The district traffic engineer testified in a deposition that he went to the accident site about a month after the accident and observed the traffic. He stated that approximately 75% of the vehicles westbound on M-20 continued onto McKinley. He testified that he observed that most of drivers of these vehicles did not appear to look for possible eastbound traffic on M-20 coming around the curve from the north, but crossed the centerline and proceeded onto McKinley as if they had the right-of-way.

This intersection was reconstructed the year following the accident. However, the reconstruction was programmed before the accident.

Case 5
M-66 and Three Mile Road
September 10
daylight

M-66 is a two-lane, north-south, asphalt road. Near the accident site, M-66 curves slightly to the northeast and Three Mile Road proceeds directly to the north, forming a Y-intersection. Three Mile Road is a two-way, two-lane, asphalt road. Except for this curve, M-66 is flat and straight and there are no visual obstructions. There is a clearly marked no-passing zone for northbound traffic. Paving markings are correct and adequate. The speed limit on M-66 is 55 mph.

There is an asphalt driveway on the west side of M-66 at approximately the intersection of the centerlines of M-66 and Three Mile Road. Figure 2-5 shows the intersection and the driveway.

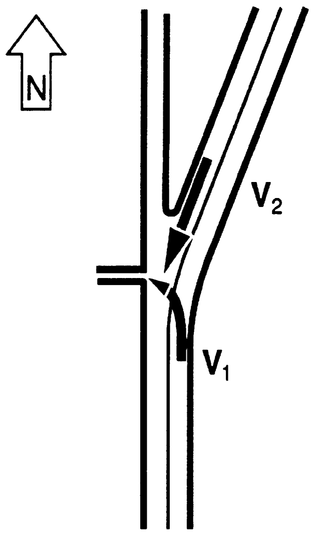


Figure 2-5 - Site of Case 5

Vehicle 2 was traveling southbound on M-66. The driver testified that she saw vehicle 1 stopped directly in front of her, with its left turn indicator on. She applied her brakes, sounded her horn, and swerved to the right to avoid vehicle 1. She was unsuccessful and her vehicle collided with the front passenger side of Vehicle 1. The driver of vehicle 1 was injured.

The driver of vehicle 1 testified that he was stopped on Three Mile Road waiting for a van to pass before making a left turn into the driveway. He never saw vehicle 2.

The weather was clear, it was daylight, and the pavement was dry.

Case 6
M-97 (Groesbeck) and Hillsdale
May 17
evening twilight

In the vicinity of the accident M-97 follows Groesbeck Road. It is a four-lane roadway with a 55 mph speed limit. Hillsdale is a two-lane, paved residential street with a 35 mph speed limit. The roadways intersect at a skewed angle and form a Y-intersection. Groesbeck curves to the left, and if a vehicle continues in the right lane of Groesbeck, it enters Hillsdale. A sketch of the intersection is shown in Figure 2-6.

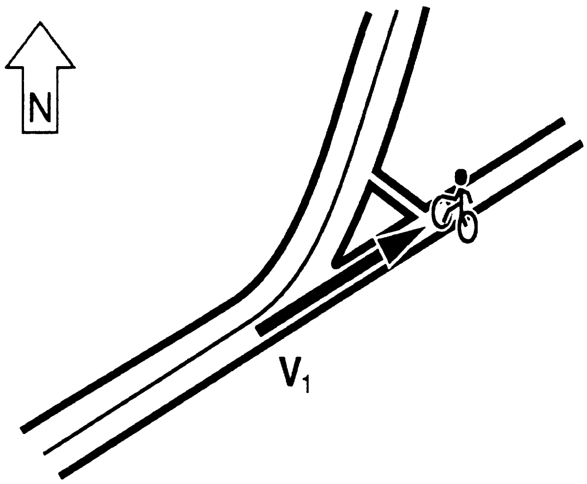


Figure 2-6 - Site of Case 6

A 14-year-old boy on a bicycle was crossing Hillsdale when he was struck and killed by a vehicle driven by a 64-year-old man. The vehicle had come from Groesbeck. It was argued that a pedestrian or cyclist on Hillsdale cannot distinguish if a vehicle will continue on Groesbeck or come onto Hillsdale.

The police accident reports say that the vehicle was going too fast and could not negotiate the curve.

Case 7
M-136, Glynshaw, Beard Roads
April 4
night

M-136 is a two-lane, twenty-foot wide, bituminous roadway with 2- to 3-foot paved shoulders. In the vicinity of the accident, the terrain is hilly and the road is winding. At the accident site, M-136 changes direction from east-west to north-south. The intersection is basically a T where the trunkline goes through the intersection on a curve. Beard Road is the minor road that continues in the westward direction while route M-136 curves north onto Glynshaw Road. Figure 2-7 shows a sketch of the intersection.

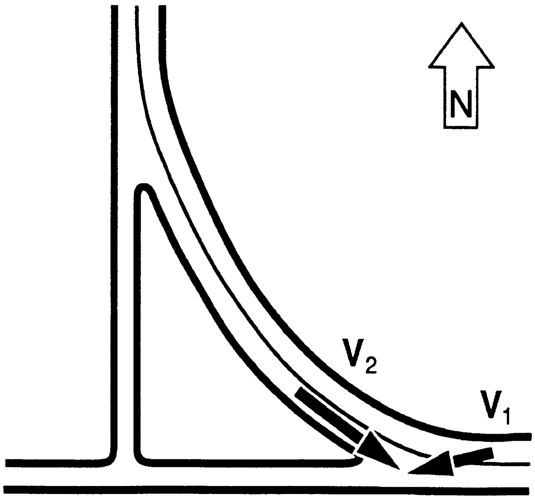


Figure 2-7 - Site of Case 7

In the area of the accident M-136 is delineated with a double yellow centerline and the pavement edge is delineated with white pavement edgelines. It has clearly marked no passing zones and the curve is delineated by chevrons.

On the westbound approach to the curve there is a "sharp right turn" advance-warning sign with a 30-mph speed advisory. Further west and closer to the intersection there is another sign saying "West M-136" and another arrow indicating a sharp right turn. As one approaches the curve there is a sign indicating traffic should go right around a median and another sign designating M-136 with an arrow to the right. Traffic continuing straight will go onto Beard Road. There is no sight-distance problem and eastbound traffic is visible.

The eastbound approach to the curve is also signed with a "sharp left turn" advance-warning and 30-mph speed-advisory sign. Closer to the curve there is a sign designating eastbound M-136 and an arrow indicating a sharp left turn.

Over the 11 years prior to this accident there were 14 accidents, of which 5 involved two cars and were similar to the accident in this case. Only two of these involved injuries. Of the others, 4 involved animals and 5 were single-vehicle accidents, where the vehicle ran off the road and either overturned or hit a fixed object. The average daily traffic on M-136 in the vicinity of the accident during this time was about 1,600 vehicles per day.

The case accident occurred at night. The weather was clear and the road was dry. Vehicle 1 was westbound on M-136, continued onto Beard Road and hit vehicle 2, which was travelling eastbound on M-136. There were no fatalities, but both drivers were injured.

Both drivers were from the area and probably have been through the intersection many times. The driver of vehicle 1 was 17 years old. She testified that she expected M-

136 to turn sharply to the right and consequently assumed she was still on M-136 and had the right-of-way.

The court decision in this case was that the curve ahead advance-warning signs were too far in advance of the curve, that the sharp turn signs misled the driver to expect a turn and not a curve, and that the "keep right" sign at the curve diverts the driver's attention from other clues of the curve.

Case 8
M-18 and M-18 Bypass
November 11
daylight

In the vicinity of the accident M-18 curves to the right to merge with M-61. The change in direction is 90 degrees from north-south to east-west. There is a two-lane road which goes straight north and intersects with M-61, which is called M-18 Bypass. The intersection of the M-18 Bypass and M-18 form a Y, specifically a special right Y-intersection. Figure 2-8 shows this intersection.

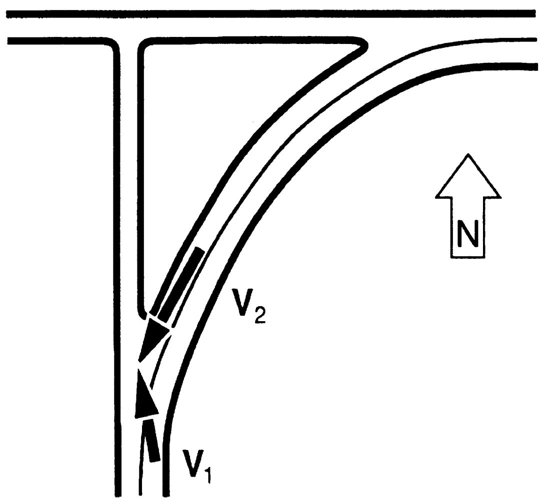


Figure 2-8 - Site of Case 8

This intersection was signed with advance-warning signs. There was a reduced speed limit sign, a no passing zone signaled by the double yellow line, and a guide sign showing the upcoming highway, that is, M-18 north and M-61 east as a curve to the right and M-61 west as a left turn. There were also a curve warning sign, a speed limit sign, and a guide sign showing an arrow angling up and to the right for M-18 North and Gladwin, and a left for the bypass to Harrison.

The accident occurred in daylight. The weather was clear and the surface was dry. There were no sight-distance problems. Vehicle 1, driven by a 30-year-old man, was northbound on M-18. Vehicle 2, driven by a 21-year-old man was proceeding southbound on M-18. Vehicle 1 crossed the centerline, as if to proceed onto the bypass, did not yield the right-of-way to vehicle 2, and hit vehicle 2 almost head-on. A passenger in vehicle 2 was killed.

The accident history of this site was interesting, but there had not been a large number of accidents. In the five years preceding the accident there were three accidents, all of which were head-ons. In the three years following this accident there were no accidents.

Also offered as evidence in this case was an accident that occurred at the same site thirteen years previously and went to litigation. Vehicle 1 was northbound on M-18 approaching the intersection just south of M-61. The weather was clear, the roads were dry, and the visibility was good. Vehicle 1 intended to go straight, did not stop and was struck head-on by vehicle 2 southbound on M-18.

At that time the five-year prior accident history consisted of four accidents—one single-vehicle collision and three rear-end accidents.

Expert Witness Opinions

The testimony presented by the highway design expert witnesses for the plaintiffs and the defense is consistent in the cases. The following is a synthesis of the opinions.

Plaintiffs

The plaintiffs' expert witnesses testify that the design of the intersections contributed to the accidents. They point out that Y-intersections have not been included in recent AASHTO publications and MDOT no longer designs new construction based on this configuration. The reason for doing so is that vehicles crossing the intersection are exposed to conflicting traffic longer than they are at a 90-degree angle, and they do not have as good visibility as they have on a 90-degree intersection. They state that Y-intersections should be eliminated through improvements such as channelization or realignment.

One of the expert witnesses states that the Y is an inherently dangerous design and even a Y-intersection with no accident history is dangerous because it has a potential for severe accidents. In his opinion, the problem cannot be fixed with signals, signing, or pavement markings, for while these can control the hazard, they are not a complete answer.

Defense

The defense agrees that Y-intersections are no longer built but notes that these intersections did not violate any standards or guidelines when they were built. No publications, such as those produced by AASHTO, require an immediate "fix" to this type of geometry. Traffic volume as well as accident experience are used to determine what sites are programmed for reconstruction.

The experts for the defense state that a Y-shaped intersection can be made reasonably safe by use of proper pavement markings, including the use of a solid yellow line and enough signing to inform the driver of the right-of-way.

Commonalities in the Case Studies

1. In six of the eight cases the driver failed to yield the right-of-way to oncoming traffic and attempted to proceed straight. The ambient conditions were consistently good (i.e., clear weather and dry pavement). Sight distance was good. Except for one case (case 7) the accidents occurred in daylight. The drivers who did not yield the right-of-way were known to be familiar with the intersection in most of these cases. Except for one case (case 2), alcohol or other controlled substances were not present.

2. In the three cases where the accident history was in the file, the accident frequency was not high enough to trigger notice. However, there had been at least one head-on accident at each these sites.

3. It appears that pavement markings, advance-warning signs, and guide signs were adequate and in accordance with the MUTCD in most of the cases. The court decided that the signing was confusing in case 7.

4. There is some evidence of driver confusion. Two accidents (5 and 7) can be attributed to driver confusion. In case 7, the court ruled that the signing was confusing. However, the driver's lack of experience might have contributed to the confusion also. Case 5 was a driveway accident. The geometry of the Y-intersection may have contributed to the driver's confusion.

5. Case 6, the case where the vehicle continued on to a residential street and struck a bicyclist, may well have been attributable to the curve and not the intersection. Speed was involved and on another curve, it might have simply been a run-off-the-road accident.

Questions

The commonalities found in the cases lead to the following questions:

1. Drivers' perception of right-of-way

Do drivers approaching the intersection with the intent of going onto the minor road believe that they have the right-of-way? Is there something inherent about these special Y-intersections that leads drivers to assume that they have the right-of-way?

2. Head-on accidents

Do the special right Y-intersections have more head-on accidents than other three-legged intersections?

3. Single-vehicle accidents

Can single-vehicle accidents at the special Y-intersections be attributed to the curve rather than the intersection itself?

4. Drivers not expecting traffic

Do drivers, unaccustomed to encountering oncoming traffic at the special right Y-sites in low-volume environments, simply forget to look for oncoming traffic?

5. Driver confusion

Are drivers genuinely confused by the geometry of the special right Y-intersection?

6. Are these accidents typical?

Are the accidents reviewed in these cases typical of accidents at special right Y-intersections, or are these rare occurrences?

2.2 REVIEW OF THE LITERATURE

A Y-intersection is a skewed three-legged intersection where the legs meet at an angle of less than 45 degrees. The focus of this research is a special case of the Y-intersection, where the main road curves to the right and a minor road continues on a tangent. Traffic on all three approaches to this intersection is two-way. This review of literature focused on the safety and operational characteristics that the special right Y-intersection shares with Y-intersections in general and those that are unique to it.

Evolution of the Design Policy

The current practice in geometric design of highways is not to build new Y-intersections (2, 3). Until 1984, the chapters on at-grade intersections in the AASHO *Policy on Geometric Design of Rural Highways* of 1954 (4) and 1965 (5) included Y-intersections along with T-intersections in discussions of three-legged intersections. It was noted that simple unchannelized three-legged intersections are appropriate for "junctions of minor or local roads, and generally junctions of minor roads with more important highways, if the skew is not too great. In rural areas this type usually is used in conjunction with two-lane roads carrying light traffic. In suburban or urban areas it may be satisfactory for higher volumes and multilane roads."

However, concerns about the safety of Y-intersections have existed since the early days of the traffic engineering profession. In 1941, Maxwell Halsey, one of the founders of the Institute of Transportation Engineers, criticized Y-intersections in general (6). Included in his list of shortcomings of Y-intersections is that the Y-intersection introduces angles of movement that are almost head-on in character and forces the motorist to look over his shoulder in an awkward angle to see whether a car is coming on the other leg of the Y.

Halsey also found fault with the large open area created by Y-intersections. He states that this increases the number of possible choices of routes, thus encouraging violations and making it increasingly difficult for one motorist to guess the path of the other. He states that the large intersection area created by the Y multiplies a potential point of conflict to many points of conflict. Halsey advised that every effort be made to build standard right-angle intersections and to standardize those which do not follow that pattern.

Y- or skewed T-intersections were discussed in what is perhaps the first published textbook on traffic engineering (7). It was pointed out that the rules for intersection planning and design call for the angle of crossing maneuvers at grade to be approximately a right angle for intersections intended to operate at high speed. It was stated that the Y or skewed T may be employed only for one-way intersection legs for intersections intended to operate at low relative speeds. It was strongly stated that in *new* design, T-intersection forms should be used when traffic is two-way, and Y- or skewed T-intersection forms should be used only when traffic is one-way.

It should be noted that the authors of this textbook, Theodore Matson, Wilbur Smith, and Frederick Hurd were associated with the Bureau of Highway Traffic at Yale University, one of the pioneering training programs of traffic engineers in the United States. Theodore Matson was also one of the founders of the Institute of Transportation Engineers.

The use of Y's with one-way legs did appear in the *AASHO Policy on Geometric Design of Rural Highways* (4) under examples of simple channelized Y-intersections. However, it was noted that the one-way turning roadway would be better eliminated and the intersection basically changed to a T. Figure 2-9 replicates the example shown in that publication.

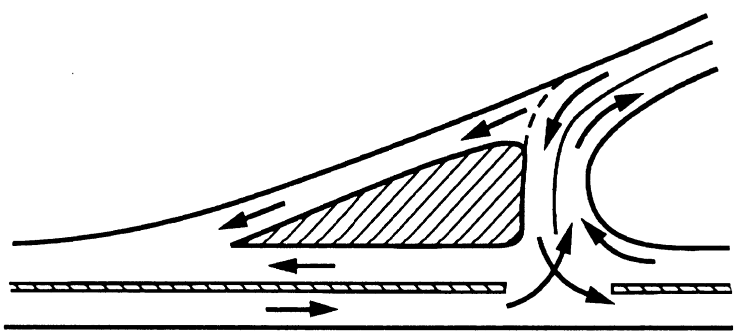


Figure 2-9 - Example of Y-Intersection with One-Way Leg

The 1984 AASHTO *Policy on Geometric Design of Highways and Streets*, known as the 1984 Green Book (3), does not mention the Y-intersection in the discussion of three-legged intersections, nor are any examples of it given. The 1984 Green Book states that the basic T-intersection is appropriate for "junctions of minor roads and generally junctions of minor roads with more important roads where the roadway intersection is not generally more than 30 degrees from normal. This would allow the angle of intersection to range from approximately 60 to 120 degrees."

There are no further modifications on three-legged intersections in the 1990 AASHTO *Policy on Geometric Design of Highways and Streets* (2).

Discussions with the members of the AASHTO Task Force on Geometric Design Policy (8) indicate that the reason why the Y-intersection was dropped from the 1984 Green Book was not the result of published research studies, but rather that the consensus of the experts in the field at that time was that the Y-intersection design should not be promoted and that a better approach would be to limit the three-legged intersections to angles between 60 and 120 degrees. They pointed out that the rotary design was also dropped from the design policy at the same time for the same reasons.

AASHTO policies on highway design are based on established practices and supplemented by recent research. Thus, they are continuously reviewed and updated. The preface of the Green Book of 1984 states that "the fact that new design values are presented does not imply that existing streets and highways are unsafe.... The publication is intended to provide guidance in the design of new and major reconstruction projects. It is not intended as a policy for resurfacing, restoration, or rehabilitation (3R) projects."

It can be concluded that there has been a school of thought, from the beginning of the traffic engineering profession, that held that Y-intersections are not safe, should not be built, and those that exist should be converted to T-intersections. Early AASHO policy, on the other hand, found the Y-intersections acceptable under certain circumstances. Since 1984 the AASHTO policy on geometric design has been that no new three-legged intersections with acute angles be built. AASHTO policy did not specify that all existing Y-intersections be immediately rebuilt.

Volume, Geometrics, and Accidents

Researchers have been trying to relate the number of intersection accidents to the geometric features and traffic volumes from the earliest days. While no studies looked specifically at the special configuration of the Y-intersection, three-legged intersections have been investigated and some references to Y-intersections can be found in the literature.

Comparison of accident rates on intersections consistently found three-legged intersections to have lower accident rates than four-legged intersections (9, 10, 11, 12). The lower accident rates on the three-legged intersections were generally attributed to the fewer possible conflict points on three-legged intersections, although it was pointed out that they also tended to be found in lower volume environments than four-legged intersections.

One of these comparisons of three- and four-legged intersections recommended that acute angle and Y-type intersections be avoided when laying out suburban subdivisions because of the safety element (11).

In work attempting to relate intersection traffic volumes to accident frequencies at three-legged intersections, researchers consistently found non-linear relationships between the accidents and volumes on the major road and the minor road. More specifically, they relate the accidents to the products of the through volumes on the major road and the volumes of specific turning movements to and from the minor road (13, 14, 15, 16, 17). These investigations also found that the involvement in accidents of minor road traffic is much higher per vehicle for low volumes than for high volumes.

A more recent study conducted by Golob et al. (18) in 1988, revisiting the question of the appropriate measure of exposure for intersection accidents, used multivariate techniques to search for the base exposure variables for non-signalized intersections, including three-legged intersections. They confirmed the old findings that the best variables are the interaction variables of the various approach flows.

A 1960 study of rural intersections in Great Britain by Charlesworth and Tanner (19) found that the largest portion of accidents on three-way intersections involved right turns from a major road. Since vehicles drive on the left in Great Britain, in a "drive-on-the-right environment" this is equivalent to a left turn from the major road to the minor road. Charlesworth and Tanner report that 37% of the accidents in their data were of that type. Furthermore, 25% of all the three-legged intersection accidents were rear-end collisions with a vehicle travelling in the same direction on the major road.

A study of characteristics of rural intersection accidents by Hanna, Flynn, and Tyler (20) looked at the two-year accident experience of 300 intersections in 42 towns and cities in Virginia. Among these intersections were 48 T-intersections and 14 Y-intersections controlled by yield or stop signs. The accident rate for the Y's was greater than for the T's, with a rate of 1.04 accidents per million vehicles entering the intersection for the Y's, and 0.82 accidents per million vehicles entering the intersection for the T's.

The Y's also had a larger portion of rear-end accidents than did the T-intersections. In this study, 66% of the accidents at Y-sites were rear-end collisions, while only 28% of the accidents on the T's were of that category. Sideswipe collisions accounted for 43% of the accidents at the T-intersections and for only 4% of the accidents at the Y sites. The proportion of angle collisions was more similar across the two sets of sites, constituting 23% of the accidents at the Y-intersections and 28% of the accidents at the T-intersections. Seven percent of the Y-intersection accidents and 17% of the T-intersection accidents were classified as "other" collision types.

A study conducted in the early 1970s (21) used the conflict technique to examine the operation of two rural Y-intersections in West Virginia with one approach controlled by a stop sign. These were conventional Y-intersections where the through movement was to the left. The traffic from the right leg was controlled by a stop sign. Both intersections were channelized and the traffic volumes on the legs after the bifurcation were between 3,500 and 4,500 vehicles per day in both cases. The researchers noted that there was a high percentage of stop-sign violations at both sites.

The most frequently observed conflict at both of these Y-intersections was the rear-end conflict. There were also cross-traffic conflicts, which were attributed to the traffic from the stop-controlled leg not stopping and crossing the flow of the traffic proceeding up the left leg. They report that these were right-angle to almost head-on conflicts.

The study of these two specific intersections pointed out that there is a potential for rear-end as well as head-on accidents at Y-intersections.

In 1981 the University of West Virginia (22, 23) undertook a study of safety at Y-intersections for the West Virginia Department of Highways (WVDOH). At that time a form of the Y-intersection, known as the "West Virginia Wye" (see Figure 2-10), was common across that state. The angles and features of these intersections varied widely, but the traffic on all approaches and all legs was two-way. Some of the configurations were very similar to the special Y-configuration addressed in this research.

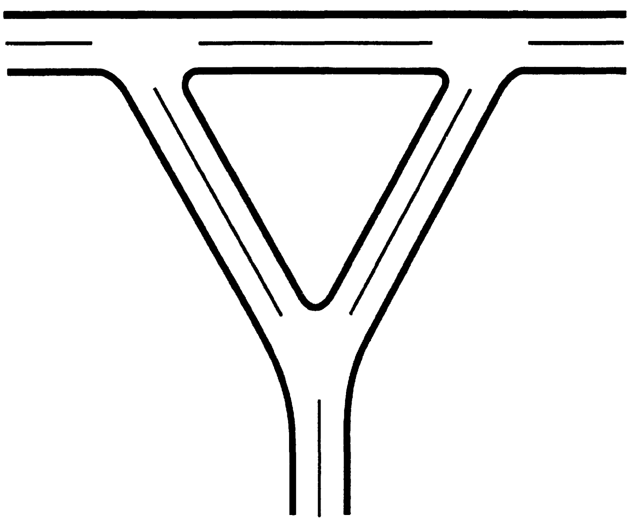


Figure 2-10 - Example of West Virginia Wye Intersection

Despite the widespread use of the West Virginia Wye, the WVDOH was not satisfied with their understanding of its safety performance. Many WVDOH engineers believed that the Y-intersection performed well in terms of safety up to a "point," but beyond that point performance deteriorated. The problem was that the point was not defined, and the conditions contributing to its existence were not known.

Y-Intersections

The primary objective of the University of West Virginia research was to investigate factors which were considered to be potential contributors to the variations in accident rates at a set of Y-intersections. The research set out to increase the understanding of the traffic safety behavior of Y-intersections, to provide a means of predicting changes in accident rates, and to provide a basis for undertaking effective countermeasures. The long-range goal of the research was to bring about a decrease in motor vehicle accidents at Y-intersections by instituting practical and effective countermeasures, without having to resort to costly alterations to the geometry of existing Y-intersections.

A set of 36 Y-intersections with at least three accidents in the vicinity of the intersections in a three-year period was selected for analysis. Accident data were acquired and field studies were made to collect geometric, signing, traffic pattern, volume, and environmental information.

Of the 428 accidents in the data set, 26% were rear-end collisions, 8% were head-on collisions, 18% were sideswipes, 34% were the result of access conflicts (driveway accidents), and 14% were fixed-object collisions. The authors report that the accident distributions by weather and by light condition were not different from those of all intersection accidents in the state.

The work centered on attempts to identify a set of causal factors and to use them in a series of linear regression models to explain the frequency and severity of accidents.

The dependent variables in the regression models compared total intersection accident rates, accident rates on various legs within 100 feet, 300 feet, and 600 feet of the intersection, accident rates by categories, and accident rates for various conditions such as wet or dark.

The independent variables were indices based on various geometric and traffic features. Included in the variable set were:

- Total size of intersection
- Total volumes on intersection
- Hazards - an index which measured the number and proximity of fixed objects on all legs of the intersection
- Centerline delineation - index indicating whether centerline conformed to MUTCD standards on all approaches
- Signing - an index reflecting the number of signs on all the approaches and whether they conform with the MUTCD
- Percent grade - index using grade and volume on each approach

- Surface condition - index reflecting type of surface (i.e., new and sharp, travelled, polished, oily)
- Sight distance - index based on percent of safe stopping distance on all approaches
- Guardrails - index based on the presence or lack of guardrails, the type if present, and a judgment of whether a guardrail was needed on all approaches
- Access roads - the presence of access roads (driveways) on the approaches and frequency of use
- Shoulder widths - index of actual shoulder width on all approaches
- Edgeline delineation - index indicating whether edgelines conformed to MUTCD standards on all approaches.
- Pavement width - index of pavement width relative to 24 ft (standard width for two lanes) on all approaches
- Degree of horizontal curvature - index reflecting degree of curve and proximity of start of the curve to the intersection, also weighted by the volume
- Conflict index - a function of approach volumes

In all, 76 models were developed, tested, and evaluated. The models, unfortunately, had very low coefficients of determination and high variability in the standard error of estimate. Examination of errors revealed no constant patterns. Thus, these models could not explain the contributions of the various geometric features to the accident occurrences at the Y-intersections. They could not be used for prediction or for the consideration of countermeasures.

The authors speculate that the small size of the sample and the possible inaccuracies of the accident records may be partially responsible for the failure of the models. They also question their use of the index-type variables, which aggregated the characteristics and features of the various approaches and legs of the intersection. They acknowledge that human factors and driver behavior are important considerations in the operation of the Y-intersection and that they were not considered in their study design.

The authors point to the fact that the significance of some of the variables in some of the models is an indication of the importance of these factors to the safety at Y-intersections but caution that more careful examination of each site is required before final determination of countermeasures is made. They end by stating that human judgment and engineering knowledge must be the final determining factors before remedial action is recommended.

Since this study, the West Virginia Department of Highways has undertaken a program of eliminating its Y-intersections by reconstructing them to T-intersections. At this time they are working toward eliminating the few that are left.

Driver Behavior

The review of the serious accidents at the special Y-intersections that resulted in litigation action (see section 2.1) indicated that typically the accident occurred when a driver proceeded straight onto the minor road from the major road without yielding the right-of-way to oncoming traffic on the major road. In each of these cases the driver made an error for some reason. This led us to examine the role of human errors in accidents, in general, and to the characteristics of the special Y-intersections that may contribute to such errors.

Human errors have been found to be major causal factors in car accidents. A large-scale study (24, 25, 26) that investigated how frequently various human, environmental, and vehicular factors are involved in traffic accidents identified human errors as definite causal factors in 70 to 80% of the 420 accidents examined in-depth by a multi-disciplinary team of researchers. About 40% of the human causal factors were classified as recognition errors, of which about 20% were improper lookout errors, i.e., failing to look or looking but failing to see.

Another 28% of the human causal errors were classified as decision errors. Of these, false assumptions, such as making a wrong assumption about who has the right-of-way, accounted for 8.3%. Another type of decision error, improper driving technique, applied to 6.2% of the decision errors. In such cases, the driver engaged in the improper control of path or speed in a manner which unduly increased the risk of an accident and involved practices which may be habitual to a particular driver, the risk involved not being fully appreciated.

Another similar study conducted by the Stanford Research Institute (27) also found that human errors were significant contributing factors in a set of accidents that were thoroughly examined by multi-disciplinary teams. In this study, human error was one of the causal factors in 83% to 93% of the accidents investigated. Of these, 42% were caused by decision failures, 34% by comprehension failures, 19% by perception failures, and 5% by action failures.

The Stanford study found that the combination of decision failures (improper maneuver, driving technique, false assumption, excessive speed) and highway-related factors (design and maintenance problems, view obstruction) accounted for 14% of the accidents examined.

It seems reasonable to assume that the driver errors made in the accidents examined in the review of the litigation files (see section 2.1) are of the recognition failure and decision failure type. Considering that most of the drivers that made the errors were local drivers who were familiar with the intersection, it is most likely that the errors are a combination of improper lookout and improper driving technique. However, the contribution of the design cannot be ruled out.

Recent work in ergonomics has been concerned with the differences between errors and violations when considering human contribution to accidents. Reason et al. (28) define violations as deliberate deviations from those practices believed necessary to maintain the safe operation of a potentially hazardous system. Violations require explanation in terms of social and motivational factors. Errors (lapses and mistakes) may be accounted for by reference to the information-processing characteristics of the individual. These researchers found that violations decreased with age but errors did not.

Questions that beg to be asked about the driver errors made at the special Y-intersections include: is the driver behavior at special Y-intersections a deliberate violation or is it a dangerous lapse or mistake? If it is an error brought about by information processing, is it design related?

Human factors psychologists tell us that certain illusion situations occur on highways that may cause information processing problems. In discussions of drivers' visional perceptions, Olson (29) illustrates an example of a perceptual trap with a photograph that shows a primary road curving sharply to the left and a connecting road continuing straight on the tangent. Furthermore, a line of trees and utility poles also continues straight. Together these combine to create an illusion that the primary road continues straight. Olson states that sometimes signing can be employed to good advantage, but in cases such as the one discussed above, the best solution would be to alter the angle of the connecting road and destroy the illusion of continuity.

Work on driver expectancy (30, 31) tells us that drivers have preconditioned sets of expected conditions, and a roadway or traffic situation produces an inclination to respond in a set manner, based on previous experience.

A set of postulates for driving behavior was developed by Woods (30) that could be used to evaluate the degree to which the proposed design conflicts with the driver's expectations. One of the postulates states that at a bifurcation point, where two branches are of unequal importance, the more direct connection will be the continuation of the more important route. Another postulate, given for left-turning maneuvers, states that left turns onto an intersecting roadway will be made from the left-hand lane. Thus, the special Y configuration presents some inconsistencies with the driver expectancy postulates. The more direct route is not a continuation of the more important path. The driver may start cutting into the left lane, here the opposing traffic lane, to make the "left turn" onto the minor road.

Woods goes on to say that if the design is not compatible with the expected situation, poor operation is likely, and he suggests the facility be redesigned to conform to driver expectation.

Conclusions Based on the Literature Review

Y-intersections, skewed forms of the three-legged intersection, have been criticized by traffic engineers since the earliest days of the profession. The major shortcomings are that the Y configuration introduces movements that are head-on in nature and forces motorists to turn their heads at awkward angles to check for traffic on the other legs of the Y. It creates larger open areas than would occur at an intersection closer to a right angle, which increases the number of possible routes and encourages violations.

There are very few studies that have examined the Y-intersection. Those that have find that Y-intersections have higher accident rates than comparable T-intersections and that rear-end collisions and conflicts tend to dominate the accident and conflict experience. Efforts to relate accident experience on Y-intersections to geometric features and traffic volumes and to develop a set of causal accident models were not successful.

Early AASHO policy found the Y-intersections acceptable under certain circumstances. However, since 1984, the AASHTO policy on geometric design has been that no new three-legged intersections with acute angles be built. AASHTO policy does not specify that all existing Y-intersections be immediately rebuilt. Many state departments of transportation are systematically removing Y-intersections from their trunklines.

Findings from various studies of driving errors in traffic accidents were applied to the special right Y-intersection configuration. Serious head-on accidents have occurred when a driver on the main road continued on the tangent onto the minor road without yielding the right-of-way to oncoming traffic on the major road. Works on human errors in driving behavior indicate that it is important to distinguish between violations and errors; that is, is the driving error a deliberate action or a mistake or lapse? Examining the possible types of errors made by drivers at special right Y-intersections against the human causal factors of traffic accidents found in the literature points to the errors being either recognition or decision errors. These may involve improper assumptions about the right-of-way, failure to look, or an improper driving action, which may be habitual, but the risk of which is not apparent to the driver.

The particular geometry of special Y-intersections has been used by human factor psychologists as a classic example of a perceptual trap (i.e., a visual optical illusion). Work on driver expectation also indicates that the characteristics of special Y-intersections are not consistent with driver expectation.

The argument that develops from the literature on driving errors is that the configuration of the special Y-intersection does contribute to the errors which may, under certain circumstances, result in accidents.

2.3 REVIEW OF COUNTERMEASURES

One of the intents of this research is to identify appropriate countermeasures for special right Y-intersections if safety problems are found to exist. We began the investigation of countermeasures for special right Y-intersections with a search of the literature for specific countermeasures for special Y-intersections. As pointed out in the previous section of this chapter, Y-intersections are no longer included in AASHTO design policies (2, 3) and consequently the literature on specific treatments of Y-intersections is sparse. Channelization was the only countermeasure or treatment for Y-intersections identified through this search (32, 33). These references give design principles and guidelines for channelization use as well as detailed examples of actual applications. Applications of channelization are very site specific and are typically used in high volume environments. We did not find any references about specific countermeasures for the special Y-intersection.

To better understand how special right Y-intersections are treated in the United States, we undertook a survey of state departments of transportation concerning their policies, treatments, and recommendations toward this type of intersection. Cost estimates for the various countermeasures were developed from the literature, from county road commission experience, and from experience of civil engineers involved in highway safety improvement projects.

Survey of State DOTs

A telephone survey of state departments of transportation was conducted to obtain information about their experiences with special Y-intersections, their policies toward Y-intersections in general, and the type of treatments that they either use or would suggest for the special type of Y-intersection.

The departments of transportation (DOTs) of 25 states were contacted for this survey. The states were selected primarily for their geographical proximity to Michigan, and secondly for possible terrain similarities.

Table 2-1 summarizes the responses to the question of whether these states have special Y-intersections, where the main road curves to the right or left and the side road continues on a tangent, on the state trunklines.

Of the 25 states, all but seven responded that they have only a few such sites and that these are located in rural areas and carry low volumes of traffic. Kentucky, Nebraska, New York, Oklahoma, Pennsylvania, South Dakota, and Tennessee stated that they have from some to many such sites and that they are located in rural and low-volume environments.

When asked if there was a program to eliminate such sites, six states said that there had been an actual formal program to eliminate Y-intersections, typically in the 1980s. Six states stated that the Y's were being eliminated as a normal consequence of upgrading and improving roads, and thirteen stated that the Y-intersections were basically being eliminated on a case-by-case basis and reconstructed if there was a safety problem.

Table 2-1 - Responses to Survey of State DOTs: Existence of Y-Intersections and Programs for Elimination

State	Do you have any "special" Y-intersections on the state trunkline?	Did you have a program to eliminate Y's from the state trunkline?
Arizona	just a few, rural, low volume	yes, in mid 80s
Arkansas	just a few	yes, eliminated about 1980
California	no	eliminated them as problems arose
Illinois	just a few	changed to T's because of safety/accident problems
Indiana	just a few, low volume, rural	case by case basis
Iowa	just a few, rural	eliminate as safety or resurfacing projects come up
Kansas	just a few, but on low-volume, non-state roads	reconstruct if accidents high
Kentucky	many, rural, low volume	no program, T if major project nearby, sight distance a factor
Maryland	just a few, rural, low volume	yes, eliminated, replaced by T's
Minnesota	several, rural	no program, just realigned in other road improvement projects; plan to eliminate them
Missouri	just a few, low volume, rural	mostly eliminated when resurfacing; minor road T'd in
Nebraska	many, rural	attempting to change them, jug-handle side road to a T
New Jersey	just a few	If accident problem, replace with T
New York	have some	reconstruct if safety problem or road being improved
North Carolina	just a few, rural low volume	eliminate if a safety problem
North Dakota	a couple, rural, low volume	high accident rate dictated their elimination
Ohio	just a few	reviewed, if problem
Oklahoma	some	are being eliminated
Pennsylvania	many	piecemeal, prioritize safety demands
South Dakota	many, rural low volume	eliminate as accident rate merits it
Tennessee	many, rural, low volume	eliminate if accident problem
Texas	just a few, rural, low volume	eliminated as normal consequence of upgrading and improving roads
Virginia	just a few, rural, low volume	site specific
West Virginia	just a few	program to eliminate them since 1980
Wisconsin	just a few	program to eliminate them about 1979 - 1984

Y-Intersections

Table 2-2 summarizes the overall policies of the states toward Y-intersections on state trunklines. The policies in all states contacted are that Y-intersections are not used in new construction and are to be eliminated on existing roads if there is a safety problem or as the road is improved.

Table 2-2 - Responses to Survey of State DOTs: Policies Toward Y-Intersections

State	What are your policies toward Y's on the state trunkline?
Arizona	Avoid building on new roads; if accident history, redo; if repaving or improving road, eliminate the Y into T
Arkansas	Avoid in new design, eliminate when accidents dictate; eliminated most about 14 years ago
California	Do not use in new roads, eliminate when safety problems arise
Illinois	Do not build Y's, use T's
Indiana	Avoid in new design, eliminate on case by case basis
Iowa	Do not use, convert to T within 15 degrees
Kansas	None
Kentucky	Avoid them, reconstruct due to accidents; never an incidental aspect of repaving or improvements
Maryland	Avoid in new design, eliminate when present
Minnesota	Do not design them that way - so no policy
Missouri	Avoid on new roads, eliminate when road is improved; if high accident rate, mitigate
Nebraska	Avoid if possible, bring side road to a T and use stop sign
New Jersey	Consider each case as it arises, accidents dictate change to a T
New York	Avoid in new designs, reconstruct if there are safety problems or road is improved
North Carolina	Avoid in new designs, eliminate where accidents demand
North Dakota	Avoid in new designs, eliminate on old roads
Ohio	None, references to Y-intersections are omitted from geometric design standards
Oklahoma	Avoid on new roads, eliminate them when present
Pennsylvania	New design - avoid Y-intersections No references to Y's in AASHTO Green Book
South Dakota	Avoid in new design, eliminate if accident rate merits it
Tennessee	Avoid on new roads, eliminate if an accident problem; signing and striping - routinely district decisions
Texas	Avoid on new roads, eliminate on old roads
Virginia	Avoid in new designs, eliminate, specific funds to eliminate on a priority system
West Virginia	Avoid in new design, eliminated most in program of reconstruction to a T
Wisconsin	We eliminated them and do not use them

When asked if there is litigation resulting from accidents at the special type of Y-intersections, three states responded that they have sovereign immunity and cannot be sued. Most of the others responded that they are not having particular problems or are not aware of any such problems with litigation stemming from accidents at the special type of Y-intersection. Only Nebraska and Pennsylvania stated that there have been some such cases and that the plaintiffs have sometimes won or the cases have been settled. The summary of responses from the states is shown in Table 2-3.

Table 2-3 - Responses to Survey of State DOTs: Y-Intersections and Litigation

State	Are litigations concerning Y-intersections a problem?
Arizona	No
Arkansas	Have state sovereignty - cannot be sued
California	No
Illinois	Not a problem; 2 or 3 over the years, must sue in court of claims, cap is $100,000 per person
Indiana	None that we are aware of, may have lost 1 case about 15 years ago. Judges and courts accepted prior designs as valid and have upheld them. As new designs have been incorporated, they have been accepted, past designs have been upheld as acceptable.
Iowa	No
Kansas	Not aware of any problems
Kentucky	Not aware of any
Maryland	No
Minnesota	We are not having problems with these types of intersections. From 1976-84, $100,000 per person, $500,000 max. Since 1984 - $200,000/person, $600,000 max. 2 cases closed - one lost.
Missouri	Not aware of any litigation re: Y
Nebraska	Yes, some litigation. Plaintiffs have won a few cases.
New Jersey	No
New York	Not aware of any
North Carolina	Not aware of any
North Dakota	State has sovereign immunity, can sue individual designer
Ohio	Not aware of any
Oklahoma	Not known
Pennsylvania	Some litigation cases - a few on minor leg, settled at least 2.
South Dakota	None
Tennessee	None
Texas	No, sovereign immunity
Virginia	No
West Virginia	No, have eliminated most Y's
Wisconsin	Not known

Y-Intersections

The last question of the survey concerned the type of treatments that have been used at the special type of Y-intersection or that the respondents would recommend using at such sites. The individual responses are summarized in Table 2-4.

Table 2-4 - Responses to Survey of State DOTs: Treatments Used at Y-Intersections

State	What treatments do you use on these Y-intersections?
Arizona	Reconstruct to T, replace yield signs with stop as sight-distance dictates; add turn pocket, restripe if room; if volumes are low, probably don't use flasher or channelize
Arkansas	Reconstruct to T, concrete channelization on minor road, mountable 4" curb, berm between main and minor roads to block headlights - common practice, extra signs - warning or intersection sign, chevrons, probably don't use flashers
California	Convert to T with stop on minor road - also have used left turn type channelization, add left turn lane if necessary, install flasher if necessary, use advance signing
Illinois	Change to T, channelize only with higher volumes, use flasher with stop if accidents
Indiana	If safety problem, program for reconstruction to a T; signing first, flasher second, realignment third; channelize - case by case decisions, occasionally add a passing blister
Iowa	Channelize - raised or painted (rural 45 mph or above) or add left turn storage , wide lanes to allow main traffic to move to right; reconstruct to T - provide lighting, use flasher if necessary, use advance signing
Kansas	Reconstruct to T if accidents high, policy is to limit use of flashers, maybe larger approach warning signs, but hardly needed in low volumes; add "left turn lane" if volumes high; may add bypass if volumes warrant
Kentucky	Reconstruct to T (driven by accidents), flasher only an interim step, channelize for heavy traffic
Maryland	Reconstruct to 90 degrees; flasher - only if warranted by accidents or sight distance; additional signs - use normal T signing, reduced speed, chevrons; left turn lane - use, depends on volume; channelize - on major intersections reconstruct to T; flasher - remedial and temporary, locals ignore
Minnesota	Reconstruct to T; review existing signing - if new signs needed increase size and/or replace; add left turn lane - review and act accordingly; channelize - depends on review and accident reasons
Missouri	When road is improved - T in side road; flasher - not necessarily, but would consider; additional signs - side road sign, have prohibited left turn
Nebraska	Reconstruct to T - bring in side road to T; use stop sign; have concerns about flashers (visibility); additional signing - only as a last resort; jug-handle the side road (bumpout); passing blisters (fly-by lanes) are misused - better to use left turn lane, if volume dictates; channelize only with paint
New Jersey	If accident problem, T it; additional signing - possibly;

	channelize - depends on width of intersection
New York	Reconstruct as T - bring road in away from curve; channelize from side road, use intersection warning signs
North Carolina	Reconstruct to T (accident record), possibly install flasher; additional signing - warning sign, diagrammatic sign, possibly add left turn lane; channelize - depends on geometrics division
North Dakota	Change to T, use flasher sometimes on as needed basis; extra signs - stop ahead, rumble strips, may use a passing blister; channelize - not much
Ohio	Reconstruct as T (within 20 degrees of 90), flatten the curve, additional signing - stop sign
Oklahoma	Reconstruct as T (T the minor road 80 - 90 degrees); do not channelize the Y - T it, then channelize; flasher - perhaps; additional signing - if circumstances dictate; use passing blister or passing lane on right curves
Pennsylvania	Reconstruct to a T; flasher - last resort; additional signing - if needed; channelize - depends on skew at intersection, no. of lanes, other factors
South Dakota	Use "buttonhook" to a T - T in the minor road; flasher - no; used additional signing in only one case; ice and snow a problem with left turn lanes and channelization; use striping occasionally
Tennessee	Reconstruct to a T; flasher - no, need to define curve; additional signs - side road sign, usual signing defines the curve; channelize - not in rural areas
Texas	Reconstruct to a T; flasher - possible, depends on line of sight and volume; additional signs - use standard T-intersection signs unless special conditions; extra lane - if traffic requires; channelize - only in urban areas
Virginia	Reconstruct to a T - easily done, no ROW or environmental problems; flasher - yes; additional signs - "Dangerous intersection" sign; may use passing blister - depends on traffic
West Virginia	Reconstruct to a T
Wisconsin	Reconstruct to a T - move intersection up curve and make it 90 degrees; use bypass lanes, add stop signs, make islands; do use flashers on most state intersections; use sign "traffic from right does not stop" - interim measure; use channelization for better sign placement, better traffic movement

The general consensus of the respondents to the survey is that no new Y-intersections should be built, existing ones should be eliminated in the normal road resurfacing or improvement programs, and Y-intersections with safety problems should modified. All 25 respondents recommended reconstruction to a T-intersection as the best possible treatment for such an intersection. Several suggested that the side road be either "jug-handled" or turned to meet the main road at an angle at most 20 degrees from the perpendicular.

Twenty respondents commented on flashers. Of these, nine had concerns about the use of flashers at the special Y-intersections, and their responses ranged from "would not use it" to "use only as a temporary measure". Nine of the respondents said the flasher is a possible treatment at the intersection. However, the line-of-sight and traffic volumes have to be considered in the decision. Two respondents indicated that the flasher would be a good treatment for the special Y-intersection.

A synthesis of the responses indicates that the flasher should only be considered at a special Y-intersection after a thorough review of the site. Consideration must be given to visibility, line-of-sight, and traffic volumes, and even then a better approach would be to realign the intersection to a T.

There were 22 responses about additional signing. All indicated that existing signing should be reviewed first. If necessary, advance-warning signs of the curve ahead and of the side road should be posted. It was suggested that if the side road is controlled by a yield sign, the yield sign should be replaced with a stop. Stop-ahead signs on the side road were also advised. Several of the respondents suggested that sharp curves be clearly marked with chevrons. Only two respondents suggested the use of unconventional signs such as "Dangerous Intersection Ahead" and "Traffic from Right Does Not Stop" (for the side road traffic).

The New York DOT responded that until 1960 a combination curve and intersection advance warning sign was permitted by the *Manual of Uniform Traffic Control Devices.* However, it was found that the intersecting stubs were often applied to the curve symbol in ways that severely reduced the symbol's effectiveness. It was therefore decided to separate the two messages to preserve the integrity of each.

Thirteen of the respondents stated that additional room for turning vehicles should be provided at the intersection. Half of them suggested a left-turn pocket and half suggested a "passing blister," also called a "fly-by lane," on the right. All indicated that this treatment depends on the traffic volume and either the available road width or right-of-way.

There were comments about channelization from 19 of the states. Basically they indicated that channelization should be considered on a case-by-case basis. However, most would not use channelization in low-volume or rural areas. If channelization is to be used on a special Y-intersection, it is the side road approach that should be channelized.

Countermeasure Costs

The costs of the various countermeasures discussed above were estimated from the literature (32) and from a survey of civil engineers experienced with implementation of highway safety improvement projects (34). All sources indicated that the actual costs of any of these countermeasures are very site specific and the estimates that follow should be considered as order of magnitude estimates. It is assumed that right-of-way (ROW) does not have to be acquired.

Channelization - Costs of channelizing an existing Y-intersection depend on the design of the channelization, the construction of the turning roadways, the islands, etc. The cost of a typical channelization is estimated to be between $150,000 and $200,000. The cost could be higher depending on the complexity of construction involved.

Reconstruction of a Y-intersection to a T-intersection - The cost of this depends on many variables, including the number of driveways that must be modified, the number of tree to be removed, the amount of ditching that needs to be done, the type of pavement, the amount of curb and gutter that needs to be installed, and the relocation of utilities. A simple straightforward modification of the intersection costs approximately $50,000. A moderate modification would cost anywhere between $50,000 and $150,000. An extensive and complex reconstruction could cost upwards of $150,000, with the upper limit depending on the complexity of the construction involved.

Turning lane - The cost of adding a turning lane for vehicles proceeding onto the minor road depends on the existing road width. If the road surface is wide enough, simply restriping the pavement can provide the turning lane. However, if the road needs to be widened the cost will generally be between $15,000 and $25,000.

Fly-by lane, passing blister - As with a turning lane, the cost of a fly-by lane depends on the existing road width. If the pavement cannot be restriped to provide this additional lane for vehicles continuing on the main road to pass those waiting to enter the side road, the additional lane has to be built. The cost is about the same as for the turning lane, between $15,000 and $25,000.

Flasher - The cost of a flasher typically consists of the flasher unit and its installation, power hook-up, and whether or not power is available at the site. A typical installation at a site where power is available costs approximately $5,000.

Upgrade signing - Sign upgrade programs involve a review of the present signing at the site and the removal and installation of the signs recommended by the review. The costs will consist mainly of the personnel costs involved in the review, in labor, and in the signs themselves. A typical cost for a sign upgrade at one location, which involves the removal of some existing signs and installation of new signs, is about $1,000 to $2,000.

CHAPTER 3
ANALYSIS OF THE WASHTENAW COUNTY Y-INTERSECTION DATA

Background

In 1985, the Washtenaw County Road Commission undertook a program of evaluating the Y-intersections on all of the roads in their jurisdiction. The study was undertaken as part of the ongoing effort to maintain a safe road system and in response to the Road Commission's experience with lawsuits. A jury in a lawsuit resulting from a 1981 fatal accident at one of the county's Y-intersections found that the geometry of the Y-intersection contributed to the cause of the accident. The Road Commission set out to examine all their Y-intersections, assess the effort and expense to convert them to T-intersections, and modify as many of them as possible.

Of the approximately 130 Y-intersections in the county road system, 60 were easily converted into T's. The remaining sites were found to require more extensive reconstruction and sometimes relocation of roads to eliminate the Y configuration. Because of limited funding, recommended modification at these sites usually involved upgrading the signing on the approaches to the intersection.

In the process of these evaluations, an information file was created for the remaining Y-intersections. Each file contained drawings of the intersection, inventory of signs, sight distances, accident summaries from 1979 through 1984, work orders for modifications and changes, and photographs of the intersection. Thus, a wealth of information about the operations and accident experience, as well as the details of the geometry and traffic control, of a set of Y-intersections had been assembled.

Since the overall objectives of this research are to compare the accident experience of a specific type of Y-intersection against that of other three-legged intersections and to identify useful types of countermeasures, the Washtenaw County Y-intersection data file presented an opportunity to explore these questions. Upon our request, the Washtenaw County Road Commission made these files available for this research project.

Objectives

The specific objectives of the exploration of the Washtenaw County data were to:

- Compare accident rates at the different types of Y-intersections found on Washtenaw County roads.
- Compare the accident types at the different types of Y-intersections.
- Compare the accident severity at the different types of Y-intersections.
- Examine the effect of the changes in signing at the Y-intersections.

- Serve as a preliminary exploration for the consequent analysis to be undertaken on the MDOT State Trunkline data.

Data File Preparation

The original information had been collected for the assessment of reconstruction potential rather than for a research study. For expediency, some information, which was obvious to those collecting it, was not included in the file. However, for research analysis, the information about each site had to be consistent. Thus, the first step in the preparation of the data was to fill in information missing from the files. This involved examining the sites on township maps and making site visits when necessary.

The original information files contained detailed accident data for the period of time from 1979 to 1984. We also needed accident information for a period of time after the changes had been made at the sites. The Michigan Department of Transportation provided us with detailed accident information from 1982 through 1991 for 45 of the sites. This allowed us to develop a five-year "before" accident data file from 1980 through 1984 and a five-year "after" accident data file from 1986 through 1990. The records from 1985 were not included because that was the year in which the changes were made.

The next step involved obtaining volume information for the study sites. The Washtenaw County Road Commission provided us with all available traffic volume count information for the county from 1986 through 1992. On average there were about two data entries per site for the time period. Sites in the more populated areas of the county had more entries, and many of the more remote rural sites had only one data entry for the entire time period. In some cases volume counts were not directly available for our specific study sites. However, in the cases where there was no volume information for the site of interest, it was often possible to make an estimate.

The estimation process consisted of entering the available traffic volume information on a township map and tracing the traffic flows on the network of roads in the township. Since many of the 45 Y-sites are in rural areas of the county, where the network of roads is relatively sparse, it was possible to deduce the volumes at sites on major roads from the volumes at upstream and downstream locations. For sites on the minor roads it was also possible to deduce a volume from its location relative to the major paths in the township network and the known traffic volumes.

The following information was developed for each site:

- Type of intersection (discussed in next section)
- Presence of island
- Size of island
- Volume on major road
- Qualitative estimate of traffic growth on major road

- Traffic signs on major road
- Volume on minor road
- Qualitative estimate of traffic growth on minor road
- Traffic signs on minor road
- Accidents by type and injury for each year from 1980-1984
- Accidents by type and injury for each year from 1986-1990
- Changes at site made in 1985

This information was entered into a computer database file for analysis. Appendix A lists the names of the 45 intersections in the Washtenaw Y file by township and shows an example of the data assembled for each site.

Analysis

Categorical analysis was selected as the methodology for the analysis of the Washtenaw Y data. The first step was to classify the 45 intersections into categories, based on the type of Y-intersection they form. One of the categories would be the special right Y-configuration, where the main route curves to the right and a minor road continues on a tangent from the curve, which is the focus of this research.

Upon examination of the sketches in the original information file, township maps, and some site visits, five types of intersections were identified. Four of the categories were variations of what is generally accepted as a Y-intersection. The other category, while not strictly a Y-intersection, was included in the initial Washtenaw Y program, and was retained for this analysis. Since no generally accepted names could be found for the various Y configurations, descriptive names were invented. The five Y-intersection categories are shown in Figure 3-1 and consist of:

Flared T

This intersection is actually a type of T-intersection. The minor road meets the major road at or very close to a right angle. In most cases a small island is present at this intersection, giving it a Y appearance. In some cases, on gravel roads, no island was present, but vehicles have enlarged the radius of the turn, giving it a Y appearance. These intersections were considered Y's by the county and are included in our analysis file for comparison.

Regular Y

This is a three-legged intersection that is not a T, nor one of the special Y's described below. A small to medium island may be present.

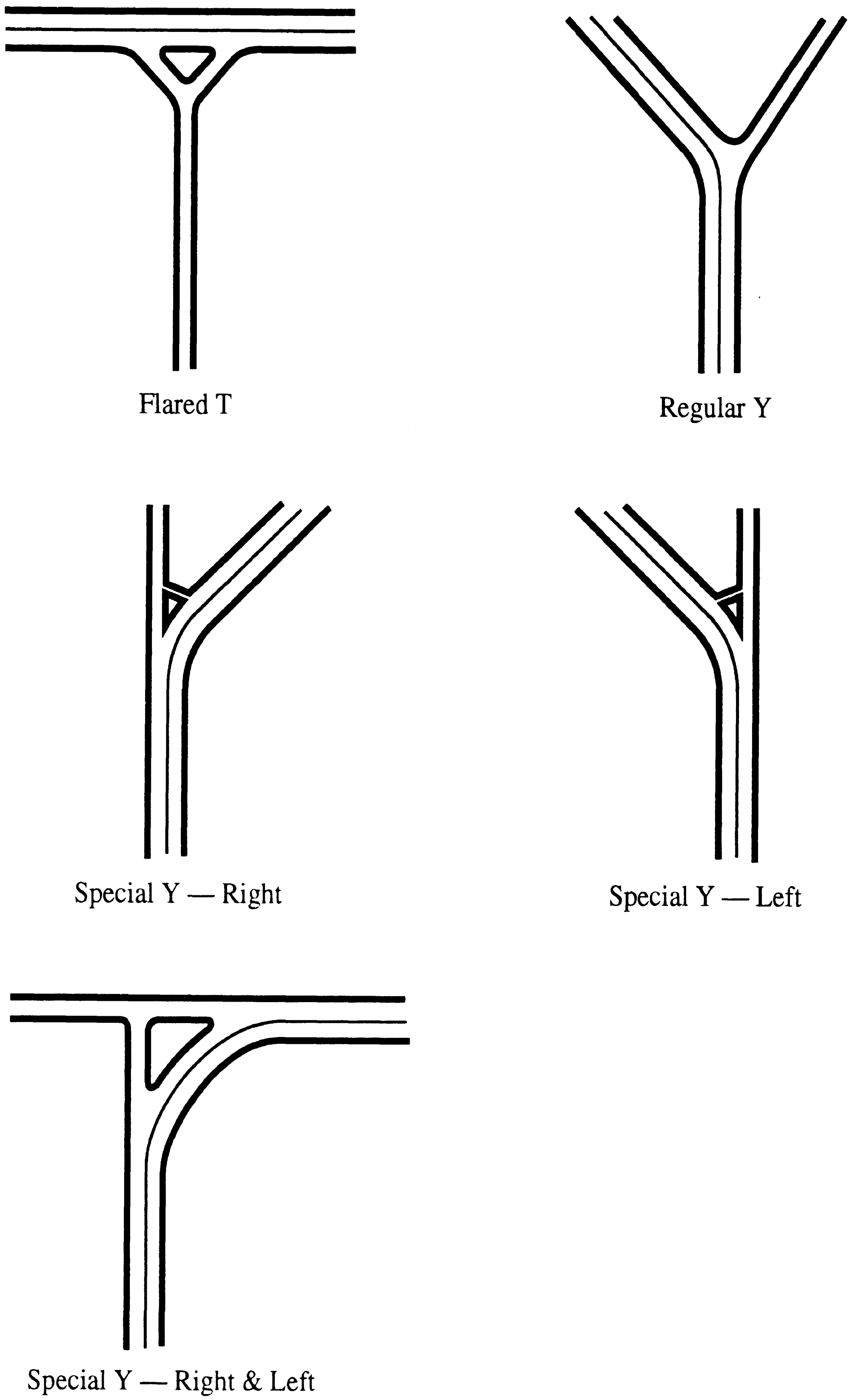


Figure 3-1 - Categories of Y in Washtenaw Data Analysis

Special Y-Right

This is a class of Y-intersections formed where the main route curves to the right and a minor road intersects with the major road on a tangent to the curve. All of the intersections of this type in this data set had a medium to large island, which provides a path for left turns from the minor road and right turns from the major road. This configuration is the major focus of this research project.

Special Y-Left

This is a class of Y-intersections where the main route curves to the left and a minor road intersects with the major road on a tangent to the curve. All of the intersections in this category have a medium to large island which provides a path for vehicles turning right from the minor road and left from the major road.

Special Y-Right/Left

This is a class of Y-intersections where the main route turns 90 degrees on a curve and there is a minor road on a tangent at the beginning of the curve from both directions. This configuration always has a large island. While this is really a combination of the two configurations described above, the data had been collected for the total combination.

Table 3-1 gives the number of sites in each category and the average daily traffic volume, rounded to the nearest 100 vehicles, on the major and minor roads for each category.

Table 3-1 - Average Volumes for Each Y-Category in Sample

Category	Number of Sites	Major Road ADT	Minor Road ADT
Flared T	16	700	300
Regular Y	9	2700	300
Special Y-Right	10	3000	400
Special Y-Left	3	1100	400
Special Y-Right/Left	7	1400	300

The table shows that the sites have relatively low volumes. All 45 sites were located in rural areas with gravel minor roads. The Flared T category had the lowest volumes, since this configuration is usually found in more remote rural areas. The special Y-Right category had the highest relative volumes. However, even these volumes are considered to be low.

Total Accidents and Accident Rates

The ten years comprising two five-year periods between 1980-1984 and 1986-1990 were used in all accident analyses. The only traffic volume information available was from 1986 to 1990. However, since the volumes for 1986-1990 were very low, it was considered reasonable to assume that the volumes did not change much from the 1980-1984 period.

Rates were calculated by summing up the accidents for all the sites in the category over the 10 years and dividing by the total 10-year volumes on the major roads. Similarly, the overall rate for all sites was calculated by dividing the total number of accidents in the file by the sum of the traffic volumes in the file.

An alternate approach would be to calculate the rates individually for each site and then average the site rates for each category. Presumably, the overall rate would then be the average of the rates in each category. One drawback of this approach is that if the sites were categorized in a different way, the overall rate would change. This would make rate comparisons difficult.

In the approach taken in this study, the overall rate remains the same by definition, no matter how the sites are categorized. Thus, a rate for a particular category may be compared to the overall rate to see if that category has a higher or lower accident rate than all the sites. To facilitate rate comparisons, relative risk measures are also presented for some of the tables. Relative risk measures are calculated by dividing the rate for each intersection type by the overall rate. The overall relative risk is therefore 1.0. Relative risk values greater than 1.0 indicate higher than average rates, while those less than 1.0 indicate below average risks. The method of relative risk has a long tradition of use in the field of epidemiology (35) and has frequently been applied in traffic safety research (36).

Table 3-2 shows the total accidents over 10 years for each intersection category, the ten-year traffic volume for that category, the accident rates, and the relative risk. The overall accident rate for all the intersections is 72.1 accidents per 100 million vehicles. The Special Y-Right/Left has the highest accident rate among the categories of intersections with 107.9 accidents per 100 million vehicles. The second highest rate, 98.4 accidents per 100 million vehicles, is for the Flared T-intersections. The Special Y-Right category has a rate of 70.6 accidents per 100 million vehicles, the Special Y-Left has a rate of 59.9 accidents per 100 million vehicles, and the Regular Y has the lowest rate, with 49.8 accidents per 100 million vehicles.

Table 3-2 - Overall Accident Rates for Y-Categories

Category	No. of Sites	Ten-Year Accident Count	Ten-Year Traffic Vol. (Millions)	Accs. per 100 Million Vehicles	Relative Risk
Flared T	16	37	37.595	98.4	1.36
Regular Y	9	44	88.330	49.8	0.69
Special Y-Right	10	77	109.135	70.6	0.98
Special Y-Left	3	7	11.680	59.9	0.83
Special Y-Right/Left	7	39	36.135	107.9	1.49
Total	45	204	282.875	72.1	1.00

Severity of Accidents

Table 3-3 shows the number of total accidents, number of injury accidents (including fatal, A-, B-, and C-injuries), ratio of injury to total accidents, injury accident rate, and relative risk of injury accidents for each category of Y for the ten-year time period under consideration. There were two fatal accidents at these sites in that time period, and these are included as injury accidents. As can be seen from the Table 3-3 total row, 39% of the accidents are injury accidents. The high percentage and rate of injury accidents for the Special Y-Left category should be viewed with caution because the sample of these sites is very small and the total number of accidents is also quite small. If the Special Y-Left category is disregarded, the injury to all accident ratio and the injury accident rates for all the categories are quite close to each other. Of these, the Special Y-Right/Left has the highest ratio, with 33.2 injury accidents per 100 million vehicles, and the Regular Y has the lowest rate, with 20.3 accidents per 100 million vehicles.

Table 3-3 - Severity of Accidents by Y-Category

Category	Accidents	Injury Accidents	Injury Acc./ All Acc.	Injury Acc. Rate*	Inj. Acc. Rel. Risk
Flared T	37	11	.30	29.3	1.05
Regular Y	44	18	.41	20.3	0.73
Special Y-Right	77	33	.43	30.2	1.08
Special Y-Left	7	5	.71	42.8	1.53
Special Y-Right/Left	39	12	3.1	3.32	1.19
Total	204	79	.39	27.9	1.00

* Injury accidents per 100 million vehicles

Accident Type Distribution

Table 3-4 shows the distribution of the accidents by accident type for each category of Y-intersection. The last category, "other," included pedestrian/cycle, parked car, backed into, and other accident types that appeared very infrequently in the data.

Table 3-4 - Distribution of Accident Types by Y-Category

	Run-off-the Road	Head-on	Rear-end	Angle	Animal	Left or Rt. Turn	Other	Total
Flared T	32	1	2	0	0	1	1	37
	86.5%	2.7%	5.4%	0.0%	0.0%	2.7%	2.7%	100.0%
Regular Y	18	12	4	1	4	3	2	44
	40.9%	27.3%	9.1%	2.3%	9.1%	6.8%	4.5%	100.0%
Special Y-Right	55	3	2	6	8	1	2	77
	71.4%	3.9%	2.6%	7.8%	10.4%	1.3%	2.6%	100.0%
Special Y-Left	7	0	0	0	0	0	0	7
	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%
Special Y-Right/Left	27	2	2	1	4	0	3	39
	69.2%	5.1%	5.1%	2.6%	10.3%	0.0%	7.7%	100.0%
Total	139	18	10	8	16	5	8	204
	68.1%	8.8%	4.9%	3.9%	7.8%	2.5%	3.9%	100.0%

Overall, run-off-the road accidents, which include fixed object and vehicle overturn accidents, account for 68% of the accidents at the Y-intersections. These accidents are typically associated with horizontal curves and speed. A review of the accident causes in these accidents indicated excessive speed as the cause in most of the cases. Regular Y sites are not on curves, and it is interesting to note that only 41% of the accidents at these sites were run-off-the-road accidents.

The next highest overall accident category is head-on with 8.8% of the total accidents. Head-on accidents accounted for 5% or less of the accidents in all the categories, except the Regular Y-Category where head-on accidents constituted 27% of the accidents.

Rear-end accidents accounted for 4.9% of the overall accidents, angle accidents for 3.9%, right or left turns 2.5%, and "other" 3.9%. Animal accidents accounted for 7.8% of the total, which is not unexpected considering the rural nature of the sites and the large deer population in rural Washtenaw County.

Table 3-5 shows the rates and relative risks for run-off-the-road, head-on, and rear-end accidents for the set of Y-intersection categories.

Table 3-5 - Accident Rates and Risks by Type for Y- Categories

	ACCIDENT RATE*			RELATIVE RISK		
Category	Run-off-the Road	Head-on	Rear-end	Run-off-the Road	Head-on	Rear-end
Flared T	85.9	2.7	5.3	1.75	.42	1.50
Regular Y	20.3	13.6	4.5	.41	2.12	1.27
Special Y-Right	50.4	2.7	1.8	1.03	.42	.51
Special Y-Left	59.9	0.0	0.0	1.22	.00	.00
Special Y-Right/Left	74.7	5.5	5.5	1.52	.86	1.55
Total	49.1	6.4	3.5	1.00	1.00	1.00

* Accidents per 100 million vehicles

The overall rate for run-off-the road accidents is 49.1 accidents per 100 million vehicles. The Flared T category has the highest rate of run-off-the-road accidents with a rate of 85.9 per 100 million vehicles, and the Regular Y has the lowest rate with 20.3 accidents per 100 million vehicles. The Special Y-Left and Special Y-Right have relatively similar rates of 59.9 and 50.4 accidents per 100 million vehicles, respectively, and the Special Y-Right/Left has a higher rate with 74.7 accidents per 100 million vehicles.

When head-on accidents are considered, the Regular Y-Category has the highest rate, with 13.6 accidents per 100 million vehicles and a relative risk of 2.12. The Special Y-Right/Left again has a higher rate than the Special Y-Right. Their respective rates for head-on accidents are 5.5 and 2.7 accidents per 100 million vehicles, and their respective relative risks are 0.86 and 0.42. There were no head-on accidents at the Special Y-Left sites, which, recall, formed a very small sample.

The overall accident rate for rear-end accidents is 3.5 accidents per 100 million vehicles. The Flared T and the Special Y-Right/Left have the highest rates, with 5.3 and 5.5 accidents per 100 million vehicles and relative risks of 1.50 and 1.55, respectively. If the Special Y-Left category is disregarded because of the small sample size, the Special Y-Right category has the lowest rate, with 1.8 accidents per million vehicles and a relative risk of 0.51.

Signing Improvements and Accidents

The original intent of the data-collection effort by the Washtenaw County Road Commission at these intersections, which were not considered for reconstruction, was to examine the signing and site distances and to improve them if necessary. Changes made at the intersections are summarized below:

Flared T

For those unpaved intersections where vehicles have increased the radius and/or created an island, the island was removed and the radius was decreased to 35 feet. Basically, the changes to the others involved installation or relocation of a side-road advance-warning sign on the major road, and stop-ahead and stop signs on the minor road. Whenever necessary, brush was removed to give sufficient sight distance from the stop locations.

Regular Y

Changes in this category of intersection mostly involved the addition or relocation of stop signs.

Special Y-Right and Special Y-Left

After the changes were made, each intersection had curve and intersection advanced warning signs on the major road and, whenever necessary, a speed advisory sign, target arrow at the curve, and stop-ahead and stop signs on the minor road. If there was an island, there were stop signs at either end of the channel. If needed, brush was cleared to give sufficient sight distance from the stop signs.

Most intersections already had some of these elements. The changes usually consisted of combining the curve and intersection advanced warning signs, installing the stop-ahead sign, relocating or installing the target arrow, and adding the stop signs in the island.

Special Y-Right/Left

After changes were made at these intersections, each had curve and intersection advanced warning signs on the major road and, whenever necessary, a speed advisory sign, a target arrow at the curve, and stop-ahead and stop signs on the minor roads.

As in the previous case, most sites already had some of the elements. The changes involved combining the curve and intersection advanced warning signs and clearing brush to ensure adequate horizontal sight distance on the curves.

The next question addressed was whether there was a difference in the accident experience at the sites after the changes were made. The accident rates for the categories of Y-intersections for five years before and after 1985 were examined. We acknowledge that a clean before/after study must be able to control for volume changes over time. We were not able to obtain the traffic volumes for the period of time before 1985. However, all the sites are rural, most are in remote areas of the county, and the volumes for the second time period are quite low. Thus, the assumption that there was little change in traffic volumes between the before and after period seems reasonable.

Table 3-6 shows that the total number of accidents and the number of injury accidents for the before and after periods are very similar. There were 101 accidents with 41 resulting in injuries in the before period and 103 accidents with 38 resulting in injuries in the after period.

Table 3-6 - Number of Accidents and Injury Accidents by Y-Category

Category	BEFORE* Total Accidents	BEFORE* Injury Accidents	AFTER* Total Accidents	AFTER* Injury Accidents
Flared T	20	4	17	7
Regular Y	24	11	20	7
Special Y-Right	33	17	44	16
Special Y-Left	4	3	3	2
Special Y-Right/Left	20	6	19	6
Total	101	41	103	38

* Before period = 1980 through 1984
After period = 1986 through 1990

Table 3-7 shows the rates and relative risks of all accidents by intersection category. The overall accident rate remained stable. However, the rates and risks for all the Y-categories except the Special Y-Right showed a slight decrease. The accident rate for the Special Y-Right increased from 60.5 to 80.6 accidents per 100 million vehicles and the relative risk increased from 0.85 to 1.17.

Table 3-7 - Accident Rates and Relative Risks for Before and After Periods by Y-Category

Category	BEFORE* Accident Rate**	BEFORE* Relative Risk	AFTER* Accident Rate**	AFTER* Relative Risk
Flared T	106.4	1.49	90.4	1.24
Regular Y	54.3	.76	45.3	.62
Special Y-Right	60.5	.85	80.6	1.17
Special Y-Left	68.4	.95	51.3	.70
Special Y-Right/Left	110.7	1.55	105.0	1.44
Total	71.4	1.00	72.8	1.00

* Before period = 1980 through 1984
After period = 1986 through 1990
** Accidents per 100 million vehicles

A possible explanation for this increase may be related to volume changes. The Special Y-Right category had higher volumes than the other categories. Although these volumes were quite low, they could have been even lower in the "before" period. Without access to the volume information for 1980-1984, we made an assumption that the volumes did not change between the two time periods. It is possible that this assumption may not be correct for the sites in the Special Y-Right category.

Table 3-8 shows the distributions of the accident types for each intersection category for the before and after time periods. The apparent reduction in run-off-the-road accidents was not significant at the 0.1 level.

Table 3-8 - Distribution of Accident Types by Y-Category for Before and After Periods

BEFORE (1980-1984)

	Run-off-the Road	Head-on	Rear-end	Angle	Animal	Left or Rt. Turn	Other	Total
Flared T	17	0	1	0	0	2	0	20
	85.0%	0.0%	5.0%	0.0%	0.0%	10.0%	0.0%	100.0%
Regular Y	10	7	3	0	3	1	0	24
	41.7%	29.2%	12.5%	0.0%	12.5%	4.2%	0.0%	54.5%
Special Y-Right	26	1	1	0	2	1	2	33
	78.8%	3.0%	3.0%	0.0%	6.1%	3.0%	6.1%	100.0%
Special Y-Left	4	0	0	0	0	0	0	4
	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%
Special Y-Right/Left	16	1	0	0	0	0	3	20
	80.0%	5.0%	0.0%	0.0%	0.0%	0.0%	15.0%	100.0%
Total	73	9	5	0	5	4	5	101
	72.3%	8.9%	5.0%	0.0%	5.0%	4.0%	5.0%	100.0%

AFTER (1986-1990)

	Run-off-the Road	Head-on	Rear-end	Angle	Animal	Left or Rt. Turn	Other	Total
Flared T	15	1	1	0	0	0	0	17
	88.2%	5.9%	5.9%	0.0%	0.0%	0.0%	0.0%	100.0%
Regular Y	8	5	1	1	1	3	1	20
	40.0%	25.0%	5.0%	5.0%	5.0%	15.0%	5.0%	100.0%
Special Y-Right	29	2	1	6	6	0	0	44
	65.9%	4.5%	2.3%	13.6%	13.6%	0.0%	0.0%	100.0%
Special Y-Left	3	0	0	0	0	0	0	3
	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%
Special Y-Right/Left	11	1	2	1	4	0	0	19
	57.9%	5.3%	10.5%	5.3%	21.1%	0.0%	0.0%	100.0%
Total	66	9	5	8	11	3	1	103
	64.1%	8.7%	4.9%	7.8%	10.7%	2.9%	1.0%	100.0%

Examination of Table 3-8 shows that the increase in the accidents in the Special Y-Right category is due to an increase in angle and animal accidents. More animal accidents can be expected if there is an increase in traffic in a rural area with a deer population. The increase in angle accidents would be consistent with a volume increase. However, it should be noted that the number of these accidents is quite small and we may simply be looking at random fluctuations.

The occurrence of accidents, other than run-off-the-road, for both the before and after periods was quite rare. While the percentages of head-on and rear-end accidents were essentially the same for both time periods, there were some changes in the percentages of the other types of accidents. However, the numbers of these accidents are so small that it is probable that there was no real change.

The examination of the data in the before and after periods indicates that the signing modifications brought about very little change in the accident experience. Run-off-the-road accidents declined in number, but the decrease was not significant. It should be noted that the sites had extremely low volumes and that the sites were already signed and controlled. The changes simply improved the existing signing.

Findings

Accident records for 45 Y-intersections in Washtenaw County were examined over two five-year periods, before and after 1985, when changes were made to signing at the intersections and approaches.

The Y-intersections examined were all located in very low-volume, rural environments. Because of these low volumes, it was assumed that the traffic volume did not increase over the 11-year period under consideration.

The 45 intersections were divided into 5 categories, two of which included the configuration where the main road curves to the right and the side road continues on a tangent. The Special Y-Right category was simply this configuration. The Special Y-Right/Left consisted of sites where the main road made a right-angle turn, creating a Special Y-Right on one approach and a Special Y-Left on the other approach.

The Special Y-Right/Left had the highest overall accident rate of the categories examined with 108 accidents per 100 million vehicles. The Flared T category had the next highest rate with 98 accidents per 100 million vehicles. The Special Y-Right group had a rate of 71 accidents per 100 million vehicles. The Special Y-Left group had a rate of 60 accidents per 100 million vehicles, and the Regular Y had the lowest overall rate with 50 accidents per 100 million vehicles.

The overall portion of injury accidents was approximately 40% of all accidents. When injury accident rates were considered, the Special Y-Left category had the highest rate. The second highest injury accident rate was for the Special Y-Right/Left sites, followed closely by the Special Y-Right sites. The Regular Y category had the lowest injury accident rate.

Overall, 68% of the accidents at these intersections were of the run-off-the-road type. They constituted 86% of the accidents at Flared T intersections and 41% of the accidents at the Regular Y intersections. In this particular sample, all the accidents on the Special Y-Left sites were run-off-the road. This may explain the high injury rate observed for the Special Y-Left sites in this sample, since the probability of injury is relatively high for this accident type compared with others. At Special Y-Right/Left and Special Y-Right sites, run-off-the road accidents accounted for 69% and 71% of the accidents, respectively.

Head-on accidents accounted for 9% of all the accidents. They accounted for 27% of the accidents at the Regular Y sites, 5% at Special Y-Right/Left sites, 4% at Special Y-Right sites, and 3% at Flared T sites.

Five percent of all the accidents were rear-end accidents. These accounted for 9% of the accidents at Regular Y sites, 5% of the accidents at both Flared T sites and Special Y-Right/Left sites, and 3% of the accidents at Special Y-Right sites.

There appears to be very little change in the accident experience between the time periods before and after the sign improvements at the sites. Run-off-the-road accidents show a non-significant decrease, and there is some indication of an increase in accidents at Special Y-Right sites. However, the Special Y-Right sites had higher volumes in 1986-1990 than the other categories. Although the volumes were still quite low, it is possible they were lower in the preceding five years. The volumes for the remaining categories were so low in the 1986-1990 period that it is very unlikely that they could have been any lower in the preceding period. Therefore, we cannot conclude that there was in fact an increase in the accident rate of the Special Y-Right category following the improvements to the signs at the intersections.

From the various analyses of the Washtenaw Y-intersections, it appears that the configuration where the main road curves to the right while the minor road continues on a tangent has an accident experience quite similar to that of other types of Y-intersections. The prevalent accident type at these sites is the run-off-the-road accident at about 70% of all accidents. Run-off-the-road accidents are generally associated with low-volume environments and curves. This analysis did not attempt to isolate the effects of the curve from that of the intersection.

There are some head-on and rear-end accidents at the sites where the main road curves to the right and the minor road continues on a tangent. However, they account for only about 10% of the accidents at the Special Y-Right/Left sites and only about 6% of the accidents at Special Y-Right sites. In contrast, at Regular Y sites, 27% of all accidents are head-ons and 9% are rear-ends.

This analysis examined sites in very low-volume environments. The sample in this analysis is too small to allow detection of significant differences among categories of intersections. Furthermore, for a better understanding of the Special Y-Right and Special Y-Left sites, the category of Special Y-Right/Left should be broken down into its two component intersections, which was not possible to do in this analysis. It is difficult to statistically assess the differences among the rates observed with such a small sample, where there are only a few accidents for very long exposures.

The next step in this research will involve examining intersections from the MDOT Trunkline data file, which should overcome some of the problems listed above. The sample of Y-intersections will be larger and will cover a broader range of volumes. The Special Y-Right/Left category will not be considered separately, but will be broken down into its component right and left categories. The effect of the curve will be considered. The larger sample will also allow the application of various robust statistical techniques that can assess the differences among rates from the occurrence of rare events observed over long exposures.

CHAPTER 4
ANALYSIS OF THE MDOT TRUNKLINE DATA

4.1 DEVELOPMENT OF THE ANALYSIS SAMPLE

Background

The Michigan Department of Transportation maintains computerized data files on the geometric and operational features and accident experience of the entire state trunkline. These files can reasonably be assumed to contain geometric, operational, and accident information for the entire population of three-legged, two-way, unsignalized intersections on the state trunkline and can serve as the base from which the sample of sites for this study can be drawn.

The objectives of the study call for comparisons of the accident experience of 1) Y-intersections against T-intersections and 2) a special type of Y-intersection, where the main road curves to the right and the minor road continues on a tangent, against other three-legged intersections. Thus, the variables of interest in selecting the study sample include the distinction of whether the intersection is on a curve (a degree of curvature of 0.25 degrees was selected as the discriminating value), whether the curve curves to the right or left, and whether the intersection is a T or a Y. Since there is a known difference in the accident experience of rural and urban areas, a rural/urban discriminator, based on surrounding population, was also included.

Population of Sites

Figure 4-1 shows the population of three-legged, non-signalized, two-way intersections in MDOT's MIDAS III file in the summer of 1993. There are 11,646 such intersections. The figure further shows that only 22% of these intersections are on curves and about 67% of the curved sites are in rural areas. The tangent sites are approximately equally divided between rural and urban areas. For curved sites, the number of sites located on left curves is basically equal to the number of sites on right curves. Approximately one-quarter of the curved sites and only 10% of the rural tangent sites and 6% of the urban tangent sites are Y-intersections.

From Figure 4-1 it can be seen that Y-intersections do not constitute a large portion of the three-legged, non-signalized, two-way intersections on the state trunkline. Only 11.5% of these intersections are Y's, with approximately half located on curves and half on tangents.

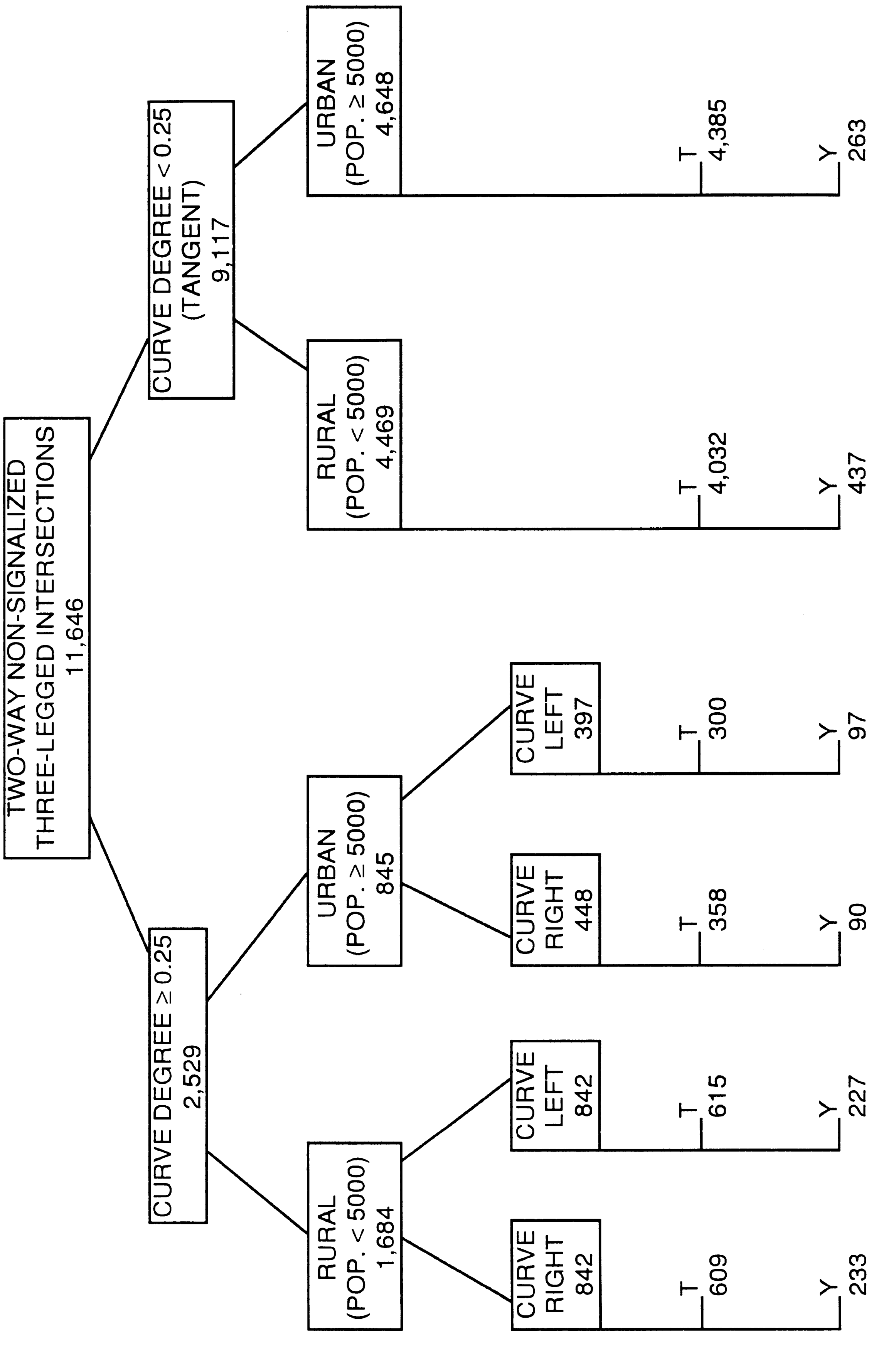


Figure 4-1 - Population of Two-way, Non-signalized, Three-legged Intersections in MIDAS III File

Match with Sufficiency File

The Sufficiency File, another MDOT data file, contained several other site variables that were not available in the MIDAS III file. Before the variables from the Sufficiency File were appended to the file, a match was made on key variables that appeared in both files. Only sites for which the two files matched were retained. Figure 4-2 shows the results of this matching. It should be noted that the matching process was more successful for rural sites than for urban sites.

First Sample

Equal cell sizes are a desired (though not necessary) property for comparative analyses. Since there were only 227 curve-right and 224 curve-left rural Y sites and equal numbers of curve/urban T's, we decided to randomly select and retain only 250 sites in all categories with more than 250 sites. If there were fewer than 250 sites in a category, all sites were retained. Figure 4-3 shows the resulting sample.

Final Sample

While the sampling process was proceeding, concurrent examination of the photologs brought into question the distinction between left and right curves. The direction of the curve is coded along the road from south to north and from east to west. Thus, a curve is coded to one side from one direction but to the other side from the opposite direction. For example, if a vehicle travelling north experiences a right curve, a vehicle travelling south on the same road will experience a left curve.

Once this was understood, and since the number of left and right curves in the file was relatively equal, it was no longer necessary to carry the distinction between left and right curves. Thus, the T-intersection sites on curves were randomly sampled again to bring the cell sizes to approximately 250. The Y-intersections sites on curves were all retained, because they were to be further broken down into subclasses. Figures 4-4 and 4-5 show the final study sample.

Categories of Y-Intersections

The Y-intersections were further classified into six categories, depending on the location of the minor leg and the angle at which the minor leg met the major road relative to the direction of the curve. All these variables were available in the data. Table 4-1 gives the values of the various variables associated with each category of Y-intersection. Figure 4-6 shows the convention used in defining the angle of the intersection. There are two sets of conditions for each category because of the coding convention used in the data, and each member of the pair is equivalent to the other by moving in the opposite direction on the same road. Figure 4-7 graphically shows the six categories of the Y-intersections.

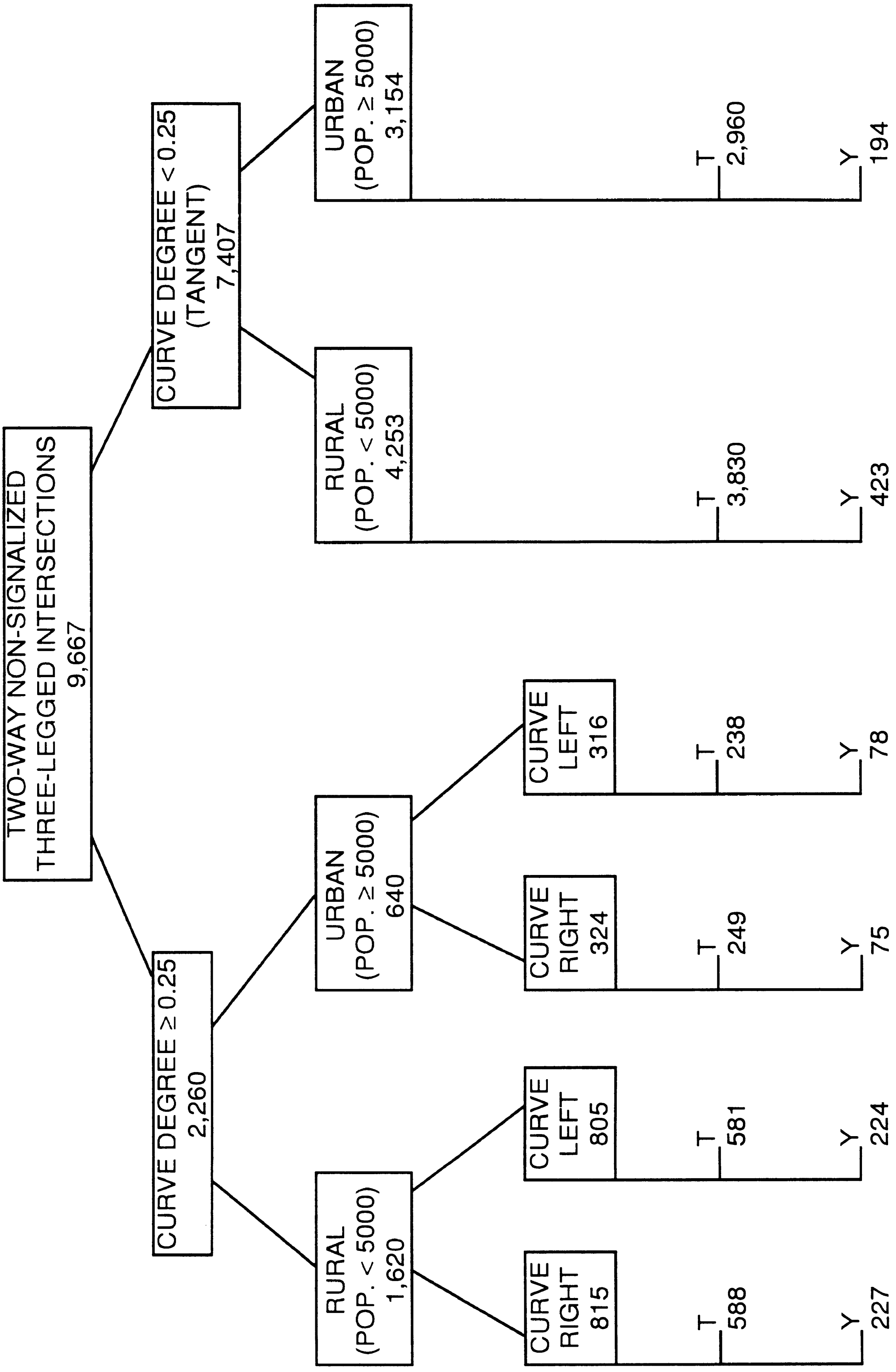


Figure 4-2 - Number of Two-way, Non-signalized, Three-legged Intersections in MIDAS III File that Matched with Key Variables in Sufficiency File

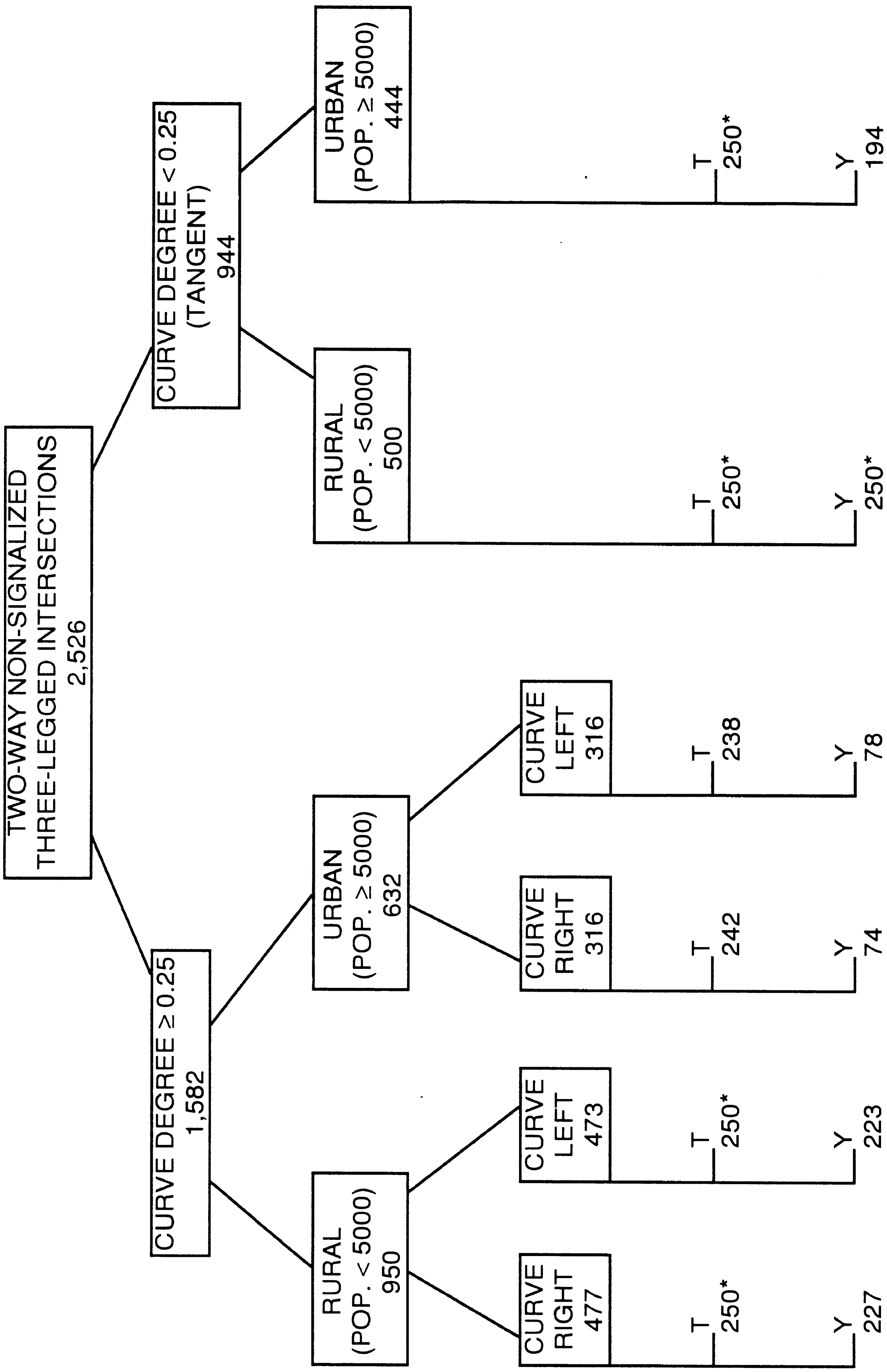
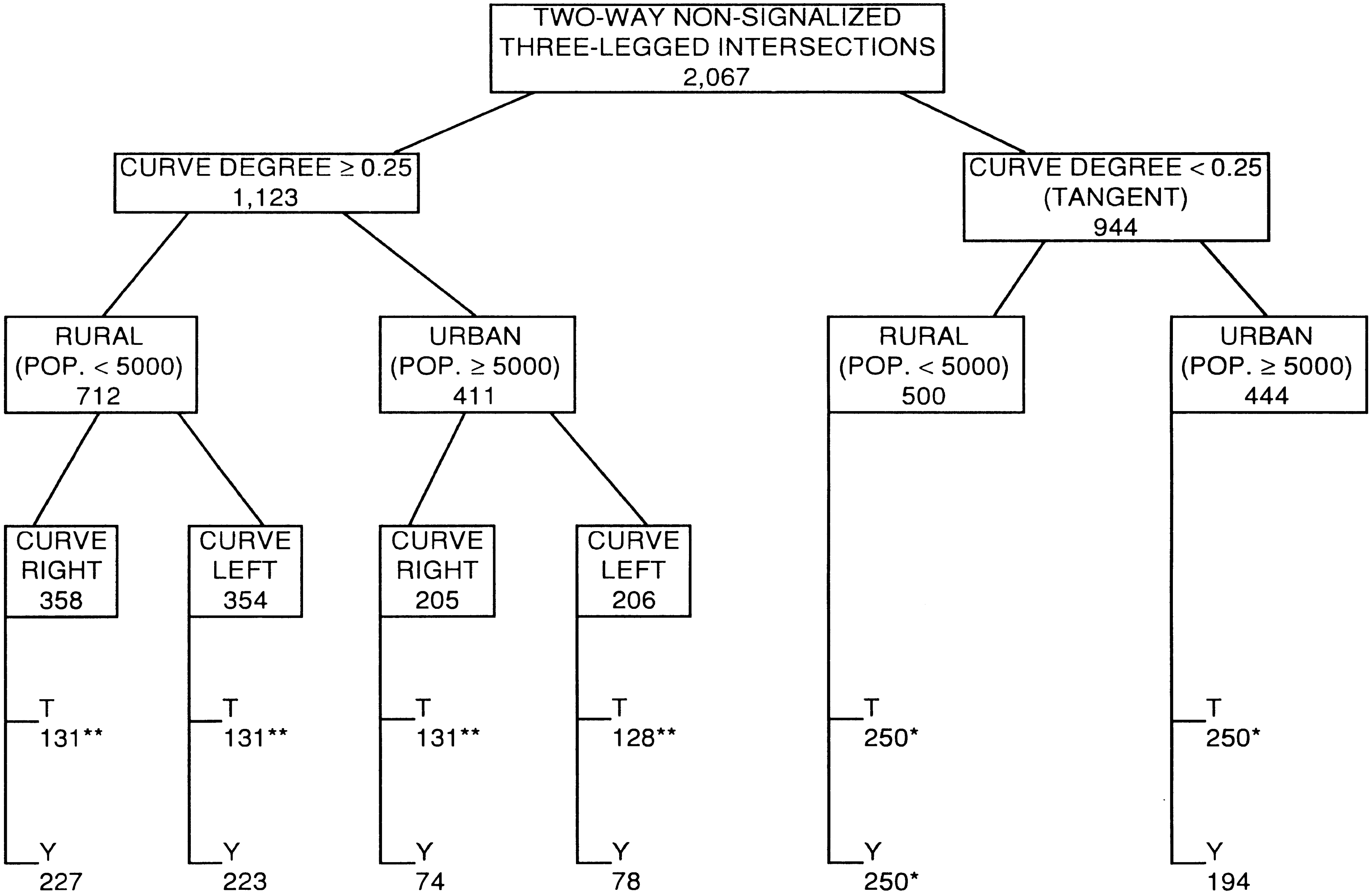


Figure 4-3 - Sample I Supplied by MDOT

*Random sample



**Second random sample
*Original random sample

Figure 4-4 - Final Sample

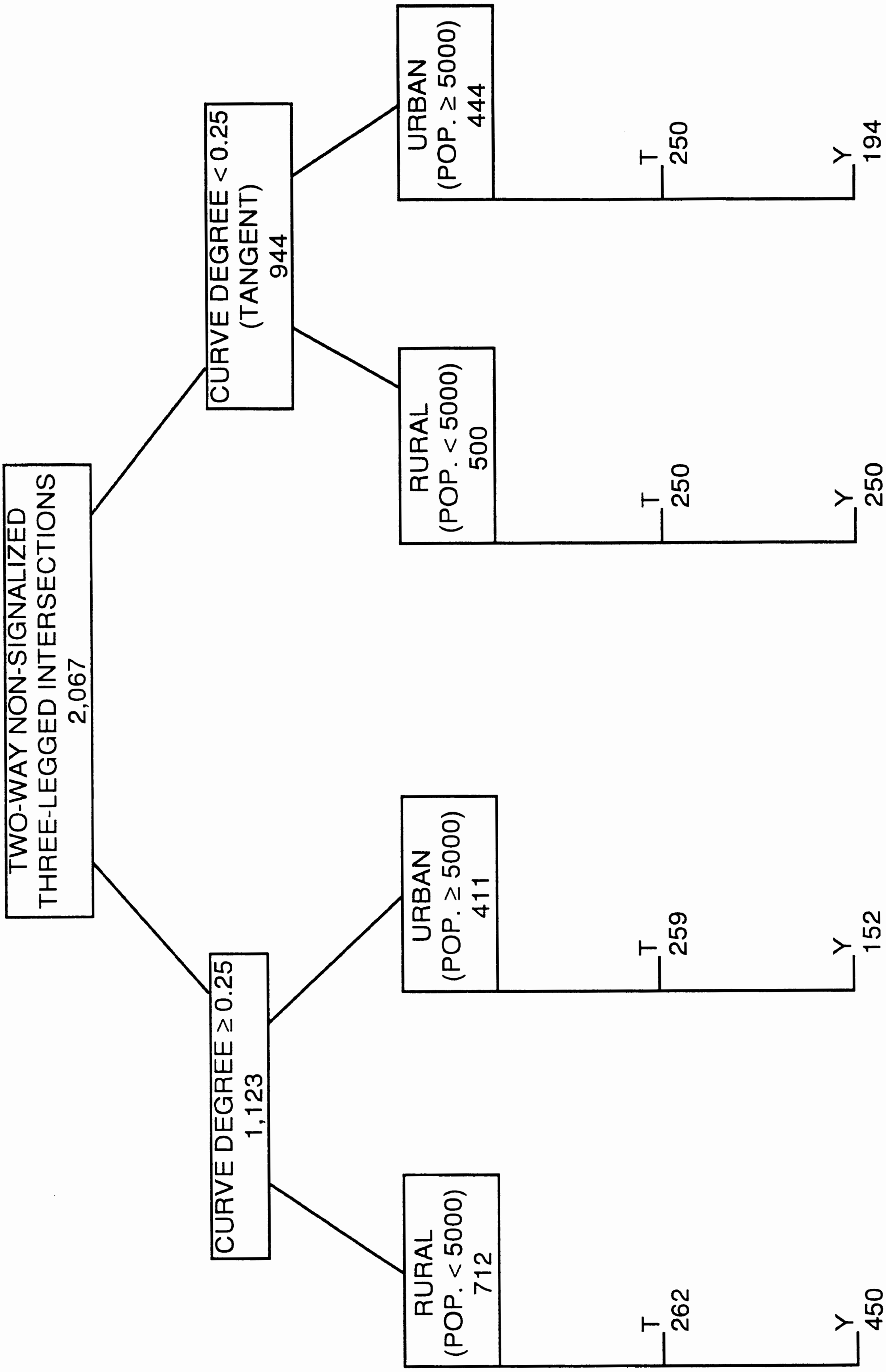


Figure 4-5 - Final Study Design

Table 4-1 - Definitions of Y-Intersection Categories

Y-Category	Curve Direction	Location of Minor leg	Angle	Minor Leg on Inside or Outside of Curve
1	right	left	Obtuse	Outside
1	left	right	Acute	Outside
2	right	left	Acute	Outside
2	left	right	Obtuse	Outside
3	right	right	Acute	Inside
3	left	left	Obtuse	Inside
4	right	right	Obtuse	Inside
4	left	left	Acute	Inside
5	none	left	Obtuse	n/a
5	none	right	Acute	n/a
6	none	left	Acute	n/a
6	none	right	Obtuse	n/a

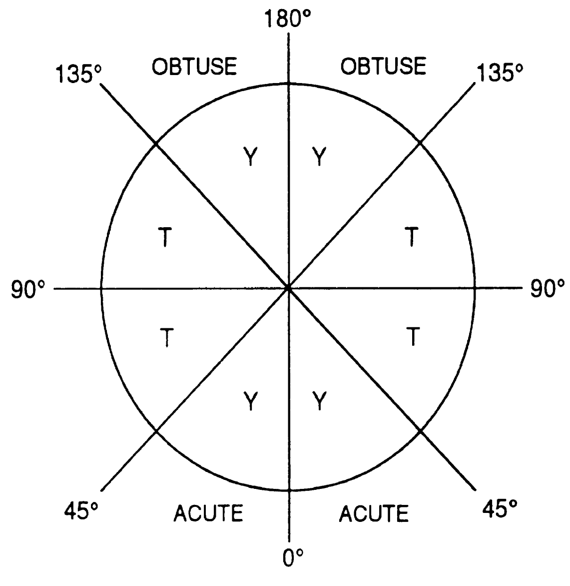


Figure 4-6 - Angles for Y and T Intersections

One of the primary objectives of this research is to examine the accident experience at a special configuration of Y-intersection where the main road curves to the right and the minor road continues on a tangent. These intersections could not be identified from the available variables in the data. However, these special intersections form a subset of Y-intersection category 1. Accordingly, all category 1 intersections were viewed on the photolog and sorted into special and not special groups.

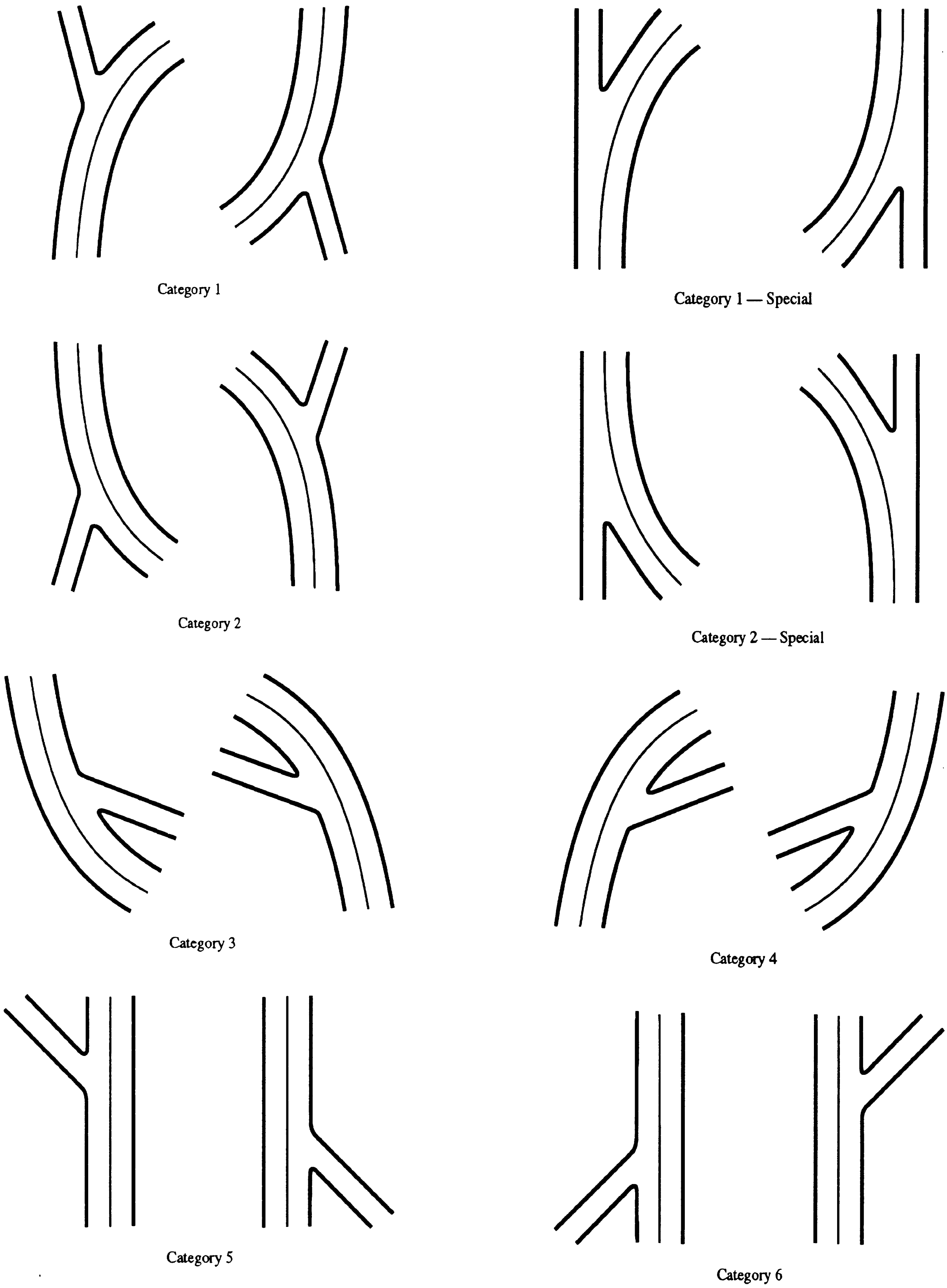


Figure 4-7 - Categories of Y-Intersections for Michigan Trunkline Analysis

Y-Intersections

To allow comparison of the special Y-intersections against intersections where the main road curves to the left and the minor road continues on a tangent, all category 2 Y-intersections were also viewed on a photolog and similarly sorted into special (left) and not special (left) groups. Figure 4-8 shows the sample further divided into all the categories of Y-intersections.

It can be seen from Figure 4-8 that 40% of the rural curve sample are category 1, the case where the main road curves to the right and the minor road forms an obtuse angle on the left side. Of these 38% form the subset of special right Y-intersections, where the side road continues on a tangent. Forty percent of the rural curve sample are category 2, where the main road curves to the left and the minor road forms an obtuse angle on the right side. Of these 35% are of the special subset where the minor road continues on a tangent.

In both category 1 and 2 the minor leg is on the outside of the curve. The rest of the rural curve sample (19%) includes cases where the minor leg is on the same side as the direction of the curve, thus, on the inside of the curve.

The distribution in the urban curve portion of the sample is similar. Thirty-seven percent are of category 1, with 32% of these in the special subset. Thirty-eight percent are of category 2, with 26% of these in the special subset. Twenty-five percent of the urban curve Y's in the sample have the minor road on the inside of the curve.

Overall there were 88 sites in the study design in the special right Y-category. These were not sampled but represent the entire population of special right Y-intersections in the state. It should be noted that some sites may have been deleted in the data file matching process. However, we know that number is very small. There may be others in the population that were not included in the MDOT files due to miscoding or some other data error. Again, we believe that this number is small. However, even allowing for the two possible errors in their number in the population, the special right Y-intersections constitute less than 1% of all the three-legged, non-signalized, two-way intersections on the Michigan state trunkline.

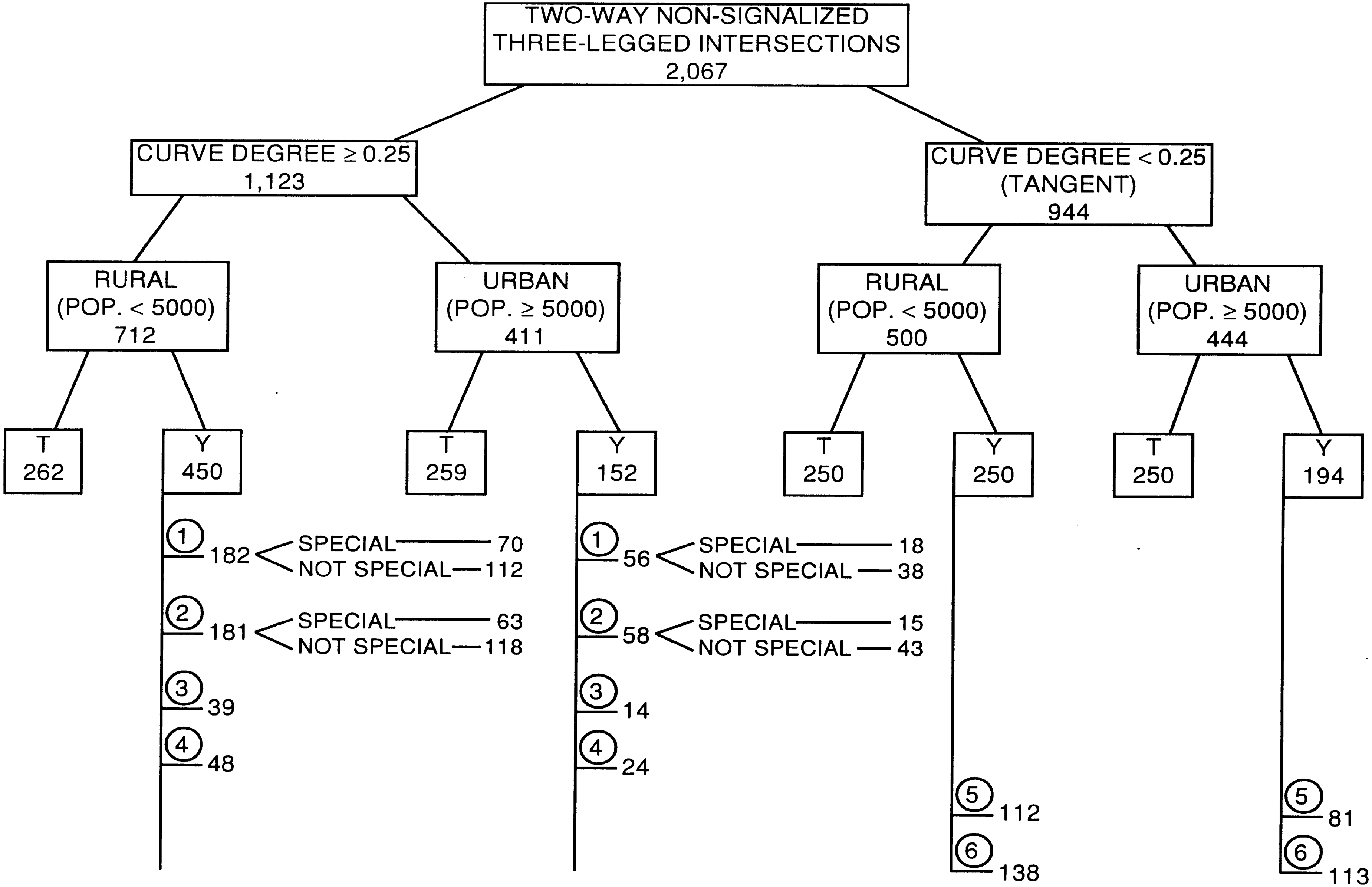


Figure 4-8 - Sample by Categories of Y

4.2 STATISTICAL ANALYSIS OF Y- VERSUS T-INTERSECTIONS

Introduction

The original raw datafile for this project was prepared by MDOT personnel using the MIDAS III file and the Sufficiency File. The analysis file was built and analyzed by UMTRI staff using SAS for Windows, version 6, on a microcomputer. In both the raw data supplied by MDOT and the analysis file built by UMTRI, one set of variables pertains to sites, and the remainder describe accidents. Police-reported traffic accidents from 1987 through 1991 are included in the analysis file. There is one record per accident in the file, and if a site had no accidents in the five-year time period, the accident variables for that record are blank. One site with six accident records was deleted from the analysis file because it was coded as a four-legged intersection. In addition, all accident records coded as "non-intersection and non-interchange area" on the Highway Area Type variable were deleted from the analysis file. Only records coded "interchange area" or "intersection area" on that variable were included. A list of variables and a codebook for the analysis file are included in Appendix B.

Table 4-2 shows the number of site records and accident records in the analysis file according to intersection type. Three dichotomous variables define intersection type. They are trunkline horizontal alignment—curve (>0.25 degrees) versus tangent; rural versus urban; and T versus Y intersection.

Table 4-2 - Number of Records in Analysis File

Intersection Type	Number of Sites	Number of Accidents
curve/rural/T	262	553
curve/rural/Y	450	1,219
curve/urban/T	259	1,800
curve/urban/Y	152	845
tangent/rural/T	250	561
tangent/rural/Y	250	736
tangent/urban/T	250	1,943
tangent/urban/Y	194	1,621
Total	2,067	9,278

The analysis file includes an average daily traffic (ADT) count on the trunkline for each site. To match this data with the accident data, the ADT for each site was multiplied by 365 times 5 to expand the daily counts to five-year traffic volumes. Rates were calculated for each category of intersection type by summing the number of accidents across all sites in a category and dividing by the sum of the five-year traffic volumes across all sites in the category. Similarly, the overall rate for all sites in the analysis file was calculated by dividing the total number of accidents in the file by the sum of traffic volumes across all sites in the file. (Please refer to the "Total Accidents and Accident Rates" section of Chapter 3 for a discussion of an alternative approach to rate calculation and a description of the relative risk technique.)

Rates for the different categories of intersection were tabulated for accidents by type and severity as well as by various operational and geometric features. Because of the effort required to carry out statistical testing of differences among the rates, statistical tests were carried out only for tables that showed promise in sorting out the relationships under investigation. These tables can be identified by the presence of asterisk (*) symbols, indicating statistical significance, or "NS," for "not significant." Single asterisks represent significance at the 5% level, and double asterisks indicate significance at the 10% level. Tables without these symbols are descriptive.

Statistical tests for differences between rates require estimates of standard errors. The standard error estimates in our analyses were based on the assumption that the rates can be modeled by classical log-linear models. Whenever the number of accidents is large, the occurrence of accidents is assumed to be Poisson distributed and the rates are assumed to be asymptotically normal. For such cases, the standard error for each intersection category can be directly estimated from the sample as the square root of the quotient of the number of accidents divided by the square of the traffic count.

However, often when the number of accidents is small and the exposure large, the variability in the rates is larger than that assumed by a Poisson model. In the presence of extra-Poisson variation, standard error estimates are too small, resulting in tests of hypotheses that are too liberal. The approach for standard error estimation for such cases (37) is described in Appendix C. The method consists of first estimating the model parameters from the observations and then selecting a variance function for the model to accommodate the over-dispersion. The final parameter estimates come from a Bayesian process that uses both the sample rates and model-based estimates to obtain the final parameters. This results in standard error estimates that can be confidently used for testing hypotheses.

Rates by Intersection Type

Table 4-3 shows the accident rates and relative risk measures for each category of intersection type. The eight categories of intersection type form four pairs of Y versus T comparisons: curve/rural, curve/urban, tangent/rural, and tangent/urban. Within each of these four pairs, the Y sites have a higher accident rate than the T sites, except among curve/urban intersections. In other words, controlling for horizontal alignment of the major road and for area type, Y sites tend to have a higher accident rate than T sites, except for the curve/urban case.

The Bayesian estimation technique mentioned previously was used to fit a model to the observed accident and traffic volume data in Table 4-3. Data for all of the intersection types were used to produce estimated rates and standard errors for each individual type of intersection. In this particular case, the estimated rates closely mirror the observed rates because the counts are large. In the most appropriate model for the data in Table 4-3, all main effects and all two-way interaction terms are significant. Two-tailed *t*-tests were conducted on each of the four pairs of estimated rates from the model, assuming infinite degrees of freedom. All four *t*-tests are significant at the 5% level (indicated by the asterisks), so the Y versus T differences described above hold when tested.

Table 4-3 - Accident Rates per 100 Million Vehicles by Intersection Type

Intersection Type	5-year Accident Count	5-year Traffic Vol. (Millions)	Accs. Per 100 Million Vehicles	Relative Risk
curve/rural/T	553	2,061	26.84 *	0.68
curve/rural/Y	1,219	3,255	37.45	0.95
curve/urban/T	1,800	3,959	45.47 *	1.15
curve/urban/Y	845	2,460	34.34	0.87
tangent/rural/T	561	2,192	25.59 *	0.65
tangent/rural/Y	736	1,880	39.16	0.99
tangent/urban/T	1,943	4,417	43.99 *	1.11
tangent/urban/Y	1,621	3,281	49.40	1.25
Total	9,278	23,505	39.47	1.00

<u>Rates by district</u>

To look at geographical variation, accident rates were computed for intersections within each of the nine MDOT districts. As shown in Table 4-4, the rates are comparable among districts, but the more heavily populated southern portion of the state tends to have higher rates.

Table 4-4 - Accident Rates per 100 Million Vehicles by District

District	5-year Accident Count	5-year Traffic Vol. (Millions)	Accs. Per 100 Million Vehicles	Relative Risk
Crystal Falls	782	1,999	39.13	0.99
Newberry	282	868	32.49	0.82
Cadillac	1,025	2,761	37.12	0.94
Alpena	728	2,450	29.71	0.75
Grand Rapids	910	2,343	38.85	0.98
Saginaw	1,142	3,231	35.34	0.90
Kalamazoo	1,921	4,313	44.54	1.13
Jackson	1,547	3,369	45.92	1.16
Metro	941	2,172	43.33	1.10
Total	9,278	23,505	39.47	1.00

Since accident rates at three-legged intersections vary by MDOT district, rates by intersection type were calculated for each district separately (Table 4-5). The difference in rates at Y and T intersections noted earlier holds consistently for curved sites. Y-intersections have higher rates than T-intersections at curve/rural sites in every district except Cadillac (District 3). Conversely, T-intersections have higher rates than Y-intersections at curve/urban sites in every district except Saginaw (District 6), where Y's have a higher rate, and Kalamazoo (District 7), where the Y and T rates are the same. Rate patterns are not as clear for tangent intersections. While overall rates show Y-intersections to have higher rates than T-intersections for both tangent/rural and tangent/urban sites, rates for T's are higher than rates for Y's within several districts. This is particularly true for tangent/urban sites.

Table 4-5 - Accident Rates per 100 Million Vehicles by District and Intersection Type

District	Intersection Type	5-year Accident Count	5-year Traffic Vol. (Millions)	Accs. Per 100 Million Vehicles	Relative Risk
Crystal Falls	curve/rural/T	54	191	28.21	0.71
	curve/rural/Y	99	300	33.02	0.84
	curve/urban/T	93	252	36.84	0.93
	curve/urban/Y	64	250	25.58	0.65
	tangent/rural/T	40	140	28.48	0.72
	tangent/rural/Y	51	214	23.83	0.60
	tangent/urban/T	202	301	67.20	1.70
	tangent/urban/Y	179	350	51.17	1.30
	SUBTOTAL	782	1,999	39.13	0.99
Newberry	curve/rural/T	17	89	19.17	0.49
	curve/rural/Y	27	99	27.41	0.69
	curve/urban/T	82	195	42.05	1.07
	curve/urban/Y	45	145	31.04	0.79
	tangent/rural/T	16	81	19.67	0.50
	tangent/rural/Y	2	26	7.61	0.19
	tangent/urban/T	57	108	52.81	1.34
	tangent/urban/Y	36	125	28.75	0.73
	SUBTOTAL	282	868	32.49	0.82
Cadillac	curve/rural/T	116	358	32.42	0.82
	curve/rural/Y	185	649	28.51	0.72
	curve/urban/T	64	165	38.75	0.98
	curve/urban/Y	59	190	31.11	0.79
	tangent/rural/T	62	297	20.91	0.53
	tangent/rural/Y	195	430	45.39	1.15
	tangent/urban/T	139	354	39.24	0.99
	tangent/urban/Y	205	319	64.25	1.63
	SUBTOTAL	1,025	2,761	37.12	0.94
Alpena	curve/rural/T	66	276	23.89	0.61
	curve/rural/Y	63	206	30.63	0.78
	curve/urban/T	298	757	39.38	1.00
	curve/urban/Y	58	261	22.26	0.56
	tangent/rural/T	41	233	17.59	0.45
	tangent/rural/Y	32	87	36.98	0.94
	tangent/urban/T	139	439	31.65	0.80
	tangent/urban/Y	31	192	16.13	0.41
	SUBTOTAL	728	2,450	29.71	0.75

Grand Rapids	curve/rural/T	30	183	16.35	0.41
	curve/rural/Y	149	350	42.55	1.08
	curve/urban/T	282	486	57.97	1.47
	curve/urban/Y	29	158	18.40	0.47
	tangent/rural/T	71	233	30.45	0.77
	tangent/rural/Y	28	87	32.24	0.82
	tangent/urban/T	229	568	40.30	1.02
	tangent/urban/Y	92	277	33.27	0.84
	SUBTOTAL	910	2,343	38.85	0.98
Saginaw	curve/rural/T	36	212	16.98	0.43
	curve/rural/Y	105	339	30.94	0.78
	curve/urban/T	162	464	34.90	0.88
	curve/urban/Y	222	514	43.19	1.09
	tangent/rural/T	76	291	26.09	0.66
	tangent/rural/Y	69	279	24.74	0.63
	tangent/urban/T	344	812	42.37	1.07
	tangent/urban/Y	128	320	40.04	1.01
	SUBTOTAL	1,142	3,231	35.34	0.90
Kalamazoo	curve/rural/T	124	351	35.31	0.89
	curve/rural/Y	256	573	44.68	1.13
	curve/urban/T	500	1,047	47.76	1.21
	curve/urban/Y	250	526	47.51	1.20
	tangent/rural/T	76	248	30.60	0.78
	tangent/rural/Y	114	331	34.47	0.87
	tangent/urban/T	273	705	38.75	0.98
	tangent/urban/Y	328	532	61.69	1.56
	SUBTOTAL	1,921	4,313	44.54	1.13
Jackson	curve/rural/T	68	211	32.26	0.82
	curve/rural/Y	275	586	46.92	1.19
	curve/urban/T	178	263	67.72	1.72
	curve/urban/Y	89	203	43.83	1.11
	tangent/rural/T	116	421	27.53	0.70
	tangent/rural/Y	170	314	54.22	1.37
	tangent/urban/T	266	673	39.55	1.00
	tangent/urban/Y	385	698	55.14	1.40
	SUBTOTAL	1,547	3,369	45.92	1.16
Metro	curve/rural/T	42	189	22.21	0.56
	curve/rural/Y	60	153	39.25	0.99
	curve/urban/T	141	329	42.83	1.09
	curve/urban/Y	29	214	13.54	0.34
	tangent/rural/T	63	247	25.54	0.65
	tangent/rural/Y	75	113	66.27	1.68
	tangent/urban/T	294	458	64.24	1.63
	tangent/urban/Y	237	469	50.56	1.28
	SUBTOTAL	941	2,172	43.33	1.10
TOTAL		9,278	23,505	39.47	1.00

Rates by degree of curve

Another important variable to consider is road curvature. The intersections were split into seven categories according to degree of curvature of the trunkline. In general, the more severely curved sites have higher accident rates (Table 4-6).

Table 4-6 - Accident Rates per 100 Million Vehicles by Degree of Curve

Degree Category	5-year Accident Count	5-year Traffic Vol. (Millions)	Accs. Per 100 Million Vehicles	Relative Risk
0 (tangent)	4,861	11,770	41.30	1.05
0.25-3	2,423	7,281	33.28	0.84
3.01-5	629	1,824	34.48	0.87
5.01-10	771	1,649	46.76	1.18
10.01-15	239	382	62.49	1.58
15.01-25	202	390	51.75	1.31
25.01-90	153	208	73.64	1.87
Total	9,278	23,505	39.47	1.00

Given the rate variation according to degree of curvature, rates for the eight intersection types were calculated controlling for degree of curve (Table 4-7). Sites where the major road continues at a tangent through the intersection are all 0-degree sites by definition. If the main road curves 0.25 degrees or more, the site is a curved intersection. Each of the degree categories in Table 4-7 shows only the relevant intersection type categories, i.e., tangent sites under degree 0 and curve sites under all the other categories. The overall pattern noted earlier of Y-intersections having higher rates among curve/rural sites and T-intersections having higher rates among curve/urban sites generally prevails when degree of curve is held constant.

Table 4-7 - Accident Rates per 100 Million Vehicles by Degree of Curve and Intersection Type

Degree Category	Intersection Type	5-year Accident Count	5-year Traffic Vol. (Millions)	Accs. Per 100 Million Vehicles	Relative Risk
0 (tangent)	tangent/rural/T	561	2,192	25.59	0.65
	tangent/rural/Y	736	1,880	39.16	0.99
	tangent/urban/T	1,943	4,417	43.99	1.11
	tangent/urban/Y	1,621	3,281	49.40	1.25
	SUBTOTAL	4,861	11,770	41.30	1.05
0.25-3	curve/rural/T	436	1,644	26.52	0.67
	curve/rural/Y	637	2,017	31.58*	0.80
	curve/urban/T	998	2,528	39.47	1.00
	curve/urban/Y	352	1,091	32.26*	0.82
	SUBTOTAL	2,423	7,281	33.28	0.84

3.01-5	curve/rural/T	51	205	24.84	0.63
	curve/rural/Y	179	444	40.27*	1.02
	curve/urban/T	313	704	44.49	1.13
	curve/urban/Y	86	471	18.26*	0.46
	SUBTOTAL	629	1,824	34.48	0.87
5.01-10	curve/rural/T	28	147	19.04	0.48
	curve/rural/Y	187	454	41.18*	1.04
	curve/urban/T	290	433	66.97	1.70
	curve/urban/Y	266	615	43.26*	1.10
	SUBTOTAL	771	1,649	46.76	1.18
10.01-15	curve/rural/T	19	25	74.95	1.90
	curve/rural/Y	62	100	61.85NS	1.57
	curve/urban/T	105	169	61.96	1.57
	curve/urban/Y	53	87	60.64NS	1.54
	SUBTOTAL	239	382	62.49	1.58
15.01-25	curve/rural/T	8	18	44.19	1.12
	curve/rural/Y	72	157	45.87NS	1.16
	curve/urban/T	43	48	90.07	2.28
	curve/urban/Y	79	168	47.15*	1.19
	SUBTOTAL	202	390	51.75	1.31
25.01-90	curve/rural/T	11	21	52.73	1.34
	curve/rural/Y	82	82	100.59*	2.55
	curve/urban/T	51	77	66.47	1.68
	curve/urban/Y	9	29	31.41*	0.80
	SUBTOTAL	153	208	73.64	1.87
TOTAL		9,278	23,505	39.47	1.00

Rates for all the curved sites in Table 4-7 were modeled, and *t*-tests were conducted on all the pairs of estimated rates. Significant differences at the 5% level are noted by an asterisk in the table. Non-significant differences are noted by "NS."

<u>Rates by area type</u>

Table 4-8 shows the rates for the intersections grouped into a more detailed rural/urban development classification. Accident rates per 100 million vehicles rise with increasing urbanization.

Table 4-8 - Accident Rates per 100 Million Vehicles by Area Type

Area Type	5-year Accident Count	5-year Traffic Vol. (Millions)	Accs. Per 100 Million Vehicles	Relative Risk
rural	2,653	8,157	32.52	0.82
small cities	2,099	6,105	34.38	0.87
rural in character	260	655	39.69	1.01
residential	1,555	3,305	47.05	1.19
outlying bus. dist.	2,389	4,739	50.41	1.28
fringe/cbd	322	544	59.22	1.50
Total	9,278	23,505	39.47	1.00

Rates for the eight intersection types were also calculated for each of the detailed area type categories (Table 4-9). The rural/urban variable used to classify intersection types is different than the detailed area type variable, and there appear to be a few inconsistencies between the two variables. Despite this, sites within each of the area type categories tend to follow the same pattern with respect to Y and T rates as exhibited by sites in the aggregate.

Table 4-9 - Accident Rates per 100 Million Vehicles by Area Type and Intersection Type

Area Type	Intersection Type	5-year Accident Count	5-year Traffic Vol. (Millions)	Accs. Per 100 Million Vehicles	Relative Risk
rural	curve/rural/T	383	1,409	27.18	0.69
	curve/rural/Y	1,012	2,652	38.16	0.97
	curve/urban/T	222	522	42.55	1.08
	curve/urban/Y	90	347	25.94	0.66
	tangent/rural/T	365	1,451	25.15	0.64
	tangent/rural/Y	430	1,277	33.67	0.85
	tangent/urban/T	80	245	32.61	0.83
	tangent/urban/Y	71	254	27.99	0.71
	SUBTOTAL	2,653	8,157	32.52	0.82
small cities	curve/rural/T	119	428	27.78	0.70
	curve/rural/Y	54	247	21.84	0.55
	curve/urban/T	481	1,489	32.31	0.82
	curve/urban/Y	293	819	35.77	0.91
	tangent/rural/T	110	397	27.73	0.70
	tangent/rural/Y	85	240	35.42	0.90
	tangent/urban/T	619	1,524	40.61	1.03
	tangent/urban/Y	338	960	35.20	0.89
	SUBTOTAL	2,099	6,105	34.38	0.87

rural in character	curve/rural/T	9	32	28.12	0.71
	curve/rural/Y	52	127	41.04	1.04
	curve/urban/T	15	56	26.98	0.68
	curve/urban/Y	17	70	24.12	0.61
	tangent/rural/T	22	124	17.68	0.45
	tangent/rural/Y	91	128	71.27	1.81
	tangent/urban/T	4	12	32.66	0.83
	tangent/urban/Y	50	106	47.18	1.20
	SUBTOTAL	260	655	39.69	1.01
residential	curve/rural/T	33	146	22.68	0.57
	curve/rural/Y	71	137	51.80	1.31
	curve/urban/T	567	831	68.19	1.73
	curve/urban/Y	136	351	38.78	0.98
	tangent/rural/T	38	175	21.76	0.55
	tangent/rural/Y	122	204	59.82	1.52
	tangent/urban/T	256	696	36.81	0.93
	tangent/urban/Y	332	766	43.34	1.10
	SUBTOTAL	1,555	3,305	47.05	1.19
outlying bus. dist.	curve/rural/T	9	46	19.73	0.50
	curve/rural/Y	30	91	32.82	0.83
	curve/urban/T	486	987	49.25	1.25
	curve/urban/Y	271	783	34.60	0.88
	tangent/rural/T	26	45	57.35	1.45
	tangent/rural/Y	8	31	25.85	0.65
	tangent/urban/T	897	1,730	51.85	1.31
	tangent/urban/Y	662	1,026	64.54	1.63
	SUBTOTAL	2,389	4,739	50.41	1.28
fringe/cbd	curve/rural/T	0	0	N/A	N/A
	curve/rural/Y	0	0	N/A	N/A
	curve/urban/T	29	75	38.79	0.98
	curve/urban/Y	38	90	42.23	1.07
	tangent/rural/T	0	0	N/A	N/A
	tangent/rural/Y	0	0	N/A	N/A
	tangent/urban/T	87	209	41.55	1.05
	tangent/urban/Y	168	170	99.05	2.51
	SUBTOTAL	322	544	59.22	1.50
TOTAL		9,278	23,505	39.47	1.00

Rates by speed limit

The intersections were also categorized according to the posted speed limit (Table 4-10). The association of speed limit and accident rate is unclear, although there is some evidence for declining rates with higher speed limits.

Table 4-10 - Accident Rates per 100 Million Vehicles by Speed Limit

Speed Limit	5-year Accident Count	5-year Traffic Vol. (Millions)	Accs. Per 100 Million Vehicles	Relative Risk
25-30	1,204	2,521	47.76	1.21
35	1,764	3,406	51.79	1.31
40	712	2,128	33.46	0.85
45	897	2,449	36.62	0.93
50	906	2,049	44.22	1.12
55	3,795	10,952	34.65	0.88
Total	9,278	23,505	39.47	1.00

Table 4-11 shows rates for the eight intersection types, controlling for speed limit. Rates for T and Y intersections generally reflect the aggregate pattern within each of the speed limit categories. The exception is for tangent/urban intersections, where Y's have higher rates than T's overall, but T's have higher rates than Y's within several of the speed limit categories.

Table 4-11 - Accident Rates per 100 Million Vehicles by Speed Limit and Intersection Type

Speed Limit	Intersection Type	5-year Accident Count	5-year Traffic Vol. (Millions)	Accs. Per 100 Million Vehicles	Relative Risk
25-30	curve/rural/T	1	9	10.54	0.27
	curve/rural/Y	7	24	29.37	0.74
	curve/urban/T	221	447	49.44	1.25
	curve/urban/Y	82	227	36.14	0.92
	tangent/rural/T	22	40	54.65	1.38
	tangent/rural/Y	14	36	39.18	0.99
	tangent/urban/T	405	792	51.15	1.30
	tangent/urban/Y	452	946	47.79	1.21
	SUBTOTAL	1,204	2,521	47.76	1.21
35	curve/rural/T	3	27	11.28	0.29
	curve/rural/Y	11	13	84.77	2.15
	curve/urban/T	318	847	37.56	0.95
	curve/urban/Y	185	533	34.71	0.88
	tangent/rural/T	3	17	17.49	0.44
	tangent/rural/Y	70	80	88.01	2.23
	tangent/urban/T	615	1,186	51.84	1.31
	tangent/urban/Y	559	704	79.45	2.01
	SUBTOTAL	1,764	3,406	51.79	1.31

40	curve/rural/T	21	40	52.09	1.32
	curve/rural/Y	7	25	27.98	0.71
	curve/urban/T	115	488	23.58	0.60
	curve/urban/Y	95	349	27.25	0.69
	tangent/rural/T	32	70	46.00	1.17
	tangent/rural/Y	31	53	58.41	1.48
	tangent/urban/T	265	791	33.50	0.85
	tangent/urban/Y	146	313	46.69	1.18
	SUBTOTAL	712	2,128	33.46	0.85
45	curve/rural/T	52	127	40.90	1.04
	curve/rural/Y	40	155	25.83	0.65
	curve/urban/T	190	544	34.95	0.89
	curve/urban/Y	147	482	30.52	0.77
	tangent/rural/T	16	88	18.18	0.46
	tangent/rural/Y	26	75	34.71	0.88
	tangent/urban/T	242	536	45.14	1.14
	tangent/urban/Y	184	443	41.52	1.05
	SUBTOTAL	897	2,449	36.62	0.93
50	curve/rural/T	21	129	16.33	0.41
	curve/rural/Y	24	68	35.34	0.90
	curve/urban/T	367	518	70.89	1.80
	curve/urban/Y	170	370	46.00	1.17
	tangent/rural/T	50	186	26.84	0.68
	tangent/rural/Y	51	42	120.30	3.05
	tangent/urban/T	139	400	34.79	0.88
	tangent/urban/Y	84	337	24.94	0.63
	SUBTOTAL	906	2,049	44.22	1.12
55	curve/rural/T	455	1,729	26.32	0.67
	curve/rural/Y	1,130	2,970	38.05	0.96
	curve/urban/T	589	1,116	52.78	1.34
	curve/urban/Y	166	501	33.15	0.84
	tangent/rural/T	438	1,791	24.45	0.62
	tangent/rural/Y	544	1,594	34.13	0.86
	tangent/urban/T	277	712	38.90	0.99
	tangent/urban/Y	196	539	36.36	0.92
	SUBTOTAL	3,795	10,952	34.65	0.88
TOTAL		9,278	23,505	39.47	1.00

Since higher-speed roads are of particular concern given their greater potential for severe accidents, the accident and traffic count data were combined for 50 and 55 mph roads and the data modeled. *T*-tests on all four pairs of estimated rates were significant at the 5% level. For these high-speed road sites, Y- intersections have higher rates in rural areas, at both curve and tangent intersections, and T-intersections have higher rates in urban areas, at both curve and tangent sites.

Rates by Intersection Type and Accident Severity

All the rates discussed so far concern all police-reported accidents, the majority of which result in only property damage. In this section, rates are compared among the different types of intersections according to accident severity. Three categories of severity are considered: 1) accidents resulting in at least one fatal or A-injury, 2) accidents resulting in at least one B- or C-injury, and 3) property-damage-only (PDO) accidents.

Table 4-12 shows the severity distribution of accidents at each of the eight intersection types. The first row of figures for each type of intersection lists accident frequencies, and the second row lists percentages. For curve/rural and curve/urban sites, Y-intersections appear to have somewhat more severe accident distributions than their T counterparts. A test of equal proportions using the chi-square statistic was applied to each of the four pairs of distributions. The difference in the severity distribution between T's and Y's is significant at the 5% level for curve/rural sites and at the 10% level for curve/urban sites. The Y and T severity distributions for tangent/rural intersections are virtually identical. Among tangent/urban sites, T-intersections tend to have slightly more severe accidents than Y-intersections, although the difference is not significant. Curve/rural/Y intersections have the highest percentage of fatal and A accidents of all the intersection types, with 8.9%.

Table 4-12 - Accident Severity Distribution by Intersection Type

	Five-Year Accident Counts			
Intersection Type	Total K and A	Total B and C	Total PDO	Total Accidents
curve/rural/T	26	124	403	553
	4.70%	22.42%	72.88%	100.00%
curve/rural/Y	109	264	846	1,219
	8.94%	21.66%	69.40%	100.00%
curve/urban/T	101	409	1,290	1,800
	5.61%	22.72%	71.67%	100.00%
curve/urban/Y	66	173	606	845
	7.81%	20.47%	71.72%	100.00%
tangent/rural/T	43	130	388	561
	7.66%	23.17%	69.16%	100.00%
tangent/rural/Y	52	176	508	736
	7.07%	23.91%	69.02%	100.00%
tangent/urban/T	78	459	1,406	1,943
	4.01%	23.62%	72.36%	100.00%
tangent/urban/Y	57	348	1,216	1,621
	3.52%	21.47%	75.02%	100.00%
Total	532	2,083	6,663	9,278
	5.73%	22.45%	71.82%	100.00%

The next severity comparison concerns the number of accidents per site at each type of intersection (Table 4-13). Overall, the urban intersections have more accidents per site than the rural intersections, not unexpectedly. A comparison of Y's and T's according to trunkline alignment and area type shows rural Y's to have slightly more accidents per site than rural T's, both overall and within each severity category. Among urban sites, differences in number of accidents per site are less clear. T-intersections have slightly more low-severity accidents than Y-intersections among curve/urban sites, while tangent/urban sites show little difference between T's and Y's in the number of accidents of each severity per site.

Table 4-13 - Average Number of Accidents per Site by Intersection Type (over 5-Year Study Period)

Intersection Type	Average K and A Accs./Site	Average B and C Accs./Site	Average PDO Accs./Site	Average No. of Accs./Site
curve/rural/T	0.10	0.47	1.54	2.11
curve/rural/Y	0.24	0.59	1.88	2.71
curve/urban/T	0.39	1.58	4.98	6.95
curve/urban/Y	0.43	1.14	3.99	5.56
tangent/rural/T	0.17	0.52	1.55	2.24
tangent/rural/Y	0.21	0.70	2.03	2.94
tangent/urban/T	0.31	1.84	5.62	7.77
tangent/urban/Y	0.29	1.79	6.27	8.36
Total	0.26	1.01	3.22	4.49

Table 4-14 shows the fatal and A-injury accident rates per 100 million vehicles at each of the eight intersection types. Among rural sites, Y-intersections have higher rates of severe accidents than their T counterparts, significant at the 5% level. However, among urban sites, the rates for T's and Y's show no statistical difference.

Table 4-14 - Fatal and A-Injury Accident Rates by Intersection Type

Intersection Type	5-year Accident Count	5-year Traffic Vol. (Millions)	Accs. Per 100 Million Vehicles	Relative Risk
curve/rural/T	26	2,061	1.26	0.56
curve/rural/Y	109	3,255	3.35 *	1.48
curve/urban/T	101	3,959	2.55	1.13
curve/urban/Y	66	2,460	2.68 NS	1.19
tangent/rural/T	43	2,192	1.96	0.87
tangent/rural/Y	52	1,880	2.77 *	1.22
tangent/urban/T	78	4,417	1.77	0.78
tangent/urban/Y	57	3,281	1.74 NS	0.77
Total	532	23,505	2.26	1.00

The data for B and C accidents also show Y-intersections to have significantly higher rates than T-intersections in rural areas (Table 4-15). Among tangent/urban sites, T's and

Y's have about the same rate, which is again similar to the situation for fatal and A-injury accidents. However, T's have a significantly higher rate of B and C accidents than Y's among curve/urban sites, whereas curve/urban T's and Y's had similar fatal and A-injury accident rates.

Table 4-15 - B- and C-Injury Accident Rates by Intersection Type

Intersection Type	5-year Accident Count	5-year Traffic Vol. (Millions)	Accs. Per 100 Million Vehicles		Relative Risk
curve/rural/T	124	2,061	6.02	*	0.68
curve/rural/Y	264	3,255	8.11		0.92
curve/urban/T	409	3,959	10.33	*	1.17
curve/urban/Y	173	2,460	7.03		0.79
tangent/rural/T	130	2,192	5.93	*	0.67
tangent/rural/Y	176	1,880	9.36		1.06
tangent/urban/T	459	4,417	10.39		1.17
tangent/urban/Y	348	3,281	10.61	NS	1.20
Total	2,083	23,505	8.86		1.00

Rates for PDO accidents show a pattern similar to that of all police-reported accidents, discussed early in this section. Namely, within each trunkline alignment/area type pair, Y's have higher rates than T's, except in the case of curve/urban sites, where T's have the higher rate (Table 4-16). This is to be expected, as 72% of the accidents in the analysis file are property damage only. All four pairs of PDO rates are significantly different at the 5% level.

Table 4-16 - PDO Accident Rates by Intersection Type

Intersection Type	5-year Accident Count	5-year Traffic Vol. (Millions)	Accs. Per 100 Million Vehicles		Relative Risk
curve/rural/T	403	2,061	19.56	*	0.69
curve/rural/Y	846	3,255	25.99		0.92
curve/urban/T	1,290	3,959	32.58	*	1.15
curve/urban/Y	606	2,460	24.63		0.87
tangent/rural/T	388	2,192	17.70	*	0.62
tangent/rural/Y	508	1,880	27.03		0.95
tangent/urban/T	1,406	4,417	31.83	*	1.12
tangent/urban/Y	1,216	3,281	37.06		1.31
Total	6,663	23,505	28.35		1.00

Rates by Intersection Type and Accident Type

To gain more insight into the accident experience at the different classes of intersections, rates were calculated for particular accident types. The Accident Type variable in the analysis file has 25 levels of accidents. These were regrouped into four broad categories as shown in Table 4-17.

Table 4-17 - Categories of Accident Type

Run-off-road	Head-on	Rear-end	Other
overturn	head-on	rear-end	misc. single vehicle
fixed object	angle straight	rear-end left turn	train
	angle turn	rear-end right turn	parked vehicle
	head-on left turn	rear-end driveway	backing
	sideswipe/opp. dir.		parking
			pedestrian
			other object
			animal
			bicycle
			sideswipe/same dir.
			other driveway
			angle driveway
			dual left turn
			dual right turn

- Run-off-road. The run-off-road category contains just two accident types, overturn and fixed object, but accounts for 20% of the accident records in the analysis file. Both of these accident types usually involve loss of control of the vehicle and often occur on curves, at night, and at high speeds. Whether an accident results in an overturn as opposed to a collision with a fixed object is often determined by the roadside environment.

- Head-on. The head-on category contains five accident types and represents 23% of the accident records. This category is expected to be the most sensitive to the intersection configuration per se. Problems with sight-distance and right-of-way may contribute to the accidents in the head-on category.

- Rear-end. The rear-end category contains four types of rear-end accidents. This is the largest category, with 39% of the accident records. Rear-end accidents commonly occur in urban areas with high traffic density.

- Other. All remaining accident types are included under the fourth category, other accidents. Fourteen accident types comprising 18% of the accident records are in this category. Nearly two-thirds of the accidents in the other category are either animal accidents or driveway accidents.

Accident rates per 100 million vehicles are shown by intersection type and accident type in Table 4-18. Separate models were generated for run-off-road, head-on, and rear-end accidents, and differences at the 5% level for each Y versus T pair are indicated in the table. Comparing Y's with T's according to trunkline alignment and area type shows Y's to have higher rates of head-on accidents than T's except for curve/urban sites. The absolute highest rates of head-ons occur at curve/urban/T intersections and tangent/urban/Y intersections. Somewhat unexpectedly, Y's also have higher rates of run-off-road accidents than comparable T's, again with the exception of curve/urban sites. One explanation is that drivers are often forced to brake or decelerate to make a turn at T-intersections, while they may think they can turn at a Y-intersection without much reduction in speed. Attempting to proceed from the major to minor road at a Y-intersection without proper deceleration may lead to loss of control and a subsequent run-off-road accident. Curve/rural/Y sites have the highest rate of run-off-road accidents. As expected, urban sites have higher rates of rear-end accidents than rural sites, and there is no clear pattern in terms of T and Y differences.

Table 4-18 - Accident Rates per 100 Million Vehicles by Intersection Type and Accident Type

Intersection	Accident Type				
Type	Run-off-road	Head-on	Rear-end	Other	Total
curve/rural/T	7.28	5.29	7.04	7.23	26.84
curve/rural/Y	13.03*	7.71*	8.08NS	8.63	37.45
curve/urban/T	7.25	12.05	19.35	6.82	45.47
curve/urban/Y	7.19NS	8.78*	13.29*	5.08	34.34
tangent/rural/T	6.52	4.52	7.66	6.89	25.59
tangent/rural/Y	10.21*	8.03*	13.89*	7.02	39.16
tangent/urban/T	4.35	8.99	22.16	8.49	43.99
tangent/urban/Y	8.14*	12.95*	22.28NS	6.03	49.40
Total	7.79	9.04	15.49	7.15	39.47

In the case of fatal and A-injury accidents, Y's have higher rates than their T counterparts for both run-off-road and head-on accidents in every category of trunkline alignment and area type (Table 4-19). However, differences are only significant at the 5% level for the run-off-road rates. (Double asterisks indicate significance at the 10% level.) Curve/rural/Y sites have the highest run-off-road rate, and curve/Y's, both urban and rural, have the highest head-on rates. For most of the categories of intersection type, rear-end rates are lower than run-off-road and head-on rates, reflecting the typically lower severity of rear-end collisions.

Table 4-19 - Fatal and A-Injury Accident Rates per 100 Million Vehicles by Intersection Type and Accident Type

Intersection	Accident Type				
Type	Run-off-road	Head-on	Rear-end	Other	Total
curve/rural/T	0.49	0.58	0.19	0.00	1.26
curve/rural/Y	1.38*	1.20**	0.61NS	0.15	3.35
curve/urban/T	0.40	1.09	0.58	0.48	2.55
curve/urban/Y	0.85*	1.38NS	0.28**	0.16	2.68
tangent/rural/T	0.50	0.64	0.46	0.36	1.96
tangent/rural/Y	1.06*	1.06NS	0.27NS	0.37	2.77
tangent/urban/T	0.20	0.59	0.43	0.54	1.77
tangent/urban/Y	0.40*	0.67NS	0.30NS	0.37	1.74
Total	0.62	0.89	0.42	0.34	2.26

The rates for B- and C-injury accidents in Table 4-20 follow the overall pattern of Y's having higher rates of run-off-road and head-on accidents than T's except for curve/urban intersections. Again the T versus Y differences are strongest for run-off-road accidents. Curve/rural/Y sites have the highest run-off-road rate, and curve/urban/T and tangent/urban/Y sites have the highest rates of head-on collisions. The highest rate of rear-end accidents occurs at tangent/urban/T sites.

Table 4-20 - B- and C-Injury Accident Rates per 100 Million Vehicles by Intersection Type and Accident Type

Intersection Type	Accident Type: Run-off-road	Head-on	Rear-end	Other	Total
curve/rural/T	2.09	1.36	2.18	0.39	6.02
curve/rural/Y	3.59*	2.00^{NS}	2.00^{NS}	0.52	8.11
curve/urban/T	1.64	2.93	4.45	1.31	10.33
curve/urban/Y	1.30^{NS}	2.03*	2.93*	0.77	7.03
tangent/rural/T	1.69	1.19	2.55	0.50	5.93
tangent/rural/Y	2.55*	2.45*	3.56**	0.80	9.36
tangent/urban/T	0.82	2.22	5.57	1.79	10.39
tangent/urban/Y	1.80*	2.96**	4.72^{NS}	1.13	10.61
Total	1.86	2.24	3.75	1.01	8.86

The pattern of rates for PDO accidents is also quite similar to the overall pattern, as expected. In general, curve/urban/T sites have higher rates of run-off-road and head-on accidents than curve/urban/Y sites, but otherwise Y's have higher rates of these kinds of accidents than T's (Table 4-21). Most of the differences are significant at the 5% level. Again the highest rate of run-off-road accidents occurs at curve/rural/Y sites, and tangent/urban/Y's and curve/urban/T's have the highest head-on rates. Urban intersections have elevated rates of rear-end collisions.

Table 4-21 - PDO Accident Rates per 100 Million Vehicles by Intersection Type and Accident Type

Intersection Type	Accident Type: Run-off-road	Head-on	Rear-end	Other	Total
curve/rural/T	4.71	3.35	4.66	6.84	19.56
curve/rural/Y	8.05*	4.52^{NS}	5.47**	7.96	25.99
curve/urban/T	5.20	8.03	14.32	5.03	32.58
curve/urban/Y	5.04^{NS}	5.36*	10.08*	4.15	24.63
tangent/rural/T	4.33	2.69	4.65	6.02	17.70
tangent/rural/Y	6.60*	4.52*	10.06*	5.85	27.03
tangent/urban/T	3.33	6.18	16.16	6.16	31.83
tangent/urban/Y	5.94*	9.33*	17.25^{NS}	4.54	37.06
Total	5.32	5.91	11.32	5.80	28.35

Intersection Type Rates Controlling for Volume

Rates per 100 million vehicles were also calculated for each of the eight intersection types within traffic volume categories. Since the relationship between accident frequency and traffic volume is not necessarily linear, comparing rates among intersection types without controlling for volume could be misleading. In the next series of tables, average daily traffic was split into four categories: 0-2,000, 2,001-5,000, 5,001-10,000, and over 10,000 vehicles per day.

All of the data in Table 4-22 were included in one model. Among rural sites, both curve and tangent, Y-intersections have consistently higher accident rates than T-intersections in each of the volume categories. All eight pairs of differences are significant at the 5% level. In contrast, T-intersections generally have higher rates than Y-intersections among curve/urban sites, but only in the highest volume category is the difference significant. Among tangent/urban sites, Y's have a higher rate than T's in the highest volume category, and the differences in rates in the other volume categories are not significant.

Table 4-22 - Accident Rates per 100 Million Vehicles by Intersection Type and Volume Level

Intersection Type	Average Daily Traffic 0-2,000	2,001-5,000	5,001-10,000	10,001+	Total
curve/rural/T	30.56	26.47	27.42	25.21	26.84
curve/rural/Y	54.72 *	35.77 *	36.43 *	36.05 *	37.45
curve/urban/T	34.18	36.68	34.96	52.35	45.47
curve/urban/Y	7.15^{NS}	32.02^{NS}	35.47^{NS}	34.35 *	34.34
tangent/rural/T	24.76	25.43	27.04	23.78	25.59
tangent/rural/Y	33.57 *	33.40 *	43.40 *	42.76 *	39.16
tangent/urban/T	47.12	37.05	41.53	45.70	43.99
tangent/urban/Y	58.29^{NS}	29.36^{NS}	38.96^{NS}	57.03 *	49.40
Total	39.04	32.05	36.03	45.26	39.47

By severity

Rates were calculated in a similar manner for each of the three levels of accident severity. Rates for fatal and A-injury accidents are shown in Table 4-23. All of the rates in the lowest volume category are based on small samples. With this in mind, the overall pattern of Y's having consistently higher rates than T's among rural intersections continues to hold among this accident subset. Among curve/urban sites, T's have higher rates in the lower volume categories, and the rates are about the same between T's and Y's at higher-volume sites. Tangent/urban sites again show a mixed pattern, and among higher-volume sites rates are about the same between T's and Y's.

Table 4-23 - Fatal and A-Injury Accident Rates per 100 Million Vehicles by Intersection Type and Volume Level

Intersection Type	Average Daily Traffic 0-2,000	2,001-5,000	5,001-10,000	10,001+	Total
curve/rural/T	1.42	0.91	2.17	0.24	1.26
curve/rural/Y	6.99	2.75	3.00	4.13	3.35
curve/urban/T	2.63	2.70	2.22	2.68	2.55
curve/urban/Y	0.00	1.94	2.51	2.90	2.68
tangent/rural/T	0.00	1.55	2.18	2.54	1.96
tangent/rural/Y	2.51	2.60	2.89	2.92	2.77
tangent/urban/T	0.00	2.30	1.35	1.90	1.77
tangent/urban/Y	10.60	0.44	1.54	1.90	1.74
Total	3.42	2.06	2.19	2.32	2.26

B- and C-injury accident rates are shown in Table 4-24, and again many of the rates in the 0-2,000 volume category may be affected by small samples. Once again Y's have consistently higher rates than T's across volume categories for all rural sites. Curve/urban T's have higher rates than curve/urban Y's in every volume category. Among tangent/urban sites, Y's have a higher rate than T's in the lowest volume category, but at higher-volume sites the rates between Y's and T's are generally comparable.

Table 4-24 - B- and C-Injury Accident Rates per 100 Million Vehicles by Intersection Type and Volume Level

Intersection Type	Average Daily Traffic 0-2,000	2,001-5,000	5,001-10,000	10,001+	Total
curve/rural/T	4.97	4.41	7.60	6.55	6.02
curve/rural/Y	9.05	7.62	8.12	9.12	8.11
curve/urban/T	13.15	8.33	7.90	11.83	10.33
curve/urban/Y	0.00	4.85	5.29	8.28	7.03
tangent/rural/T	1.90	6.18	6.18	5.99	5.93
tangent/rural/Y	7.02	7.44	9.78	12.75	9.36
tangent/urban/T	6.73	6.23	8.41	11.68	10.39
tangent/urban/Y	15.90	6.57	7.91	12.42	10.61
Total	6.97	6.65	7.72	10.80	8.86

The PDO rates in Table 4-25 again show Y's to have higher rates than T's among rural intersections. Curve/urban T's have higher rates than curve/urban Y's in both the lowest and highest volume categories, but the Y and T rates are comparable in the intermediate categories. Among tangent/urban sites, T's have higher rates in every volume category except the highest, where Y's have the higher rate.

Table 4-25 - PDO Accident Rates per 100 Million Vehicles by Intersection Type and Volume Level

Intersection	Average Daily Traffic				
Type	0-2,000	2,001-5,000	5,001-10,000	10,001+	Total
curve/rural/T	24.16	21.15	17.65	18.42	19.56
curve/rural/Y	38.67	25.40	25.32	22.80	25.99
curve/urban/T	18.41	25.65	24.85	37.84	32.58
curve/urban/Y	7.15	25.23	27.66	23.17	24.63
tangent/rural/T	22.85	17.70	18.67	15.25	17.70
tangent/rural/Y	24.05	23.36	30.73	27.09	27.03
tangent/urban/T	40.39	28.53	31.78	32.11	31.83
tangent/urban/Y	31.80	22.35	29.51	42.71	37.06
Total	28.65	23.34	26.12	32.13	28.35

By accident type

Accident rates were also calculated controlling for volume for each of the four accident types defined earlier. Table 4-26 shows the rates for run-off-road accidents. All police-reported, run-off-road accidents are included. In general, Y's have higher run-off-road rates than comparable T's for almost every combination of intersection type and volume level. The exceptions are urban sites in the lowest volume category, where T's have higher rates (but sample sizes are small), and a few of the higher-volume sites, where the rates are about the same between T's and Y's.

Table 4-26 - Run-Off-Road Accident Rates per 100 Million Vehicles by Intersection Type and Volume Level

Intersection	Average Daily Traffic				
Type	0-2,000	2,001-5,000	5,001-10,000	10,001+	Total
curve/rural/T	12.79	7.01	7.87	4.85	7.28
curve/rural/Y	24.27	13.62	12.53	6.52	13.03
curve/urban/T	10.52	7.20	7.54	7.07	7.25
curve/urban/Y	0.00	12.61	7.15	6.53	7.19
tangent/rural/T	6.66	7.02	6.79	5.45	6.52
tangent/rural/Y	17.54	10.90	10.06	5.58	10.21
tangent/urban/T	23.56	7.21	3.45	4.22	4.35
tangent/urban/Y	5.30	10.52	7.23	8.36	8.14
Total	16.60	9.95	7.76	6.20	7.79

The head-on accident rates in Table 4-27 show Y's to have higher rates than comparable T's in all the volume categories for rural intersections. Among curve/urban sites, T's generally have higher head-on rates than Y's. For tangent/urban sites, T's have higher rates at the lower-volume sites, and Y's have higher rates at the higher-volume sites.

Table 4-27 - Head-On Accident Rates per 100 Million Vehicles by Intersection Type and Volume Level

Intersection	Average Daily Traffic				
Type	0-2,000	2,001-5,000	5,001-10,000	10,001+	Total
curve/rural/T	2.84	4.41	7.74	3.39	5.29
curve/rural/Y	6.17	6.91	9.35	6.95	7.71
curve/urban/T	5.26	8.78	8.25	14.60	12.05
curve/urban/Y	0.00	4.85	7.68	9.97	8.78
tangent/rural/T	0.95	2.25	5.94	5.99	4.52
tangent/rural/Y	2.51	6.75	10.61	7.97	8.03
tangent/urban/T	3.37	9.51	8.15	9.33	8.99
tangent/urban/Y	0.00	6.14	11.48	14.62	12.95
Total	3.55	5.99	8.71	11.04	9.04

Rear-end accident rates are shown in Table 4-28. In general it seems that rates between Y and T sites show less difference for rear-end collisions than for other types of accidents. At rural sites, Y's continue to have generally higher rates than T's, although only among the higher-volume tangent/rural intersections are the Y rates overwhelmingly higher than the T rates. T's have higher rear-end accident rates than Y's in most of the volume categories of curve/urban intersections. Y's and T's variously have higher rates among tangent/urban intersections, but the rates between them are fairly close in each of the volume categories.

Table 4-28 - Rear-End Accident Rates per 100 Million Vehicles by Intersection Type and Volume Level

Intersection	Average Daily Traffic				
Type	0-2,000	2,001-5,000	5,001-10,000	10,001+	Total
curve/rural/T	2.13	5.32	6.65	12.61	7.04
curve/rural/Y	2.88	6.07	8.12	16.94	8.08
curve/urban/T	10.52	12.15	13.13	23.83	19.35
curve/urban/Y	0.00	6.31	13.10	14.48	13.29
tangent/rural/T	1.90	6.74	7.64	9.99	7.66
tangent/rural/Y	4.01	6.58	16.81	24.70	13.89
tangent/urban/T	16.83	9.84	18.83	24.89	22.16
tangent/urban/Y	21.20	8.33	13.89	28.24	22.28
Total	4.18	7.06	12.50	22.21	15.49

For the sake of completion, rates are shown for the miscellaneous "other" category of accidents in Table 4-29.

Table 4-29 - "Other" Accident Rates per 100 Million Vehicles by Intersection Type and Volume Level

Intersection	Average Daily Traffic				
Type	0-2,000	2,001-5,000	5,001-10,000	10,001+	Total
curve/rural/T	12.79	9.73	5.16	4.36	7.23
curve/rural/Y	21.39	9.17	6.44	5.65	8.63
curve/urban/T	7.89	8.55	6.03	6.85	6.82
curve/urban/Y	7.15	8.25	7.54	3.37	5.08
tangent/rural/T	15.23	9.41	6.67	2.36	6.89
tangent/rural/Y	9.52	9.17	5.92	4.52	7.02
tangent/urban/T	3.37	10.49	11.10	7.26	8.49
tangent/urban/Y	31.80	4.38	6.37	5.81	6.03
Total	14.70	9.05	7.07	5.81	7.15

Discussion of Y versus T Accident Rates

One objective of this study was to compare the accident experience at Y-intersections with the accident experience at T-intersections. To help meet this objective, accident rates per 100 million vehicles were calculated for eight categories of intersection type. In this way, accident rates could be compared between Y and T sites that were similar in terms of trunkline horizontal alignment and area type. The major findings of this analysis are summarized below.

- Y's had higher accident rates than T's for curve/rural, tangent/rural, and tangent/urban intersections. T's had higher rates among curve/urban intersections.

- This overall pattern tended to hold when rates were compared controlling (separately) for MDOT district, degree of curvature, rural/urban development, and speed limit. Exceptions were found among tangent/urban intersections, which showed mixed results for various levels of district and of speed limit.

- In general, higher accident rates were observed in the more populous MDOT districts, at sites with higher degrees of curvature, and in more urbanized areas. There was some evidence for a decline in rates with an increase in posted speed limit. This would be consistent with higher rates in urbanized, heavily populated areas where speed limits tend to be lower.

- Accidents at curve sites tended to be more severe at Y-intersections than T-intersections. At tangent/rural sites, the severity distributions for Y's and T's were about the same. At tangent/urban sites, accidents were slightly more severe at T-intersections, although the difference was not significant.

- At rural intersections, Y's had more accidents per site than T's, both overall and in each severity category. At curve/urban intersections T's had more low-severity accidents per site than Y's. At tangent/urban sites, Y's and T's had comparable numbers of accidents per site, both overall and at each severity level.

Y-Intersections

- At rural intersections, Y's consistently had higher accident rates than T's at all three levels of accident severity. Rates were more variable according to severity for urban sites. Among curve/urban sites, Y's and T's had comparable rates of the most severe accidents, while T's had higher rates of less severe and property damage accidents. Among tangent/urban sites, Y's and T's had similar rates for fatal and injury accidents, while Y's had higher rates of property damage accidents.

- Y's had higher rates than T's of both run-off-road and head-on type accidents for all categories of intersection type except curve/urban sites. This held for all levels of severity of run-off-road and head-on accidents, although some of the head-on rate differences were not significant. Y's also had a higher rate of these two accident types at curve/urban intersections, for fatal and A-injury accidents only.

- When rates were calculated controlling for volume, the overall patterns of Y's having higher rates than T's among rural sites was found to hold. This remained true for all levels of severity.

- Among curve/urban sites, T-intersections had a consistently higher rate than Y's in every volume category, although the difference was only significant in the highest volume category. Results were more variable when different severity levels were considered while controlling for volume.

- Among tangent/urban sites, Y-intersections had a higher rate than T's in both the lowest and highest volume categories. T's had higher rates in the mid-volume categories. Mixed results were observed at different levels of severity.

- In general, the overall pattern of Y's having higher rates than T's except at curve/urban sites was found to hold for both run-off-road and head-on accidents, controlling for volume, although a few exceptions were observed.

Thus, the most consistent evidence for Y-intersections having higher accident rates than T-intersections was observed among rural sites. This pattern generally held no matter which control variables were considered. Curve/urban sites generally exhibited the opposite pattern, that is, T-intersections usually had a higher rate than Y's. In general, Y-intersections were found to have a higher rate than T's among tangent/urban sites, but this pattern often did not hold when rates were compared across levels of certain control variables.

It may be noteworthy that curve/urban/Y intersections are the least common of the eight types of three-legged intersections on the Michigan State Trunkline. Prior to sampling, there were about 3.5 times as many curve/urban/T sites as curve/urban/Y sites. Even though all curve/urban/Y intersections were included in the sample, they number only 152 sites. It is conceivable that some curve/urban/Y sites with high accident frequencies had previously been reconstructed into T-intersections. Reconstruction of these sites would result in a higher average level of safety for the remaining Y sites. While countermeasures may also be applied to curve/urban/T intersections with frequent accidents, they generally will remain T-intersections, and the safety benefits of the countermeasures will probably be less dramatic than transforming a Y-intersection into a T.

This could be a possible explanation for the higher average accident rate at curve/urban/T intersections compared with curve/urban/Y intersections. Curve/urban/T's may exhibit a broader range of accident experiences than curve/urban/Y's, where the sites that experienced frequent accidents may no longer be Y's. It could also be a factor in the variability in the rates between tangent/urban T's and Y's, again because T-intersections of this type are much more common than Y's.

4.3 STATISTICAL ANALYSIS OF CATEGORIES OF Y-INTERSECTIONS

In addition to the comparison of the accident experience of Y- versus T-intersections, a second objective of this project was the assessment of the safety of a special type of Y-intersection. Referred to here as a "special right" Y-intersection, the configuration is one where the main road curves to the right and the minor road continues on a tangent from the main road. A driver proceeding from the major to the minor road is exposed to the threat of oncoming traffic. While this is technically a turning maneuver, in reality the driver is continuing on a straight path, and might not realize that he/she must yield to on-coming traffic.

In this section, intersections are classified into nine different categories according to site configuration (Fig. 4-9). Category 1/special is the special right intersection just described. Category 1/not special is the same, except that the minor road is not on a tangent to the major road. The minor road is still on the outside of the curve. While a driver proceeding from the main road to the minor road at this kind of intersection also must spend a certain amount of time in the opposing lane, it should be more obvious that the driver is making a turn and therefore should yield.

A category 2/special, or special left, intersection is one where the main road curves to the left and the minor road continues on a tangent. Here a driver turning onto the minor road faces no threat of opposing traffic. In category 2/not special intersections, the minor road is again on the outside of a left-curving main road, but not on a tangent.

Category 3 and 4 sites feature the minor road on the inside curve of the major road. In the category 3 case, the main road curves to the left, and the driver must cross the opposing lane to turn onto the minor road. Category 4 curves are the opposite configuration. The main road curves to the right, and the driver need not cross the opposing lane to make the turn.

Category 5 and 6 sites are tangent Y-intersections. The main road does not curve at the intersection but proceeds straight through. At a category 5 site, a driver must make a left turn to travel onto the minor road, thus crossing the opposing lane. In contrast, the similar maneuver at a category 6 site is a right turn with no threat of oncoming traffic.

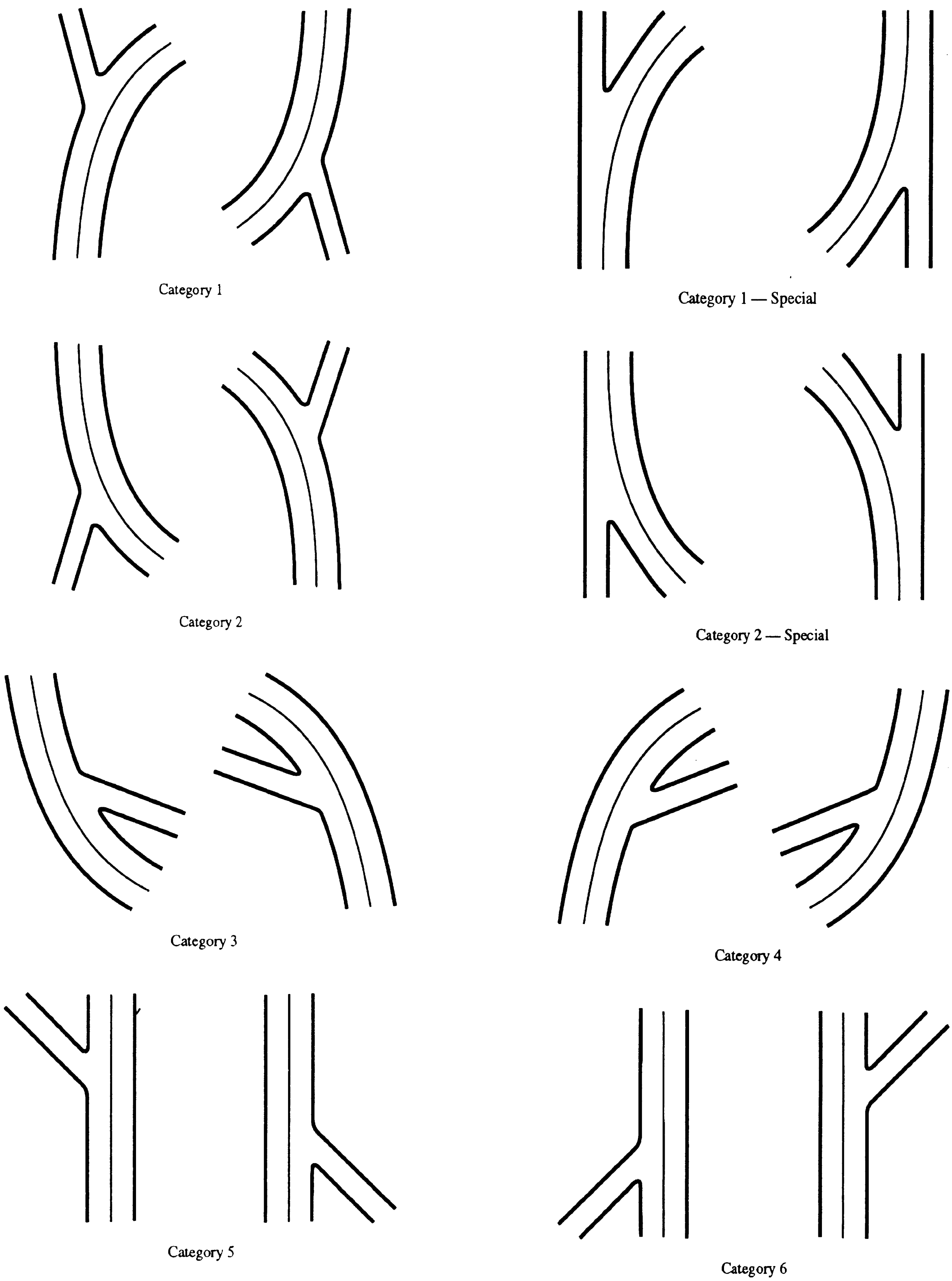


Figure 4-9 - Categories of Y-Intersections for Analysis

The ninth category of intersection configuration included in this section is simply all T-intersections. Most comparisons in this section will be among the different types of Y-intersections, with particular emphasis on the special right configuration. T-intersections are included in the tables as a point of reference.

Table 4-30 shows the accident rates and relative risk measures for each of the categories of Y-intersections. Interestingly, among all of the curved Y sites (categories 1 through 4), the special lefts have the highest accident rate. This is somewhat surprising because proceeding onto the minor road does not require yielding to oncoming traffic at this type of intersection. Special right intersections, where this could be expected to be a problem, have a lower than average accident rate. The highest rate of all is found at category 5 sites, tangent Y's where turning onto the minor road requires crossing the opposing lane. This rate is just slightly higher than the special left rate. The lowest rate is found among category 4 sites, Y's with the minor road on the inside of a right curve.

Table 4-30 - Accident Rates per 100 Million Vehicles by Y-Category

Y-Category	5-year Accident Count	5-year Traffic Vol. (Millions)	Accs. Per 100 Million Vehicles		Relative Risk
1/special	270	782	34.52		0.87
1/not special	479	1,321	36.26	NS	0.92
2/special	350	715	48.96	*	1.24
2/not special	593	1,526	38.85	NS	0.98
3	166	548	30.28	NS	0.77
4	206	823	25.04	*	0.63
5	1,197	2,302	52.01	*	1.32
6	1,160	2,859	40.57	*	1.03
T	4,857	12,629	38.46	**	0.97
Total	9,278	23,505	39.47	*	1.00

T-tests were conducted using the observed rates and the estimated standard errors for the data in Table 4-30. The rate for the special right type of intersection was compared with each of the other rates in the table. An asterisk indicates significance at the 5% level, a double asterisk denotes significance at the 10% level, and "NS" means there is no significant difference in the rates. Special right intersections have a rate significantly lower than special left, category 5, category 6, and all intersections at the 5% level and lower than T-intersections at the 10% level. Only category 4 sites have a rate significantly lower than special right intersections.

Rates by Area Type

Rates were calculated for each of the Y categories according to area type. The sites were split into rural and urban intersections using the same variable that defined intersection type. Among rural intersections, T's have a lower rate than any of the categories of Y-intersections (Table 4-31). Category 5 sites have the highest rate, and category 2 sites, both special and not special, also have high rates. Among urban sites, special left intersections have the highest rate, followed by categories 5 and 6 and T-intersections. The lowest rates are found at category 3 and 4 sites and at special right intersections.

Table 4-31 - Accident Rates per 100 Million Vehicles by Area Type and Y-Category

Area Type	Y-Category	5-year Accident Count	5-year Traffic Vol. (Millions)	Accs. Per 100 Million Vehicles		Relative Risk
rural	1/special	202	526	38.39		0.97
	1/not special	286	813	35.19	NS	0.89
	2/special	195	467	41.75	NS	1.06
	2/not special	313	776	40.33	NS	1.02
	3	98	297	33.03	NS	0.84
	4	125	376	33.25	NS	0.84
	5	398	815	48.85	*	1.24
	6	338	1,065	31.74	*	0.80
	T	1,114	4,253	26.19	*	0.66
	SUBTOTAL	3,069	9,387	32.69	*	0.83
urban	1/special	68	256	26.57		0.67
	1/not special	193	508	37.97	*	0.96
	2/special	155	248	62.54	*	1.58
	2/not special	280	750	37.32	*	0.95
	3	68	251	27.04	NS	0.69
	4	81	447	18.14	*	0.46
	5	799	1,487	53.74	*	1.36
	6	822	1,794	45.81	*	1.16
	T	3,743	8,376	44.69	*	1.13
	SUBTOTAL	6,209	14,117	43.98	*	1.11
TOTAL		9,278	23,505	39.47		1.00

In sum, the intersections of primary interest—special right sites—appear to be among the safest of all non-signalized three-legged intersections in urban areas. Their rate is about 40% lower than the aggregate urban rate and significantly lower than all but category 3 and 4 sites. (*T*-tests were again conducted by estimating standard errors without modeling.) Among rural sites, special right intersections have a rate that is about 17% higher than the aggregate, but there is no statistical difference between the special right rate and the rate for any of the other curved Y sites.

Rates by Accident Severity

Table 4-32 shows the severity distribution of accidents for each of the Y categories. The most striking thing about the table concerns the percentages of the most severe group of accidents—those resulting in fatal or A-injuries. Severe accidents account for 7% to nearly 10% of the accidents at the curved Y sites (categories 1 through 4), while only 4-5% of the accidents at tangent Y's and T's are severe. This is consistent with curved Y-intersections being more common in rural areas compared with tangent Y's and T's.

Table 4-32 - Accident Severity Distribution by Y-Category

Y-Category	Total K and A	Total B and C	Total PDO	Total Accidents	
	Five-Year Accident Counts				
1/special	22	68	180	270	
	8.15%	25.19%	66.67%	100.00%	
1/not special	46	110	323	479	NS
	9.60%	22.96%	67.43%	100.00%	
2/special	30	83	237	350	NS
	8.57%	23.71%	67.71%	100.00%	
2/not special	47	120	426	593	NS
	7.93%	20.24%	71.84%	100.00%	
3	15	29	122	166	NS
	9.04%	17.47%	73.49%	100.00%	
4	15	27	164	206	*
	7.28%	13.11%	79.61%	100.00%	
5	58	272	867	1,197	*
	4.85%	22.72%	72.43%	100.00%	
6	51	252	857	1,160	*
	4.40%	21.72%	73.88%	100.00%	
T	248	1,122	3,487	4,857	**
	5.11%	23.10%	71.79%	100.00%	
Total	532	2,083	6,663	9,278	NS
	5.73%	22.45%	71.82%	100.00%	

Lower severity injury accidents (those resulting in B- or C-injury) represent 25% of the accidents at special right intersections and between 20% and 24% at the other intersection categories, except categories 3 and 4 where they comprise just 17.5% and 13%, respectively. PDO accidents make up from 67-68% of the accidents at special right, not-special right, and special left intersections, and about 72-80% of the accidents at all of the other categories.

The severity distribution for special right intersections was compared with the distributions for each of the other intersection categories using a test of equal proportions. Accidents at special right intersections were found to be significantly more severe than accidents at category 4, 5, and 6 sites at the 5% level and T-intersections at the 10% level. No significant differences were observed for the special right severity distribution compared with not-special right, special left, not-special left, or all three-legged intersections.

Table 4-33 shows the number of accidents per site in each severity category and overall. The greatest number of fatal and A-injury accidents per site occurs at special left intersections. The least occurs at category 4 and 6 sites. Category 5 sites have the most B- and C-injury and PDO accidents per site. Special right intersections are on par with all three-legged intersections in terms of the number of severe accidents per site. Special right sites have fewer lower severity injury accidents and PDO accidents per site than the aggregate.

Table 4-33 - Average Number of Accidents per Site by Y-Category (over 5-Year Study Period)

Y-Category	Average K and A Accs./Site	Average B and C Accs./Site	Average PDO Accs./Site	Average No. of Accs./Site
1/special	0.25	0.77	2.05	3.07
1/not special	0.31	0.73	2.15	3.19
2/special	0.38	1.06	3.04	4.49
2/not special	0.29	0.75	2.65	3.68
3	0.28	0.55	2.30	3.13
4	0.21	0.38	2.28	2.86
5	0.30	1.41	4.49	6.20
6	0.20	1.00	3.41	4.62
T	0.24	1.10	3.42	4.76
Total	0.26	1.01	3.22	4.49

Table 4-34 shows the fatal and A-injury rates per 100 million vehicles for each intersection category. Special left intersections have the highest rate of severe accidents. The lowest rates are found at category 4 and 6 sites and at T-intersections. Special right intersections have a rate 24% higher than the aggregate.

Table 4-34 - Fatal and A-Injury Accident Rates by Y-Category

Y-Category	5-year Accident Count	5-year Traffic Vol. (Millions)	Accs. Per 100 Million Vehicles	Relative Risk
1/special	22	782	2.81	1.24
1/not special	46	1,321	3.48	1.54
2/special	30	715	4.20	1.85
2/not special	47	1,526	3.08	1.36
3	15	548	2.74	1.21
4	15	823	1.82	0.81
5	58	2,302	2.52	1.11
6	51	2,859	1.78	0.79
T	248	12,629	1.96	0.87
Total	532	23,505	2.26	1.00

The situation changes for rates of B- and C-injury accidents (Table 4-35). Special left intersections again have a high rate, but category 5 intersections have about the same rate. The rate at special right intersections is about the same as the overall rate. The lowest rates appear at category 3 and 4 intersections.

Table 4-35 - B- and C-Injury Accident Rates by Y-Category

Y-Category	5-year Accident Count	5-year Traffic Vol. (Millions)	Accs. Per 100 Million Vehicles	Relative Risk
1/special	68	782	8.69	0.98
1/not special	110	1,321	8.33	0.94
2/special	83	715	11.61	1.31
2/not special	120	1,526	7.86	0.89
3	29	548	5.29	0.60
4	27	823	3.28	0.37
5	272	2,302	11.82	1.33
6	252	2,859	8.81	0.99
T	1,122	12,629	8.88	1.00
Total	2,083	23,505	8.86	1.00

Category 5 sites and special left sites have the highest rates of property damage accidents among the categories considered (Table 4-36). The lowest rates are found at category 3 and 4 intersections and at category 1 sites, both special and not special. Special right intersections have a PDO rate about 19% lower than the aggregate rate.

Table 4-36 - PDO Accident Rates by Y-Category

Y-Category	5-year Accident Count	5-year Traffic Vol. (Millions)	Accs. Per 100 Million Vehicles	Relative Risk
1/special	180	782	23.01	0.81
1/not special	323	1,321	24.45	0.86
2/special	237	715	33.15	1.17
2/not special	426	1,526	27.91	0.98
3	122	548	22.26	0.79
4	164	823	19.94	0.70
5	867	2,302	37.67	1.33
6	857	2,859	29.97	1.06
T	3,487	12,629	27.61	0.97
Total	6,663	23,505	28.35	1.00

Rates by area type

Accident rates were also calculated for each severity category separately for rural and urban sites. Table 4-37 shows the resulting fatal and A-injury accident rates. In general, the rural sites have a higher rate of these severe accidents than the urban ones. Among rural sites, categories 3 and 5 have the highest rate of fatal and A-injury accidents. The special and not-special right and left intersections also have elevated rates, but perhaps more interesting is that they all have rates remarkably similar to each other. Among urban sites, special left intersections have the highest rate of severe accidents, with a rate 2.5 times that of all three-legged intersections. Special right intersections have a lower than average rate.

Table 4-37 - Fatal and A-Injury Accident Rates per 100 Million Vehicles by Area Type and Y-Category

	Y-Category	5-year Accident Count	5-year Traffic Vol. (Millions)	Accs. Per 100 Million Vehicles	Relative Risk
rural	1/special	17	526	3.23	1.43
	1/not special	29	813	3.57	1.58
	2/special	16	467	3.43	1.51
	2/not special	26	776	3.35	1.48
	3	12	297	4.04	1.79
	4	9	376	2.39	1.06
	5	33	815	4.05	1.79
	6	19	1,065	1.78	0.79
	T	69	4,253	1.62	0.72
	SUBTOTAL	230	9,387	2.45	1.08
urban	1/special	5	256	1.95	0.86
	1/not special	17	508	3.34	1.48
	2/special	14	248	5.65	2.50
	2/not special	21	750	2.80	1.24
	3	3	251	1.19	0.53
	4	6	447	1.34	0.59
	5	25	1,487	1.68	0.74
	6	32	1,794	1.78	0.79
	T	179	8,376	2.14	0.94
	SUBTOTAL	302	14,117	2.14	0.95
TOTAL		532	23,505	2.26	1.00

Table 4-38 shows the same breakdown of rates, this time for B- and C-injury accidents. Urban sites generally have higher rates than rural ones for this category of accidents. Among rural sites, elevated rates are found at category 5 intersections and at special right and special left sites. Special right intersections have a rate 49% higher than all rural sites. Among urban sites, special left intersections again have the highest rate, and category 5 intersections have a rate nearly as high.

Table 4-38 - B- and C-Injury Accident Rates per 100 Million Vehicles by Area Type and Y-Category

	Y-Category	5-year Accident Count	5-year Traffic Vol. (Millions)	Accs. Per 100 Million Vehicles	Relative Risk
rural	1/special	58	526	11.02	1.24
	1/not special	66	813	8.12	0.92
	2/special	52	467	11.13	1.26
	2/not special	60	776	7.73	0.87
	3	13	297	4.38	0.49
	4	15	376	3.99	0.45
	5	95	815	11.66	1.32
	6	81	1,065	7.61	0.86
	T	254	4,253	5.97	0.67
	SUBTOTAL	694	9,387	7.39	0.83
urban	1/special	10	256	3.91	0.44
	1/not special	44	508	8.66	0.98
	2/special	31	248	12.51	1.41
	2/not special	60	750	8.00	0.90
	3	16	251	6.36	0.72
	4	12	447	2.69	0.30
	5	177	1,487	11.90	1.34
	6	171	1,794	9.53	1.08
	T	868	8,376	10.36	1.17
	SUBTOTAL	1,389	14,117	9.84	1.11
TOTAL		2,083	23,505	8.86	1.00

Table 4-39 shows the similar breakdown of rates for property damage accidents. Category 5 and not-special left intersections have the highest rural rates, and category 5 and special left sites have the highest urban rates. Special right intersections have a rate about on par with other rural sites and about 35% lower than other urban sites.

Table 4-39 - PDO Accident Rates per 100 Million Vehicles by Area Type and Y-Category

	Y-Category	5-year Accident Count	5-year Traffic Vol. (Millions)	Accs. Per 100 Million Vehicles	Relative Risk
rural	1/special	127	526	24.14	0.85
	1/not special	191	813	23.50	0.83
	2/special	127	467	27.19	0.96
	2/not special	227	776	29.25	1.03
	3	73	297	24.60	0.87
	4	101	376	26.86	0.95
	5	270	815	33.14	1.17
	6	238	1,065	22.35	0.79
	T	791	4,253	18.60	0.66
	SUBTOTAL	2,145	9,387	22.85	0.81

urban	1/special	53	256	20.71	0.73
	1/not special	132	508	25.97	0.92
	2/special	110	248	44.38	1.57
	2/not special	199	750	26.52	0.94
	3	49	251	19.48	0.69
	4	63	447	14.11	0.50
	5	597	1,487	40.15	1.42
	6	619	1,794	34.50	1.22
	T	2,696	8,376	32.19	1.14
	SUBTOTAL	4,518	14,117	32.00	1.13
TOTAL		6,663	23,505	28.35	1.00

It is possible to summarize the accident experience at special right intersections in rural and urban areas. Rural special right intersections have higher than average rates of fatal and injury accidents than other rural three-legged intersections. Their rate of fatal and A-injury accidents is 32% higher and their rate of B- and C-injury accidents is 49% higher than the other rural intersections analyzed. In contrast, rural special right intersections have about the same rate of PDO accidents as other rural sites. Furthermore, urban special right intersections have lower accident rates than other urban three-legged intersections at all three levels of accident severity.

Rates by Accident Type

Rates were calculated by Y-category for each of the four broad classes of accident type defined earlier. The highest rate of run-off-road accidents is found at special left intersections (Table 4-40). Their rate is 2.4 times the aggregate. Special right, not-special right, and category 5 intersections also have elevated rates of run-off-road accidents. The head-on category is somewhat surprising because the highest rates are found at category 6 sites and at special left and not-special left intersections. One might expect category 5 and special and not-special right sites to have higher head-on rates, because of the potential danger of oncoming traffic when turning onto the minor road. The highest rate of rear-end accidents takes place at the tangent Y intersections and at T-intersections. This is consistent with their more urban character.

T-tests were conducted between special right intersection rates and rates for the other Y-intersections within each accident category. Special right intersections have significantly higher run-off-road accident rates than several of the other Y categories. However, special right intersections do not have a significantly higher rate of head-on collisions than any of the other Y sites, and their rate is significantly lower than four of the Y categories. For rear-end accidents, special right intersections have a significantly higher rate than category 4 sites, a significantly lower rate than tangent Y's, and rates comparable to all of the other Y categories.

Table 4-40 - Accident Rates by Y-Category and Accident Type

Y-Category	Run-off-road		Head-on		Rear-end		Other	Total
	Accident Type							
1/special	11.89		7.03		9.85		5.75	34.52
1/not special	10.52	NS	6.81	NS	12.11	NS	6.81	36.26
2/special	19.02	*	11.61	*	9.79	NS	8.53	48.96
2/not special	8.91	*	10.88	*	11.27	NS	7.80	38.85
3	7.84	*	5.47	NS	9.85	NS	7.11	30.28
4	6.57	*	5.23	NS	6.93	*	6.32	25.04
5	11.34	NS	9.56	*	24.11	*	7.00	52.01
6	6.93	*	12.45	*	15.28	*	5.91	40.57
T	6.11		8.57		16.30		7.48	38.46
Total	7.79		9.04		15.49		7.15	39.47

Rates by area type

The same rates were calculated after first splitting the sites into rural and urban categories. Table 4-41 shows the rates in rural areas. Special left, special right, and category 5 sites have the highest rate of run-off-road accidents. Not-special left intersections have the highest head-on rate, and category 5 and 6 sites have the highest rate of rear-end collisions. For this table, run-off-road, head-on, and rear-end data were each modeled separately to produce estimated rates and standard errors to use in t-tests. Note that the head-on rate in rural areas is not significantly higher at special right intersections than it is at any of the other categories of Y-intersections.

Table 4-41 - Accident Rates per 100 Million Vehicles by Y-Category and Accident Type at Rural Sites Only

Y-Category	Run-off-road		Head-on		Rear-end		Other	Total
	Accident Type							
1/special	14.63		7.41		9.12		7.22	38.39
1/not special	11.44	*	5.91	NS	9.60	NS	8.24	35.19
2/special	19.27	NS	8.14	NS	5.78	*	8.56	41.75
2/not special	11.73	*	10.57	**	7.99	NS	10.05	40.33
3	11.80	NS	5.39	NS	7.75	NS	8.09	33.03
4	10.11	*	7.45	NS	6.65	*	9.04	33.25
5	14.61	NS	8.96	NS	17.55	*	7.73	48.85
6	6.85	*	7.32	NS	11.08	NS	6.48	31.74
T	6.89		4.89		7.36		7.05	26.19
Total	9.68		6.50		8.92		7.60	32.69

In urban areas, special left intersections have the highest rate of both run-off-road and head-on accidents (Table 4-42). Category 6 intersections also have a high head-on rate. The highest rate of rear-end accidents is found at category 5 sites and at T-intersections. Rates in Table 4-42 were modeled in the same way as the rates in Table 4-41. The head-on accident rate for special right intersections is significantly lower than the head-on rate for special left, not-special left, and category 6 intersections and similar to the head-on rate for the other Y categories.

Table 4-42 - Accident Rates per 100 Million Vehicles by Y-Category and Accident Type at Urban Sites Only

Y-Category	Accident Type: Run-off-road	Head-on	Rear-end	Other	Total
1/special	6.25	6.25	11.33	2.74	26.57
1/not special	9.05 NS	8.26 NS	16.13 NS	4.52	37.97
2/special	18.56 *	18.16 *	17.35 NS	8.47	62.54
2/not special	6.00 NS	11.20 *	14.66 NS	5.46	37.32
3	3.18 *	5.57 NS	12.33 NS	5.96	27.04
4	3.58 *	3.36 **	7.17 *	4.03	18.14
5	9.55 NS	9.89 NS	27.71 *	6.59	53.74
6	6.97 NS	15.49 *	17.78 **	5.57	45.81
T	5.72	10.43	20.83	7.70	44.69
Total	6.54	10.73	19.85	6.86	43.98

Rates by severity

Rates were also calculated according to accident type for each level of accident severity. Rates for the most severe accidents are shown in Table 4-43. Special left intersections again have the highest rate of run-off-road accidents. Their rate of severe run-off-road accidents is 3.6 times the overall rate. The highest rate of severe head-on accidents is found at special and not-special left intersections. Not-special right intersections have the highest rate of severe rear-end accidents.

Table 4-43 - Fatal and A-Injury Accident Rates per 100 Million Vehicles by Y-Category and Accident Type

Y-Category	Accident Type: Run-off-road	Head-on	Rear-end	Other	Total
1/special	1.02	1.02	0.51	0.26	2.81
1/not special	1.29	1.44	0.68	0.08	3.48
2/special	2.24	1.68	0.14	0.14	4.20
2/not special	0.79	1.64	0.39	0.26	3.08
3	1.28	0.91	0.55	0.00	2.74
4	0.73	0.49	0.49	0.12	1.82
5	0.91	1.17	0.22	0.22	2.52
6	0.42	0.52	0.35	0.49	1.78
T	0.36	0.75	0.44	0.40	1.96
Total	0.62	0.89	0.42	0.34	2.26

The rates for B- and C-injury accidents in Table 4-44 show special left sites to have the highest run-off-road rate, followed by special right intersections. Category 6 intersections have the highest head-on accident rate, followed by special and not-special left intersections. The highest rate of rear-end accidents is found at category 5, T, and category 6 intersections.

Table 4-44 - B- and C-Injury Accident Rates per 100 Million Vehicles by Y-Category and Accident Type

Y-Category	Run-off-road	Head-on	Rear-end	Other	Total
	Accident Type				
1/special	3.58	2.30	2.30	0.51	8.69
1/not special	2.65	1.89	3.03	0.76	8.33
2/special	5.74	2.80	2.52	0.56	11.61
2/not special	2.10	2.75	2.49	0.52	7.86
3	0.91	0.91	2.74	0.73	5.29
4	0.97	0.61	0.97	0.73	3.28
5	2.69	2.48	5.47	1.17	11.82
6	1.57	3.01	3.36	0.87	8.81
T	1.43	2.12	4.14	1.19	8.88
Total	1.86	2.24	3.75	1.01	8.86

Rates for property damage accidents are shown in Table 4-45. Special left intersections have the highest run-off-road rate. Category 6 intersections have the highest rate of head-on accidents, followed by special left sites. Category 5 intersections have the highest rear-end collision rate, and category 6 and T-intersections also have elevated rates.

Table 4-45 - PDO Accident Rates per 100 Million Vehicles by Y-Category and Accident Type

Y-Category	Run-off-road	Head-on	Rear-end	Other	Total
	Accident Type				
1/special	7.29	3.71	7.03	4.99	23.01
1/not special	6.59	3.48	8.40	5.98	24.45
2/special	11.05	7.13	7.13	7.83	33.15
2/not special	6.03	6.49	8.39	7.01	27.91
3	5.66	3.65	6.57	6.38	22.26
4	4.86	4.13	5.47	5.47	19.94
5	7.73	5.91	18.42	5.60	37.67
6	4.93	8.92	11.58	4.55	29.97
T	4.32	5.69	11.71	5.89	27.61
Total	5.32	5.91	11.32	5.80	28.35

One reason for examining accident rates for different types of accidents was to see whether special right intersections have a higher rate of head-on type accidents than other three-legged intersections. It was found that special right sites have a 22% *lower* rate of head-on collisions than the aggregate head-on rate. However, special right intersections have a 15% higher rate of the most severe head-on accidents than three-legged intersections in general and a 14% higher rate of head-ons in rural areas.

Special right intersections were found to have a run-off-road rate 53% higher than the aggregate. This is entirely driven by the rural sites because, among urban sites, special right intersections have a run-off-road rate slightly lower than the aggregate. The run-off-road rate at special right intersections is especially high for fatal and injury accidents.

As expected, rear-end collisions are not a problem at special right intersections. Overall, the rear-end accident rate is 36% lower at special right sites compared with all three-legged sites. However, among fatal and A-injury accidents, special right intersections have a rear-end collision rate 21% higher than the aggregate.

Rates Controlling for Volume

Rates per 100 million vehicles were also calculated for each Y-category controlling for traffic volume. The same four levels of volume used previously are examined here. Interestingly, at the lowest traffic volume level, special right intersections have an accident rate 1.8 times the overall rate for that volume category (Table 4-46). This is second only to category 3 intersections. In the 2,001-5,000 category, special right intersections have a rate 22% higher than the overall rate for that category. However, in each of the two lower volume categories, the special right accident rate is significantly higher than only two other types of Y-intersections. (One model was fit to all of the data in Table 4-46.) At higher volumes of traffic, special right intersections have a lower accident rate than other intersections. In the 5,001-10,000 category, the special right accident rate is 17% below the aggregate, and in the highest volume category, the special right rate is 35% below the aggregate. Special right intersections have a significantly lower rate than several of the other Y categories in each of the higher two volume levels.

Thus, the lower the traffic volume, the higher the accident rate of special right intersections compared with other three-legged intersections. In the lower two volume categories, special right intersections have a higher than average accident rate, and in the higher two volume categories, their accident rate is below average. Also, the accident rate at special right intersections is higher relative to special left intersections the lower the traffic volume. In the lowest volume category, special right intersections have a higher accident rate than special left sites. In the other three volume categories, special left intersections have a higher rate than special right sites, and the gap increases with increasing traffic volume. However, it is important to bear in mind that most of the rate differences in the two lower volume categories involving special right sites are not statistically significant.

Table 4-46 - Accident Rates per 100 Million Vehicles by Y-Category and Volume Level

Y-Category	0-2,000	2,001-5,000	5,001-10,000	10,001+	Total
	Average Daily Traffic				
1/special	71.93	39.02	29.97	29.24	34.52
1/not special	45.45 NS	29.50 *	35.90 NS	42.31 *	36.26
2/special	60.66 NS	44.69 NS	41.78 *	66.46 *	48.96
2/not special	51.05 NS	32.13 NS	42.95 *	38.25 NS	38.85
3	85.82 NS	38.38 NS	22.92 NS	26.91 NS	30.28
4	30.50 *	34.12 NS	35.13 NS	15.53 *	25.04
5	40.13 NS	42.56 NS	44.33 *	60.80 *	52.01
6	32.48 *	24.63 *	38.27 **	49.25 *	40.57
T	30.62	29.61	33.86	44.91	38.46
Total	39.04	32.05	36.03	45.26	39.47

<u>By severity</u>

Rates were calculated in a similar manner for each level of accident severity. Rates for fatal and A-injury accidents are shown in Table 4-47. Sample sizes are small, particularly in the lowest traffic volume category. Special right intersections have a rate 2.7 times the rate for all three-legged intersections in the lowest volume category. The rate for special right sites is slightly above other intersections in the 2,001-5,000 category and slightly below other intersections in the 5,001-10,000 category. Special right intersections have a rate 71% higher than the aggregate in the highest volume category. However, special right intersections do not have the highest serious accident rate in any of the volume categories. Special left intersections have a higher rate at each level of average daily traffic.

Table 4-47 - Fatal and A-Injury Accident Rates per 100 Million Vehicles by Y-Category and Volume Level

Y-Category	0-2,000	2,001-5,000	5,001-10,000	10,001+	Total
	Average Daily Traffic				
1/special	9.38	2.30	1.74	3.97	2.81
1/not special	3.25	1.90	3.66	4.98	3.48
2/special	12.13	3.59	2.50	6.90	4.20
2/not special	5.94	1.33	3.94	3.12	3.08
3	13.20	5.76	1.43	0.60	2.74
4	5.08	3.79	1.82	0.74	1.82
5	4.34	3.21	2.46	2.21	2.52
6	2.38	1.08	1.85	1.93	1.78
T	0.96	1.66	1.93	2.14	1.96
Total	3.42	2.06	2.19	2.32	2.26

The rates for B- and C-injury accidents in Table 4-48 show special right intersections to have a 35% higher accident rate than all intersections in the lowest volume category, a 73% higher rate in the 2,001-5,000 volume category, a rate about the same as the aggregate in the 5,001-10,000 category, and a rate 40% lower in the highest volume category. Only in the 2,001-5,000 volume category do special right intersections stand out as having among the highest rates.

Table 4-48 - B- and C-Injury Accident Rates per 100 Million Vehicles by Y-Category and Volume Level

	Average Daily Traffic				
Y-Category	0-2,000	2,001-5,000	5,001-10,000	10,001+	Total
1/special	9.38	11.48	7.67	6.44	8.69
1/not special	6.49	5.95	6.86	12.69	8.33
2/special	12.13	11.97	9.64	14.42	11.61
2/not special	8.31	5.84	7.45	9.36	7.86
3	13.20	3.84	5.25	5.98	5.29
4	7.62	3.16	3.65	2.71	3.28
5	6.51	11.08	9.27	14.12	11.82
6	8.71	4.32	8.26	10.96	8.81
T	5.10	6.00	7.63	10.89	8.88
Total	6.97	6.65	7.72	10.80	8.86

Rates for PDO accidents are shown in Table 4-49. As with the overall rates in Table 4-46, the PDO rates show that the lower the traffic volume, the higher the accident rate of special right intersections compared with other intersections. In the lowest volume category, special right sites have a rate 86% higher than the aggregate, while in the highest volume category, their rate is 41% lower than the aggregate.

Table 4-49 - PDO Accident Rates per 100 Million Vehicles by Y-Category and Volume Level

	Average Daily Traffic				
Y-Category	0-2,000	2,001-5,000	5,001-10,000	10,001+	Total
1/special	53.17	25.25	20.56	18.83	23.01
1/not special	35.71	21.65	25.38	24.64	24.45
2/special	36.39	29.13	29.64	45.14	33.15
2/not special	36.81	24.96	31.56	25.77	27.91
3	59.42	28.79	16.23	20.33	22.26
4	17.79	27.17	29.66	12.08	19.94
5	29.28	28.28	32.60	44.48	37.67
6	21.39	19.23	28.17	36.36	29.97
T	24.56	21.95	24.29	31.87	27.61
Total	28.65	23.34	26.12	32.13	28.35

By accident type

Rates were also calculated for each of the four accident type categories while controlling for volume. The high run-off-road rate for special right intersections noted earlier appears to hold only for lower volume sites. Table 4-50 shows special right sites to have a run-off-road rate well above the aggregate in each of the two lowest volume categories, while the special right rate is about the same as the overall in the 5,001-10,000 category and about 20% lower than the aggregate in the highest volume category. Special right intersections, along with special left sites, have the highest rate in the second-lowest volume category, while special left and category 3 sites have higher rates than special right sites in the lowest volume category, although the rates are not significantly higher.

Table 4-50 - Run-Off-Road Accident Rates per 100 Million Vehicles by Y-Category and Volume Level

	Average Daily Traffic				
Y-Category	0-2,000	2,001-5,000	5,001-10,000	10,001+	Total
1/special	28.15	19.51	8.02	4.96	11.89
1/not special	19.48 NS	9.76 *	11.43 NS	8.96 NS	10.52
2/special	40.44 NS	19.15 NS	18.21 *	16.93 *	19.02
2/not special	17.81 **	10.09 *	10.96 NS	5.42 NS	8.91
3	59.42 NS	14.07 **	2.86 *	3.59 NS	7.84
4	10.17 *	12.00 *	7.30 NS	3.7 NS	6.57
5	17.35 **	16.03 NS	12.41 NS	8.74 NS	11.34
6	15.84 **	6.91 *	5.54 *	7.17 NS	6.93
T	11.48	7.08	6.19	5.45	6.11
Total	16.60	9.95	7.76	6.20	7.79

Special right intersections were earlier observed to have a lower than average rate of head-on accidents. This generally holds when controlling for traffic volume, except in the lowest volume category. Table 4-51 shows special right sites to have a head-on rate 4.4 times the aggregate in the lowest volume category. Special right intersections have the highest rate in this volume level, although category 3 sites also have a high rate. However, because the sample sizes in the lowest volume category are small, the rate for special right intersections is not significantly higher than the rates for any of the other Y categories. In the two intermediate volume categories, special right intersections have a rate similar to the aggregate, and in the highest volume category, the overall rate is 2.5 times the special right rate.

Table 4-51 - Head-On Accident Rates per 100 Million Vehicles by Y-Category and Volume Level

	Average Daily Traffic				
Y-Category	0-2,000	2,001-5,000	5,001-10,000	10,001+	Total
1/special	15.64	7.65	7.32	4.46	7.03
1/not special	3.25 NS	4.04 **	7.09 NS	9.96 NS	6.81
2/special	4.04 NS	8.78 NS	8.57 NS	22.57 *	11.61
2/not special	4.75 NS	6.90 NS	14.24 *	11.66 *	10.88
3	13.20 NS	7.04 NS	3.34 *	5.98 NS	5.47
4	2.54 NS	7.58 NS	7.30 NS	3.45 NS	5.23
5	2.17 NS	8.45 NS	9.55 NS	10.50 **	9.56
6	2.38 NS	5.18 NS	12.24 *	16.36 *	12.45
T	2.55	5.29	7.63	10.64	8.57
Total	3.55	5.99	8.71	11.04	9.04

Special right intersections were earlier observed to have a lower than average rate of rear-end accidents. As Table 4-52 shows, this consistently holds true at each traffic volume level. Category 5 intersections have the highest rate of rear-end collisions at each level of traffic volume.

Table 4-52 - Rear-End Accident Rates per 100 Million Vehicles by Y-Category and Volume Level

	Average Daily Traffic				
Y-Category	0-2,000	2,001-5,000	5,001-10,000	10,001+	Total
1/special	3.13	5.36	10.80	15.37	9.85
1/not special	1.62	7.14	12.12	18.92	12.11
2/special	0.00	7.58	6.78	20.06	9.79
2/not special	3.56	4.51	10.96	16.75	11.27
3	0.00	8.32	8.12	14.35	9.85
4	5.08	3.79	9.58	6.90	6.93
5	6.51	9.04	15.55	35.65	24.11
6	4.75	5.62	14.76	20.39	15.28
T	4.47	7.75	12.48	22.35	16.30
Total	4.18	7.06	12.50	22.21	15.49

Rates for "other" accidents are shown in Table 4-53.

Table 4-53 - "Other" Accident Rates per 100 Million Vehicles by Y-Category and Volume Level

	Average Daily Traffic				
Y-Category	0-2,000	2,001-5,000	5,001-10,000	10,001+	Total
1/special	25.02	6.50	3.83	4.46	5.75
1/not special	21.10	8.57	5.26	4.48	6.81
2/special	16.18	9.18	8.21	6.90	8.53
2/not special	24.93	10.62	6.79	4.43	7.80
3	13.20	8.96	8.59	2.99	7.11
4	12.71	10.74	10.95	1.48	6.32
5	14.10	9.04	6.82	5.91	7.00
6	9.51	6.91	5.73	5.32	5.91
T	12.12	9.50	7.56	6.48	7.48
Total	14.70	9.05	7.07	5.81	7.15

Light Condition

The final Y-category comparison concerns light condition. It would be most interesting to calculate accident rates according to light condition, but it is not possible to categorize the exposure data this way. Instead, the distribution of accidents according to light condition for each category of intersection is shown in Table 4-54. Special right and special left intersections have the lowest proportions of daylight accidents and the highest proportions of dark/unlit accidents. Tests of equal proportions using the chi-square statistic were applied to see if these differences are significant. The distribution of accidents by light condition at special right intersections was found to be significantly different from the overall distribution at the 5% level and from not-special right sites at the 10% level. No significant differences were found between the special right distribution and the distributions from any of the other curved Y sites. The distribution at special left sites was found to be significantly different at the 5% level from the aggregate distribution, not significantly different from category 3 sites, and significantly different at the 10% level from not-special right, not-special left, and category 4 sites.

Table 4-54 - Light Condition Accident Distribution by Y-Category

	Five-Year Accident Counts					
Y-Category	Daylight	Dawn/ Dusk	Dark/ Lit	Dark/ Unlit	Unknown	Total
1/special	147	12	14	96	1	270
	54.44%	4.44%	5.19%	35.56%	0.37%	100.00%
1/not special	281	31	35	131	1	479
	58.66%	6.47%	7.31%	27.35%	0.21%	100.00%
2/special	183	16	30	121	0	350
	52.29%	4.57%	8.57%	34.57%	0.00%	100.00%
2/not special	352	36	35	169	1	593
	59.36%	6.07%	5.90%	28.50%	0.17%	100.00%
3	100	6	8	52	0	166
	60.24%	3.61%	4.82%	31.33%	0.00%	100.00%
4	125	8	7	66	0	206
	60.68%	3.88%	3.40%	32.04%	0.00%	100.00%
5	787	63	139	206	2	1,197
	65.75%	5.26%	11.61%	17.21%	0.17%	100.00%
6	828	49	108	171	4	1,160
	71.38%	4.22%	9.31%	14.74%	0.34%	100.00%
T	3,401	206	428	812	10	4,857
	70.02%	4.24%	8.81%	16.72%	0.21%	100.00%
Total	6,204	427	804	1,824	19	9,278
	66.87%	4.60%	8.67%	19.66%	0.20%	100.00%

Both the special right and the special left accident distributions by light condition are significantly different from the aggregate distribution. This is because the aggregate distribution primarily includes accidents at tangent Y's and at T-intersections. These sites tend to be more commonly found in urban areas than curved Y's and therefore tend to have relatively more daytime accidents and fewer nighttime accidents than curved Y sites. It was thought that the potentially confusing nature of special right and special left intersections might also result in these sites having a different distribution of accidents by light condition compared with the other curved Y sites. While the raw frequencies show high percents of accidents at special right and special left intersections during dark/unlit conditions, when visibility is at a minimum, the statistical tests provide only weak support for different light condition distributions at special right and special left sites compared with the other curved Y sites.

Discussion of Special Right Intersections

One of the main objectives of this research is to determine whether a particular configuration of the Y-intersection, where the main road curves to the right and the cross road continues on a tangent, has an abnormally high accident rate when compared with other types of three-legged intersections. Evidence of this was sought in the comparison of accident rates at these special right intersections with rates from other three-legged intersections. It should be noted that the class of three-legged intersections against which the special right Y-intersection was compared includes T-intersections and that the previous analysis found that T-intersections have, with one exception, a consistently safer accident record than Y-intersections. Our analysis compared the accident rates for the special right Y-intersection against the aggregate rate of all three-legged intersections and against the rates of the other categories of Y-intersections. Rates were calculated for rural versus urban areas, different accident severities, different accident types, and controlling for traffic volume on the main road.

The accident rates found in this analysis are somewhat lower than the rates calculated in the analysis of the Washtenaw County data. This may be related to the differences in the road types, the uncertainty of the volume information for the Washtenaw County sites, and the differences in definitions of intersection types. Additionally, the higher rates for Washtenaw County are consistent with previous studies that have found higher per-vehicle involvements for sites with very low side road volumes. It should also be remembered that while the data for the Michigan trunkline intersections were developed for statistical analyses, the data for the Washtenaw County Y's were not. Although rates differed, there was a similarity of accident patterns between the data sets. However, we place more confidence in the findings based on the analysis of the Michigan trunkline data.

The main findings of the special right intersection analysis are listed below.

- Considering overall accident rates per 100 million vehicles at three-legged intersections, special right intersections have a rate 13% lower than the aggregate. When only rural sites are examined, the special right Y-intersection has an accident rate 17% higher than the rate for all rural three-legged intersections. However, the accident rate for the rural special right Y-intersection is not significantly different than the accident rates for other rural curved Y-intersections. When only urban three-legged intersections are examined, the urban special right Y-intersection has an accident rate that is 40% lower than the aggregate rate and that is significantly lower than the rates of most of the other categories of Y-intersections.

- Just over 8% of accidents at special right intersections involve a fatality or A-injury, as compared with the aggregate rate for all three-legged intersections of just under 6%. However, the rate for these severe accidents at the special right Y-intersection is similar to the rates for these accidents at the other categories of curved Y-intersections.

- Further examination of the rates of the fatal and A-injury accidents by the rural/urban classification shows that rural special right Y-intersections have a rate 32% higher than that of all rural three-legged intersections taken together. However, the rate of these severe accidents at rural special right Y-intersections is on par with the rates at other rural curved Y-intersections. The rate of these severe accidents at urban special right Y-intersections is 9% lower than the aggregate rate for all urban three-legged intersections.

- The rate of B- and C-injury accidents at special right intersections is on par with the aggregate rate for all three-legged intersections and the rate for PDO accidents is 19% below the aggregate rate.

- Special right Y-intersections had about the same number of fatal and A-injury accidents per site as all three-legged intersections and lower numbers of B- and C-injury accidents and PDO accidents than all three-legged intersections.

- When rates were calculated according to accident type, it was found that special right intersections have a 53% higher rate of run-off-road accidents, a 22% lower rate of head-on accidents, and a 36% lower rate of rear-end collisions compared with all three-legged intersections.

- Examining these rates by the rural/urban classification shows that the high rate of run-off-road accidents at special right sites is driven by the rate at rural intersections, not urban ones. Also, rural special right intersections have a 14% higher rate of head-on accidents than all rural three-legged intersections. However, it should be pointed out that the head-on accident rate for rural special right Y-intersections is on par with the head-on accident rates for the other rural curved Y-intersections.

- Examination of severity by type of accident shows that when run-off-road, rear-end, and head-on accidents occur at the special right Y-intersection, they tend to be more severe than similar types of accidents at all three-legged intersections considered together. However, this is generally true for all the curved Y-intersection categories.

- Accident rates were also examined by categories of traffic volume. Special right intersections were found to have a higher rate relative to other three-legged intersections for traffic volumes below 5,000 vehicles per day and lower rates for volumes greater than 5,000 vehicles per day. The accident rate in the lowest volume categories for special right Y-intersections was, in most cases, not significantly different from the rates for the other categories of Y-intersection.

- Rates of different types of accidents at special right Y-intersections vary with traffic volume. Special right sites have a higher rate of run-off-road accidents for traffic volumes below 5,000 vehicles per day than all three-legged intersections. The rate of head-on accidents is higher than the aggregate for volumes under 2,000 vehicles per day. Special right intersections have lower than average rear-end accident rates across every level of traffic volume.

Y-Intersections

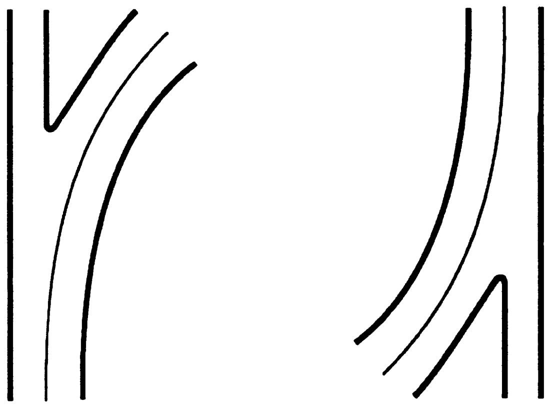
In general, the data analyses conducted do not show special right intersections to pose a unique risk relative to other three-legged intersections. Overall, this intersection configuration has a below average accident rate compared with all three-legged intersections. Special right intersections do have a higher proportion of severe accidents and a higher severe accident rate than all three-legged intersections taken together, but the special right Y-sites are similar in these respects to other curved Y-intersections. There is no evidence that special right Y-intersections have an abnormally high level of head-on accidents. Special right intersections were found to have higher than average head-on accident rates in rural areas and among sites with the lowest traffic volumes, but, in both cases, the head-on rates at special right Y-sites are not significantly higher than the rates for any of the other categories of Y-intersection. The special right Y-sites were found to have a high rate of run-off-the-road accidents, particularly in rural areas, at low traffic volumes, and for fatal and A-injury accidents.

The analysis indicates that the only way in which the accident experience at special right Y-intersections differs from that of other Y-intersections is in the high rate of severe run-off-the-road accidents in low volume rural areas. This pattern of accidents is usually associated with horizontal curves and speed. The special right Y-intersection, by definition, is located on a curve and speeding is often associated with low volume rural environments. Thus, these findings suggest that the curve inherent to the special right Y-intersection is a key factor associated with accidents at these locations.

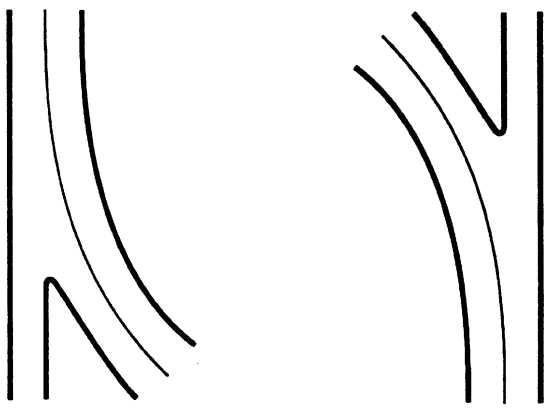
CHAPTER 5
SPECIAL Y-INTERSECTIONS

Introduction

In this chapter the special Y-intersections are further examined. The special Y-intersections are those where the main route curves to the right or left and a minor road continues on a tangent as shown in Figure 5-1. There are 166 such sites in the analysis data file. Note that this is not a sample but a census of all such sites on the state trunkline that have been recorded in the MDOT Trunkline data files and have passed the data consistency checks of this research (see section 4.1 of this report). There are 88 Special Y's to the right and 78 Special Y's to the left. The special Y's constitute approximately 12% of the total number of two-way, non-signalized Y-intersections and about 1.4% of all two-way, non-signalized three-legged intersections on the state trunkline.



Category 1 — Special



Category 2 — Special

Figure 5-1 - Special Y-Right and Special Y-Left Intersections

The preceding chapter examined the special Y sites as part of the broader categories of Y-intersections and also as special categories. In general, the Michigan trunkline data showed special left sites to pose more of a traffic safety risk than special right sites. Special left sites have an accident rate per 100 million vehicles that is 24% higher than all three-legged intersections. The special left rate is the highest of all the curved Y categories and is significantly higher than the rate for special right intersections. Special right sites have a rate 13% lower than the aggregate.

In rural areas, special right and special left sites both have accident rates somewhat higher than the aggregate. However, these rates are in line with the other categories of curved Y-intersections. In urban areas, special right sites have an accident rate 40% below the aggregate. This is among the lowest urban accident rates. In contrast, special left sites have the highest urban accident rate, registering 42% above the rate for all urban three-legged intersections.

Both special right and special left intersections have elevated rates of fatal and A-injury accidents. Special right sites have a rate 24% higher than the aggregate, and special left sites have the highest rate of all the Y categories, with a risk 85% higher than all three-legged intersections.

Special left sites have the highest rate of run-off-road accidents of all the categories of Y-intersections, and special right sites also have an elevated rate of these accidents. The run-off-road rate for special left sites is 2.4 times the aggregate, while special right sites have a rate 1.5 times the aggregate. Special left sites have a rate of head-on accidents that is 28% higher than the rate for all sites, while special right sites have a head-on accident rate 22% lower than the overall. Special right and special left sites have virtually the same rate of rear-end accidents, and this rate is about 36-37% lower than the rear-end accident rate for all three-legged intersections.

This chapter reports on additional statistical analyses of the special Y-intersections, an analysis of UD-10 police accident forms, and a field study of 53 special Y sites. The field study was conducted to complement the other analyses and provide more insight into the factors associated with safety at the special class of Y-intersections.

5.1 ANALYSIS OF SIDE ROAD DATA

Side Road Volumes

In order to examine the accident experience at the group of special Y-intersections in more detail, additional information about the minor roads at these intersections was collected. County road commissions were contacted to obtain the average daily traffic count on the side road for each of the special Y-intersections. Either the most recent actual traffic count or an estimated traffic count by the county field engineer were acceptable responses. Side road traffic counts, either actual or estimated, were obtained for 76 of the 166 special Y sites.

Table 5-1 shows these 76 sites categorized by whether they are special right or special left intersections and according to three levels of side road volume: 0-250 vehicles per day, 251-1,000 vehicles, or more than 1,000 vehicles. For each of the resulting six categories the table indicates the number of sites, their combined number of accidents, their combined five-year traffic volume *on the main road*, and their accident rate per 100 million vehicles on the main road. Interestingly, the accident rate at the special right intersections shows virtually no variation according to side road volume, while the rate at special left sites increases with increasing side road volume.

Table 5-1 - Accident Rates at Special Y-Intersections with Side Road Volume Data

Special Status	Side Road ADT	Number of Sites	5-year Accident Count	5-year Traffic Vol. (Millions)	Accs. Per 100 Million Vehicles
Right	0-250	16	43	96	44.64
	251-1000	11	38	85	44.59
	1001+	12	67	140	47.86
	SUBTOTAL	39	148	322	46.03
Left	0-250	10	15	66	22.65
	251-1000	15	69	131	52.65
	1001+	12	150	170	88.05
	SUBTOTAL	37	234	368	63.65
TOTAL		76	382	689	55.43

In Table 5-2 accident rates by severity are shown for the 76 special Y's with side road volume data. The pattern observed for special left intersections in Table 5-1 of increasing accident rates with increasing side road volume continues to hold for all three levels of accident severity. Special right intersections were earlier observed to have a roughly constant accident rate at different levels of side road volume. Table 5-2 shows that this remains true for PDO accidents, but the rates for injury accidents show some variation with side road volume.

Table 5-2 - Accident Rates per 100 Million Vehicles by Severity at Special Y-Intersections with Side Road Volume Data

Special Status	Side Road ADT	Accident Severity Fatal and A-Injury	B- and C-Injury	PDO	Total
Right	0-250	4.15	9.34	31.15	44.64
	251-1000	2.35	14.08	28.16	44.59
	1001+	5.00	7.14	35.72	47.86
	SUBTOTAL	4.04	9.64	32.35	46.03
Left	0-250	3.02	4.53	15.10	22.65
	251-1000	7.63	12.97	32.05	52.65
	1001+	9.39	22.31	56.35	88.05
	SUBTOTAL	7.62	15.78	40.26	63.65
TOTAL		5.95	12.91	36.57	55.43

Accident rates for the 76 special Y's with side road volume data were also calculated according to accident type (Table 5-3). At special left intersections, the rates of head-on and rear-end accidents increase dramatically as volume on the minor road rises. At special right sites, the same is true for rear-end accidents, but the head-on rate shows little variation with side road volume.

Table 5-3 - Accident Rates per 100 Million Vehicles by Accident Type at Special Y-Intersections with Side Road Volume Data

Special Status	Side Road ADT	Accident Type Run-off-road	Head-on	Rear-end	Other	Total
Right	0-250	19.73	9.34	4.15	11.42	44.64
	251-1000	14.08	7.04	16.43	7.04	44.59
	1001+	10.72	7.86	23.58	5.72	47.86
	SUBTOTAL	14.31	8.09	15.86	7.78	46.03
Left	0-250	13.59	1.51	0.00	7.55	22.65
	251-1000	30.52	9.16	4.58	8.39	52.65
	1001+	27.00	29.94	24.07	7.04	88.05
	SUBTOTAL	25.84	17.41	12.78	7.62	63.65
TOTAL		20.46	13.06	14.22	7.69	55.43

Side Road Condition

Other potentially interesting information about the side roads at the special Y-sites concerns the pavement type and the road markings. These characteristics are relevant to whether the side road might be perceived as a continuation of the major road, thus contributing to a "perceptual trap" for the driver. The more similar the side road and main road at a special Y-intersection are in terms of pavement type and quality of road markings, the greater the potential for a perceptual trap (this will be discussed in greater detail in section 5.2).

Data on the side road pavement and markings were collected for the 53 special Y-sites that were visited as part of the field study. The side roads at the field sites were either paved or gravel, while all of the main roads were paved. Thus, at sites with gravel side roads it should be more clear that the side road is not a continuation of the major road. The other data element of interest concerns the road markings. The side roads were categorized according to whether their road markings contrasted with the markings on the main road. For example, if the main road was marked with white edgelines and a double yellow centerline, all in good condition, while the side road either did not have such markings or they were deteriorating, contrast would be present at the site. If the major road and side road had similar road markings in roughly the same condition, then no contrast was present at the site. Since gravel roads do not have lines, contrast was present at all sites with gravel side roads. The 53 sites were therefore divided into three categories based on side road condition: 1) gravel/contrast, 2) paved/contrast, and 3) paved/no contrast.

Table 5-4 shows these 53 sites categorized by whether they are special right or special left intersections and according to their category of side road condition. The total number of sites, total number of accidents, combined five-year traffic volume on the main road, and accident rate per 100 million vehicles are shown. The rates do not lend a great deal of support to the perceptual trap hypothesis. At the special right sites, the gravel/contrast sites have the highest rate of the three categories, despite the fact that gravel side road sites should have a low potential for a perceptual trap. For the special left sites, the paved/contrast sites have the highest rate, and the paved/no contrast sites have the lowest rate. Again this is contrary to expectations. Although not shown in Table 5-4, the accident rates for the special right and special left sites combined are 87.19 for gravel/contrast sites, 81.38 for paved/contrast sites, and 75.44 for paved/no contrast sites. These rates are in reverse order from what would be expected if a perceptual trap effect were a major factor in the accidents.

Table 5-4 - Accident Rates per 100 Million Vehicles at Special Y-Intersections with Side Road Condition Data

Special Status	Side Road Condition	Number of Sites	5-year Accident Count	5-year Traffic Vol. (Millions)	Accs. Per 100 Million Vehicles
Right	Gravel/Contrast	9	59	65	90.81
	Paved/Contrast	9	60	139	43.27
	Paved/No Contrast	8	93	112	82.97
	SUBTOTAL	26	212	316	67.15
Left	Gravel/Contrast	4	18	23	77.12
	Paved/Contrast	17	181	157	114.95
	Paved/No Contrast	6	78	115	68.08
	SUBTOTAL	27	277	295	93.78
TOTAL		53	489	611	80.02

In Table 5-5 accident rates by severity are shown for the 53 special Y's with side road condition data. No clear pattern between side road condition and accident rate is apparent at any level of severity for either special right or special left sites.

Table 5-5 - Accident Rates per 100 Million Vehicles by Severity at Special Y-Intersections with Side Road Condition Data

		Accident Severity			
Special Status	Side Road Condition	Fatal and A-Injury	B- and C-Injury	PDO	Total
Right	Gravel/Contrast	6.16	35.40	49.25	90.81
	Paved/Contrast	5.05	10.82	27.40	43.27
	Paved/No Contrast	8.03	13.38	61.56	82.97
	SUBTOTAL	6.33	16.79	44.03	67.15
Left	Gravel/Contrast	4.28	12.85	59.98	77.12
	Paved/Contrast	9.53	31.12	74.30	114.95
	Paved/No Contrast	8.73	15.71	43.64	68.08
	SUBTOTAL	8.80	23.70	61.28	93.78
TOTAL		7.53	20.13	52.36	80.02

Accident rates were also generated for different types of accidents for the sites with side road condition data (Table 5-6). Again the relationship between side road condition and accident rate is unclear.

Table 5-6 - Accident Rates per 100 Million Vehicles by Accident Type at Special Y-Intersections with Side Road Condition Data

		Accident Type				
Special Status	Side Road Condition	Run-off-road	Head-on	Rear-end	Other	Total
Right	Gravel/Contrast	47.71	21.55	7.70	13.85	90.81
	Paved/Contrast	14.42	4.33	15.14	9.38	43.27
	Paved/No Contrast	19.63	21.41	33.01	8.92	82.97
	SUBTOTAL	23.12	13.94	19.95	10.14	67.15
Left	Gravel/Contrast	47.13	8.57	4.28	17.14	77.12
	Paved/Contrast	41.28	31.12	25.40	17.15	114.95
	Paved/No Contrast	29.68	18.33	17.46	2.62	68.08
	SUBTOTAL	37.24	24.38	20.65	11.51	93.78
TOTAL		29.95	18.98	20.29	10.80	80.02

Both side road volume and side road condition data were collected for a total of 31 sites. Analyses of accident rates were attempted on this group of sites incorporating both sets of data. However, the sample size was too small to support such a detailed breakdown of the data.

5.2 ANALYSIS OF ACCIDENT REPORTS

To gain a better understanding of the accidents at the special Y-intersections, the details of accidents themselves, as reported on UD-10 police accident forms, were examined. All non-animal accidents occurring at the 166 special right and special left Y-intersections during 1991 were identified, and hardcopies of the corresponding UD-10 forms were obtained from the Michigan State Police. There was a total of 112 accidents, 97 of which did not involve animals.

The first step in the review of the UD-10 forms for these accidents was a check of the accident site description on the UD-10 form against the site description in our analysis file. This review found that 38 of these accidents did not occur at the locations indicated in the analysis file. The review continued with the 59 accidents that were correctly located.

Of the 59 accidents at the special Y-sites, 29, or about half, were single-vehicle, loss of control accidents. Twelve accidents, or approximately 20%, involved collisions of vehicles on the side road and did not involve any vehicles travelling on the main road. Six accidents, or 10%, involved a vehicle on the side road failing to yield the right-of-way to a vehicle on the major road. Five accidents, or 8.5%, involved vehicles traveling the same direction on the main road, and three accidents, or about 5%, involved vehicles travelling in opposite directions on the main road. There were four accidents that did not fit any of the above categories.

The UD-10 forms for these 59 accidents were carefully read and summarized. From the diagram and narrative on the reports it was possible to determine driver intent and direction of travel of the vehicles involved. It was also possible to assess the contribution of the Y geometry, curve, and road surface condition to the accident. Three levels of contribution were used: definitely yes, possibly, and no. Light condition and alcohol use were also noted.

Table 5-7 shows the results of the analysis of contributory factors. The presence of the Y-intersection was found to definitely contribute in only 12% of the accidents. In 42% of the cases it could not be concluded that the Y did or did not contribute to the occurrence of the accident, so these cases were classified as "possibly." The presence of the Y-intersection was definitely not a contributory factor in 46% of the accidents.

Table 5-7 - Contributory Factors for Accidents at the Special Y-Sites

Factor	Yes	Possibly	No	Total
Y Geometry	7	25	27	59
Curve	24	13	22	59
Road Surface	15	8	36	59

When the contribution of the curve was examined, it was found to be a definite contributory factor in 41% of the cases, a possible contributory factor in 22% of the cases, and definitely not a contributory factor in 37% of the cases.

The accidents were also examined from the perspective of road surface condition. Road surface was found to be a definite contributing factor in 25% of the cases, a possible contributing factor in 14% of the cases, and definitely not a factor in 61% of the cases.

If the categories of definitely yes and possibly yes are combined, then the special Y-intersection was a contributing factor in 54% of the cases, the curve was a contributing factor in 63% of the cases, and road surface was a contributing factor in 39% of the cases.

Table 5-8 shows the number of cases classified by day versus night and whether or not any driver had been drinking alcohol prior to the accident. The table indicates that 56% of the accidents occurred at night and 44% occurred during the day. Considering that there is much more travel during the day than at night, this indicates a disproportionate percentage of nighttime accidents.

Table 5-8 - Associated Factors for Accidents at the Special Y-Sites

Factor	Yes	No	Total
Night	33	26	59
Alcohol	16	43	59

Alcohol was involved in 27% of the cases. The portion of all accidents in 1991 in Michigan that involved alcohol is 7.6%. This over-representation of alcohol suggests that impaired drivers may have difficulty negotiating the curve or may be confused by the Y-intersection.

The data were analyzed to test if these was a difference in the contributory factors between the special right and special left Y-intersections. Table 5-9 shows the number of accidents classified by right and left intersection type and whether or not the Y, curve, and road surface were found to be contributing factors. In this tabulation the definite and possible classifications were combined. The table also shows the distribution of day/night accidents and presence of alcohol by intersection type.

A standard contingency table analysis was carried out testing the null hypothesis of no difference between right and left special Y-intersections for each of the factors. In each case the null hypothesis could not be rejected at the 5% level. This indicates that there is essentially no difference between special right and left Y-intersections with respect to the influence of the Y geometry, curve, or road surface condition, or to the incidence of nighttime or alcohol-related accidents.

Table 5-9 - Accidents by Contributory and Associated Factors for Special Y-Sites

	Right		Left	
Factor	Yes/Possibly	No	Yes/Possibly	No
Y Geometry	9	12	23	15
Curve	10	11	27	11
Road Surface	6	15	17	21
	Yes	No	Yes	No
Night	11	10	22	16
Alcohol	6	15	10	28

The results of the analysis of the UD-10 accident forms from the special right and special left Y-intersections show that the most frequent type of accident that occurs at these sites is single-vehicle accidents where there is a loss of control. The presence of the curve appears to contribute as much to the occurrence of accidents as does the presence of the intersection. There is a greater chance of accidents at these sites occurring at night. Alcohol is present in a disproportionate number of these accidents. There is no difference in these factors between accidents at special right or left Y-sites.

5.3 FIELD OBSERVATIONS

Selection of Sites

The study design called for site visits to approximately 50 special Y sites with the "worst" accident experience. To identify special Y sites with the worst accident experience, lists were generated of all sites ranked according to frequencies and rates of all accidents and head-on accidents.

Lists of the 50 sites with the most accidents and the highest accident rates were generated for the entire data set of 2,067 three-legged intersections, for all accidents and for head-on accidents. Next, lists were generated for the 50 sites with the highest accident frequencies and rates among the 1,046 Y-intersections in the analysis file.

There were 11 special Y-intersections (4 "rights" and 7 "lefts") in the lists of overall highest frequency and rate of accidents. The two lists of head-on experience produced only two additional special Y sites (one right and one left). The lists of Y sites produced 6 more unique special Y sites (4 "rights" and 2 "lefts"). Together all six lists yielded 19 special Y sites.

Since the list was short of the desired 50 sites, the accident frequencies of all special Y sites were examined next. There were 50 sites that had four or more non-animal accidents in the five-year period. Sixteen of the nineteen sites identified in the first step were among these fifty sites. The other three sites had fewer than four non-animal accidents, but the traffic volumes were very low, resulting in high accident rates. It was decided to include all 53 sites in the set of sites to be visited. The final list consisted of twenty-six special right Y-sites and twenty-seven special left Y-sites.

A field crew went to each of the sites and collected information about the traffic control, sight distance, signing, pavement markings, and delineation. They photographed each site from the approaches to the intersection and observed the behavior of drivers making turns. They checked each site for optical illusion effects (i.e., whether the minor road seemed like a continuation of the major road) and noted the reasons that led them to their conclusions. They also noted anything that seemed unusual about each site. The list of site names and sample field study forms can be found in Appendix D, and photographs of each site are included in Appendix E.

Table 5-10 presents traffic accident and traffic volume information for each site, whether the site is a special right or left Y, and any additional features found at the site.

Table 5-10 - Field Site Accident Rates

Site No.	5-year Acc. Count	ADT	Rate per 100 Million Vehicles	Y-Category	Comments
1	2	500	219.2	special right	slightly modified to T
2	27	7,390	200.2	special left	reconstructed to T
3	6	3,640	90.3	special right	slightly modified to T
4	5	5,680	48.2	special right	
5	6	6,240	52.7	special right	flasher/channelized
6	5	2,660	103.0	special left	channelized
7	5	4,720	58.0	special left	
8	4	5,100	43.0	special right	
9	7	1,740	220.4	special right	
10	5	3,500	78.3	special left	chevrons
11	11	2,380	253.3	special right	
12	7	6,520	58.8	special right	
13	5	25,540	10.7	special right	four lanes
14	14	4,280	179.2	special right	
15	14	12,830	59.8	special right	
16	17	2,120	439.4	special left	
17	5	2,600	105.4	special left	slightly modified to T
18	3	900	182.6	special left	
19	3	580	283.4	special left	
20	6	7,680	42.8	special left	channelized
21	5	990	276.7	special right	
22	7	4,600	83.4	special left	
23	18	12,200	80.8	special left	channelized
24	8	5,720	76.6	special left	channelized
25	6	7,020	46.8	special left	
26	6	3,960	83.0	special right	
27	27	21,650	68.3	special left	channelized
28	46	13,720	183.7	special left	channelized
29	7	12,400	30.9	special left	
30	7	6,040	63.5	special right	
31	6	3,630	90.6	special left	channelized
32	18	9,540	103.4	special right	channelized
33	6	2,320	141.7	special right	
34	4	5,950	36.8	special left	
35	6	8,150	40.3	special left	
36	16	5,950	147.3	special left	
37	6	2,320	141.7	special right	flasher, stop on trunkline
38	11	7,970	75.6	special right	channelized
39	13	3,050	233.6	special left	
40	6	3,630	90.6	special left	slightly modified to T
41	5	3,550	77.2	special right	
42	7	6,460	59.4	special left	
43	21	13,680	84.1	special right	reconstructed to T/five lanes
44	4	3,300	66.4	special right	slightly modified to T
45	6	4,420	74.4	special left	
46	10	5,920	92.6	special left	channelized/chevrons
47	14	15,650	49.0	special right	five lanes
48	5	6,470	42.3	special right	
49	4	3,730	58.8	special left	slightly modified to T
50	5	14,320	19.1	special right	channelized
51	4	1,500	146.1	special left	slightly modified to T
52	5	4,220	64.9	special right	
53	13	4,220	168.8	special right	

Types of Sites Encountered

Reconstruction

It can be seen from Table 5-10 that site 2 and site 43 are no longer Y-intersections. All the photolog images used to identify special Y sites were photographed between 1988 and 1991. These were the latest available images at the time of this study and also corresponded with the accident data records used in the analysis. The changes therefore do not affect the analysis in the previous chapter and demonstrate possible countermeasures for the special Y sites. It should be noted that sites 2 and 43 had among the highest accident counts of the 53 intersections in the set, so it is not surprising that they were reconstructed to T-intersections.

Modification

At seven intersections the alignment of the minor road at the intersection had been slightly modified to change the configuration closer to a T. This appears to have been done when the trunkline was repaved. Site 1 is an example of a simple form of this modification, where a short section of the minor road was paved. Site 44 shows a more extensive modification, where not only a short section of minor road was paved, but a curb was added. These modified intersections, however, tended to look like special Y's from a distance.

Channelization

Channelization was found at eight of the left sites and at four of the right sites. Site 6 is a typical example of a channelized special left Y-site. Traffic can continue onto the minor road on the one-way tangent section. Traffic from the minor road uses the two-way leg that forms a right angle with the major road. Traffic turning left from the major to the minor road also uses the two-way leg.

Sites 5, 32, 38, and 50 were channelized special right Y-intersections. Traffic leaves the minor road via a one-way leg that is tangent to the curve, and the traffic turning from the major road to the minor road uses the two-way leg that is perpendicular to the major road.

Except for sites 13, 43, and 47, which had multiple lanes on the approach to the intersection, all the remaining sites had one lane in each direction on all approaches to the intersection.

Flasher

Site 5, a special Y-right intersection, was channelized and also utilized a flasher. There is a separate "turn" lane with a curb and gutter. An overhead yellow beacon and case sign with "right" on it hang over this lane indicating the path for the trunkline traffic. A one-sided overhead "stop" case sign and a red flasher hang over the through lane. The traffic out of the minor road is controlled by a "stop" sign. The overhead case sign is blank from this approach. Traffic on the trunkline from the other direction was channeled to the right of a very small island and controlled by a stop sign. It is apparent that more than one tactic is being used to indicate the path for the trunkline traffic and control this Y-intersection.

One other special right intersection was controlled with a flasher. At site 37, the movement from the trunkline onto the minor road had the right-of-way, while the trunkline traffic from the other direction was controlled by a stop.

<u>Signs and pavement markings</u>

The most common treatments encountered at the sites were a curve ahead advance-warning sign, sometimes with a speed advisory, on the trunkline and stop-ahead and stop signs on the minor road. The trunkline usually had a double yellow centerline and white edgelines. The minor road, if paved, typically had a center line and sometimes edgelines. Sites 15 and 11 show the typical signing and pavement markings on special right Y-sites, and sites 16 and 34 exhibit the typical signs and pavement markings found at special left Y-sites.

Target arrows are used fairly commonly at such sites. Examples of typical use can be seen at sites 11 and 46. Chevrons, while not used very frequently, were found at some of the sites. Site 46 shows a good example of the use of chevrons to delineate the curve.

Driver Behavior

At special Y-sites, travelling straight on the tangent is technically a turn. During the site visits the field crew was instructed to observe the signalling behavior of drivers turning onto and out of the minor road. It can be argued that indicating an intent to turn implies that the drivers are conscious of the fact that they are leaving one roadway and entering another. The observers spent about 20 to 30 minutes at a site, during which time they observed the turning traffic. The number of turning vehicles observed at the sites ranged from 0 to 40.

At 18 of the 26 special right Y-sites vehicles were observed turning onto the minor road by continuing straight or technically making a left turn. At 12 of these sites all drivers signalled their intent to turn. Vehicles did not signal left at the special Y-right intersections controlled with flashers or at intersections where an exclusive lane was available for vehicles continuing on the tangent. In all, 112 vehicles were observed entering the minor road from the major road by making a "left" turn. Of these, 77, or 69%, signalled left.

Eighty vehicles were observed exiting the minor road at the special right Y-sites. Of these, 31, or 39%, signalled their intent. The field crew observed that, generally, the vehicles making a left turn onto the major road tended to signal, while those continuing on the tangent into the right lane of the major road did not.

Y-Intersections

Turning movements were observed at 22 of the 27 special left Y-sites. Generally, vehicles entering the minor road by continuing on a tangent were not observed to signal. At 10 of the 22 sites where some vehicles turned, none signalled to the right. Of the 119 vehicles continuing on the tangent to the minor road, 108, or 91%, did not signal to the right. The field crew observed 140 vehicles leaving the minor road at the special left Y-intersections. Of these, 81, or 58%, were observed to signal. No distinction in signalling behavior was observed between vehicles proceeding straight onto the main road versus those making a right turn.

These observations indicate that a large portion of drivers entering the minor road at special right Y-intersections are conscious of the fact that they are turning off the main road. The others have either neglected to signal or do not consider this movement a turn. It was noted that drivers tend not to signal when an exclusive lane is provided for the "left turn" movement.

The observations also indicate that vehicles continuing straight on the tangent without crossing the opposing traffic stream, either by exiting the minor road at a special right Y-intersection or by continuing straight onto the minor road at a special left Y-intersection, do not signal. We speculate that this is because they do not consider this movement to be a turn.

Visual Effects

Each site was examined for a "perceptual trap" effect, both in the field and from the photographs. The "perceptual trap" refers to the phenomenon where the minor road appears to be a continuation of the major road. Since the minor road of a special Y continues on a tangent while the major road curves either to the right or to the left, one of the features of a "perceptual trap" is already in place. The observers first looked down the road from the viewpoint of a driver and decided whether the minor road appeared to be a continuation of the major route. Then they noted the reasons and features of the site that led them to that conclusion.

At most of the intersections the minor road did not appear to be a continuation of the main road to the observers. They explained that the centerlines and edgelines very clearly marked the main path.

Examination of the photographs shows that typically the pavement and pavement markings on the trunkline were in much better condition than on the minor roads. The pavement markings on the trunkline generally consisted of a double yellow centerline and white edgelines, while those on the paved minor roads consisted of a centerline but no edgelines. When there were edgelines, they were quite worn. Thus, there usually was a distinct contrast in the pavements and markings of the two roads. Furthermore, the pavement markings on the trunkline curved with the roadway and distinctly delineated the curve. In some cases the white edgeline continued as a dashed line through the opening in the intersection. When the centerline and edgelines curved with the main road, the main path was clear even at sites where the utility poles and tree lines continued along the minor road. Cases 10 and 12 are typical examples of sites where the contrast between pavements and pavement markings is good and the eye is not fooled as to which is the main path.

The observers found that sites where the pavements and pavement markings on both the main and minor road were in poor condition tended to be more confusing. Examples of this can be seen in cases 17 and 25.

If pavement contrast is the key factor, then there should have been confusion with situations where both the pavements and markings on both roads were in good condition. However, the "good/good" combinations were found in urban areas or in locations were the minor route carried a significant amount of traffic. Typically such locations had four lanes and/or were channelized and did not fool the eye as to the path of the trunkline. Examples can be seen in case 27.

These observations indicate that pavement contrast and delineation of the curve are features that are important in conveying the path of the trunkline to the driver. From these observations, it can be argued that good pavement markings are essential in marking the trunkline path at special Y-sites.

5.4 SUMMARY

This chapter examined the characteristics of special right and left Y-intersections in greater detail. County road commissions provided side road volume estimates for 76 of the 166 special Y-intersections in the analysis file. Accident rates per 100 million vehicles on the major road were calculated for these sites to see if there was a relationship between accident rate and side road volume. The results showed special right Y-intersections to have no variation in accident rates at different levels of side road volume. However, special left Y-intersections showed an increasing accident rate with increasing average daily traffic on the side road.

Accident rates for different levels of side road traffic were also calculated according to severity and accident type. The accident rate at special left Y-intersections increased with increasing side road volume at all three levels of accident severity. At special right Y-intersections, the rate of PDO accidents remained roughly stable at all levels of side road volume. Injury accident rates at special right Y-sites showed some variation with changes in side road volume, but no clear pattern was discernible. Special left Y-intersections also showed increasing rates of head-on and rear-end accidents as side road volume climbed. Only the rate of rear-end accidents showed a similar pattern at special right Y-sites.

Data on the surface type of the side road and the contrast in pavement markings between the side road and major road were collected by a field crew for 53 special Y-intersections. It has been suggested that special Y-intersections pose a "perceptual trap" to drivers since the minor road continues at a tangent from the major road. This optical illusion may be enhanced if the road surface type and pavement markings are similar between the two roads, as well as by images such as tree lines or telephone poles continuing along the roadside at a tangent. To see if the perceptual trap hypothesis was apparent in the accident rates at special Y-sites, the 53 intersections with data on pavement type and road markings were divided into three categories based on pavement type on the side road and whether there was contrast between the two roads in terms of markings. It was expected that the likelihood of appearing as a perceptual trap should increase from gravel/contrast sites to paved/contrast sites to paved/no contrast sites and that a similar increase in accident rate might be observed.

Accident rates were calculated for these three categories of sites. Rates were calculated for special right and special left intersections both separately and combined, and rates were also calculated according to accident severity and type. Most of the analyses showed no relation between accident rate and degree of perceptual trap potential, therefore providing no support for the perceptual trap hypothesis. In fact, when special right and special left Y-intersections were combined, accident rates declined from gravel/contrast to paved/contrast to paved/no contrast sites, precisely opposite to what would be predicted by the hypothesis. However, this is a relatively small sample of sites, and other factors might be involved which could dampen the effects of a perceptual trap.

Police accident forms for all the accidents at the 166 special right and left Y-intersections for 1991 were reviewed. There were 59 accidents that did not involve animals and for which the location information was correct. The level of contribution to the occurrence of the accident made by the Y geometry, the curve, and the road surface was assessed during the review. The type of accident, directions of travel, light conditions, and whether or not alcohol was involved were also noted. The difference in the contribution or association of these factors between special right and left Y-sites was tested.

Of the accidents at the special Y-intersections, almost half were single-vehicle accidents involving loss of control. Approximately 20% involved collisions of vehicles on the side road only. About 10% involved a vehicle on the side road failing to yield the right-of-way to a vehicle on the major road, 8.5%, involved vehicles traveling the same direction on the main road, and 5% involved vehicles travelling in opposite directions on the main road.

The presence of the special Y-intersection was found to definitely contribute to the accident in only 12% of the cases, possibly in 42% of the cases, and definitely not in 46% of the cases. The curve was found to be a definite contributing factor in 41% of the accidents, a possible factor in 22%, and not a factor in 37% of the cases. The road surface definitely contributed in 25% of the cases, possibly contributed in 14%, and did not contribute in 61% of the cases. A disproportionate number of these accidents occurred at night and involved alcohol. Statistical tests indicate that there is no difference in the contributions of these five factors to accident occurrence between right or left sites.

The results of this analysis indicate that the presence of the curve contributes to the occurrence of accidents at these sites as much as the intersection itself. The over-involvement of alcohol in these accidents suggests that impaired drivers in particular have difficulty negotiating this geometry.

Based on their frequency and rate of all accidents and head-on accidents, the 53 special Y-sites with the poorest accident history were identified and visited by a field crew. The crew recorded information about the traffic control, sight distance, signing, pavement markings, and delineation of each site, photographed the intersection, and observed driver behavior. Since the time of the most recent photolog images of the sites available to this study, two of the sites had undergone major reconstruction to transform them to T-intersections, and seven sites had been modified to bring the configuration closer to a T. The latter sites continued to look like special Y-sites from a distance, although as one approached the intersection it was apparent that the minor road did not continue on a tangent. Channelization was observed at twelve of the 53 sites, and two sites had a flasher.

Whenever possible, the field crew noted whether drivers proceeding from the major road to the minor road at the 53 sites used their turn signal. At special right Y-intersections, drivers commonly signalled their intent to turn left onto the minor road, except at sites with a flasher or where an exclusive lane was available for continuing on the tangent. In contrast, drivers typically did not signal when turning right onto the minor road at special left intersections. When proceeding from the minor road to the major road at special right intersections, drivers tended not to signal when continuing on a tangent onto the major road but often signalled when turning left onto the major road. At special left Y-intersections, 58% of drivers leaving the minor road were observed to signal.

These observations suggest that drivers tend to signal at special Y-intersections when performing maneuvers that involve crossing the opposing traffic lane. This may mean that drivers recognize that they are proceeding onto a different roadway, such as when entering the minor road at a special right intersection. Drivers tend not to signal if they can proceed without crossing the opposing lane, such as entering the minor road at a special left intersection, or entering the major road at a special right Y-intersection. This may be because they do not consider these maneuvers to be turns.

CHAPTER 6
FINDINGS AND IMPLICATIONS FOR A COUNTERMEASURE PROGRAM

This research was concerned with a special configuration of the Y-intersection, where the major road curves to the right and the side road continues on a tangent to the curve. This intersection is called a special right Y-intersection in this study. This type of intersection was not designed deliberately but is a consequence of the pattern of the original section roads of Michigan that followed the land surveys. Over time, the main roads were built to favor the major traffic flows. This particular type of Y-intersection was often due to abrupt changes in alignments required to follow the section roads. Many of these special right Y-intersections still exist today, and some can be found on the Michigan state trunkline road system.

Y-intersections have been criticized since the earliest days of the traffic engineering profession. The major shortcomings are that the Y-configuration introduces movements that are head-on in nature and forces motorists to turn their heads at awkward angles to check for traffic on the other legs of the Y. It also creates larger open areas than would occur at an intersection closer to a right angle, which increases the number of possible routes and encourages violations.

The special right Y-intersection amplifies some of the problems of the general Y-intersection. A vehicle turning left from the main highway to the crossroad at the locations where the main road curves to the right has to travel a considerable distance in the opposing traffic lane, thus increasing the opportunity for a collision with an oncoming vehicle. A vehicle on the crossroad attempting to turn left onto the main road may have difficulty in observing traffic approaching from the left.

Since 1984, the AASHTO policy on geometric design has been that no new three-legged intersections with acute angles be built. However, AASHTO policy does not specify that all existing Y-intersections be rebuilt. The prevailing approach of state departments of transportation toward existing Y-intersections, including the special right Y's, is to eliminate them from the state road network when the road segment on which they are located is resurfaced or improved, or to reconstruct them if they exhibit safety problems. The practice at the MDOT is the same and the special right Y-intersections in Michigan are being eliminated as the roads are resurfaced or as safety problems are identified.

Since funds for safety improvements are finite, programs for such improvements use criteria based on safety experience and risk to select intersections or road segments for treatment. Over time there had been several severe accidents at special right Y-intersections in Michigan, and questions about the safety record of these types of intersections were raised. Accordingly, the objectives of this research were to investigate the type and circumstances of accidents at special right Y-intersections and to propose appropriate remedial actions or countermeasures if an accident problem were found to exist.

Y-Intersections

A review of eight case studies of serious crashes at the special type of Y-intersection showed that in six of the eight cases the driver failed to yield the right-of-way to oncoming traffic and attempted to proceed straight onto the minor road. The ambient conditions were consistently good and the pavement was dry. Sight distance was good and with one exception the accidents occurred in daylight. The drivers who did not yield the right-of-way were known to be familiar with the intersection in most of these cases and, except for one case, alcohol or other controlled substances were not present.

Accident frequencies were available for three of the cases and were not high enough to merit notice. However, closer examination showed a pattern of head-on accidents at these three sites. In addition, one of the case studies provides evidence of speeding on curves.

The review of the case studies led to the following set of questions:

1. Do drivers approaching the intersection with the intent of going onto the minor road believe that they have the right-of-way? Is there something inherent about these special Y-intersections that leads drivers to assume that they have the right-of-way?

2. Do the special right Y-intersections have more head-on accidents than other three-legged intersections?

3. Can single-vehicle accidents at the special Y-intersections be attributed to the curve rather than the intersection itself?

4. Do drivers, unaccustomed to encountering oncoming traffic at the special right Y-sites in low-volume environments, simply forget to look for oncoming traffic?

5. Are drivers genuinely confused by the geometry of the special right Y-intersection?

6. Are the accidents reviewed in these cases typical of accidents at special right Y-intersections, or are these rare occurrences?

6.1 SUMMARY OF FINDINGS

Analysis of accident experience at special Y-sites began with the review of an information file collected by the Washtenaw County Road Commission for a safety improvement program at Y-intersections. Analyses of the Washtenaw Y-intersection data indicate that the special right Y-intersection has an accident experience quite similar to that of other types of Y-intersections. The prevalent accident type at these sites is the run-off-road accident at about 70% of all accidents. A before/after study found that incremental improvements in signing at the Y-intersections did not change the accident occurrence at these sites.

The major effort of the study centered on the analysis of geometric and accident data from the Michigan trunkline system. First, the accident experience of Y-intersections was compared against that of T-intersections, and then the accident experience at the special right Y-sites was compared against that of other Y-intersections and three-legged intersections in general.

The comparison of Y-intersections against T-intersections found that Y's had consistently higher accident rates than T's with the exception of curved sites in urban areas, where the T's had higher accident rates. A plausible explanation for this is that urban Y-intersections are modified as soon as they exhibit safety problems, leaving only relatively safe sites in that category

The analysis also showed that accidents at curved sites tended to be more severe at Y-intersections than at T-intersections. At rural curved sites, Y's had higher rates than T's of both run-off-road and head-on accidents. However, further investigation showed that the curved Y-intersections tended to be on more severe curves than the curved T intersections. Thus, there may be a confounding effect of degree of curvature that is not captured by this comparison.

As a category, the special right Y-intersection was found to have an overall average accident rate below that for three-legged intersections. Special right Y-intersections do have a higher portion of severe accidents and a higher severe accident rate than all three-legged intersections taken together, but the special right Y-sites are similar in these respects to other curved Y-intersections.

Taken as a group, special right Y-sites have a 22% lower head-on accident rate than all three-legged intersections taken together. In urban areas the head-on accident rate of special right Y-intersections is 42% lower than the aggregate rate for head-on accidents at urban three-legged intersections. In rural areas the rate of head-on collisions at special right Y-intersections is 14% higher than that for all rural three-legged intersections. However, the head-on rate for special right Y-intersections, both urban and rural, is either significantly lower or similar to that of the other categories of Y's.

When severity of accidents was examined, it was found that when head-on accidents do occur at special right Y-intersections, they tend to be more severe than head-on collisions at all three-legged intersections considered together. However, this is generally true of all curved Y-intersections and is probably a result of high speeds at these predominantly rural sites.

The special right Y-sites were found to have a high rate of run-off-road accidents. The rate for run-off-road accidents for special right Y-intersections is 53% higher than that for all three-legged intersections. This is entirely driven by the rural sites because among the urban sites, special right Y's have a rate for run-off-road collisions that is slightly lower than the aggregate.

The rate of run-off-road accidents resulting in fatality or injury at special right Y-sites is also elevated, which again is probably a reflection of high speeds. Further investigations showed that the higher rates of run-off-road accidents at special right Y-intersections held only for volumes below 5,000 ADT. At volumes between 5,000 and 10,000 ADT the rate was similar to the aggregate for all three-legged intersections, and at volumes above 10,000 ADT, the rate was 20% below the aggregate.

As part of this research, 53 special Y-sites were visited by a field crew. The crew recorded information about the traffic control, sight distance, signing, pavement markings, and delineation of each site, photographed the intersection, and observed driver behavior.

Overall, they found that the centerlines and edgelines clearly defined the curve of the main road. The field crew recorded their perceptions of continuity of the main road to the side road. They looked for the optical illusion of a perceptual trap by checking for continuations of the roadway, tree lines, fence lines, utility poles, and pavement contrast. Overall, they found that the centerlines and edgelines clearly defined the curve of the main road, and the contrast in pavements and markings minimized the perception of continuity. Their observations stress the important role of the edgelines and centerlines in identifying the main path.

To see if the perceptual trap hypothesis was apparent in the accident rates at special Y-sites, the 53 intersections with data on pavement type and road markings were divided into three categories based on pavement type on the side road and whether there was contrast between the two roads in terms of markings. It was expected that the likelihood of appearing as a perceptual trap should increase from gravel/contrast sites to paved/contrast sites to paved/no contrast sites and that a similar increase in accident rate might be observed.

Rates were calculated for special right and special left Y-intersections, both separately and combined, and rates were also calculated according to accident severity and type. Most of the analyses showed no relation between accident rate and degree of perceptual trap potential, therefore providing no support for the perceptual trap hypothesis.

The field crew also noted whether drivers proceeding from the major road to the minor road sites used their turn signal. It is speculated that drivers using their signals are aware that they are making a turn. At special right Y-intersections, drivers commonly signalled their intent to turn left onto the minor road, except at sites with a flasher or where an exclusive lane was available for continuing on the tangent. In contrast, drivers typically did not signal when turning right onto the minor road at special left Y-intersections. When proceeding from the minor road to the major road at special right intersections, drivers tended not to signal when continuing on a tangent onto the major road but often signalled when turning left onto the major road. About 60% of the drivers proceeding from a minor road onto a major road in either direction at the special left sites signalled. It appears that when drivers are proceeding onto another road without crossing the path of the other stream of traffic, they do not signal. However, if they are crossing the opposing traffic's path, they signal.

The Questions Revisited

The review of the case studies of severe accidents at special right Y-intersections led to a series of questions at the beginning of this research. These questions are now revisited in light of the findings of this research.

1. Do drivers approaching the intersection with the intent of going onto the minor road believe that they have the right-of-way? Is there something inherent about these special Y-intersections that leads drivers to assume that they have the right-of-way?

The literature review found that the particular type of geometry of the special Y-intersection is used by human factors psychologists as a classic example of a perceptual trap, i.e., a visual optical illusion. If, in fact, drivers perceive the side road as a continuation of the main path then it can be argued that there is something inherent about these intersections that leads drivers to believe that they have the right-of-way.

Although no direct studies of driver perceptions were conducted in this research, the field observations of road continuity and signalling patterns, as well as the analysis of pavement differences, do not support the argument that drivers proceeding to the minor road from the major road at special right Y's believe they have the right-of-way.

2. Do the special right Y-intersections have more head-on accidents than other three-legged intersections?

The findings of this research indicate that the special right Y-intersection does not exhibit a uniquely high level of head-on accidents relative to other types of three-legged intersections. However, when head-on collisions occur, there is a higher likelihood of a severe accident than there is at all types of three-legged intersections considered together. This higher likelihood is shared by the other categories of curved Y-intersections.

3. Can single-vehicle accidents at the special Y-intersections be attributed to the curve rather than the intersection itself?

Single-vehicle accidents are typically run-off-road collisions, and the special right Y-sites were found to have a high rate of run-off-road accidents at low-volume rural intersections. A review of police accident forms of accidents at special Y-intersections revealed a pattern of accidents in terms of type, severity, and circumstances similar to that for low-volume, rural, horizontal curves. Examining these records for contributing factors pointed to the presence of an interactive effect between the intersection and the curve in the occurrence of accidents

This study was not designed to quantify the contributions of the curve and the intersection to single-vehicle accidents at special Y-intersections. A different study design that compares accident experience at curved road sections with and without intersections would have to be carried out. However, the analyses conducted in the present effort indicate a strong effect of the curve and perhaps an interaction of the curve and the intersection on the occurrence of run-off-road accidents.

4. Do drivers, unaccustomed to encountering oncoming traffic at the special right Y-sites in low-volume environments, simply forget to look for oncoming traffic?

Whether or not drivers look for oncoming traffic in low-volume environments cannot be directly answered from the analyses carried out in this study. A study that compares driver inattention in different driving environments would need to be conducted to respond to this question.

5. Are drivers genuinely confused by the geometry of the special right Y-intersection?

Again this question cannot be directly answered from the studies conducted in this research. However, if confusion at special right Y-intersections were a common problem, we would expect the accident experience at these intersections to differ significantly from other curved Y-intersections. That it does not suggests that driver confusion is not a widespread problem. In the review of police accident records, it was found that a disproportionate percentage of the accidents at special Y-intersections occurred at night and involved alcohol. Thus, it is possible that the geometry of the special Y-intersection is confusing to an impaired driver, although it is difficult to separate the effects of the curve from the effects of the intersection in this case.

6. Are the accidents reviewed in these cases typical of accidents at special right Y-intersections, or are these rare occurrences?

Most of the accidents reviewed in the case studies were severe or fatal head-on accidents. This analysis found that only 3% of all the accidents at the special right Y-intersections on the Michigan state trunkline roads are head-ons that result in a severe or fatal injury. Therefore, these accidents cannot be considered typical of accidents at the special right Y-intersections and are rare occurrences.

6.2 IMPLICATIONS FOR COUNTERMEASURE PROGRAM

The findings of this research show that the special right Y-intersection does not exhibit unusual or unique accident patterns relative to other three-legged intersections. The results indicate that the special right Y-intersection should be treated as a member of the set of curved Y-intersections in the development of countermeasure prioritizing programs. The exception to this is the set of special right Y-intersections in low-volume, rural areas, where the rate of severe run-off-road accidents is particularly high. These sites should be grouped together with rural horizontal curves in the development of treatment priorities.

Identifying Problem Locations

Membership in the class of special right Y-intersections is not sufficient for an intersection to be a candidate for remedial action. Since these intersections should be considered together with all curved Y-intersections, any special right Y-intersection that has accident characteristics worse than the average curved Y-intersection should be considered as a possible candidate for safety improvement. In particular, the rates for total accidents, head-on accidents, and run-off-road accidents per vehicle volume should be considered. Since sites with very few accidents but low traffic volumes can exhibit high rates relative to traffic volume, consideration should also be given to the number of accidents at a site over time. Therefore, a process for identifying special right Y-intersections for possible safety improvements should also include a check if the number of accidents per year is greater than that of an average curved Y-intersection.

The following table shows the average accident rate for curved Y-intersections for both rural and urban areas that can serve as threshold values for identifying problem special right Y-sites.

Table 6-1 - Threshold Rates for Identifying Problem Special Right Y-Sites

Accident Rate per 100 Million Vehicles	Rural	Urban
Total Accidents	37.5	34.3
Head-On Accidents	7.7	8.8
Run-Off-Road Accidents	13.0	7.2
Number of Accidents per Site per Year	0.5	1.1

Countermeasures

From the review of policies toward Y-intersections and treatments for special right Y-intersections, it is quite clear that the modification of the intersection to a T-configuration is the most highly recommended treatment for any problem Y-intersection. However, other types of treatments may be applicable depending on the accident pattern at the site.

Urban Areas

Special right Y-intersections in urban areas that exceed the accident rates listed in Table 6-1 should be quite rare. As indicated earlier, the category of special right Y-intersections has lower accident rates in urban areas than other types of curved Y intersections. However, it is possible that changes in land development increased traffic, altered traffic patterns, and increased accidents at a location that previously did not exhibit safety problems. In any event, an urban special right Y-intersection that exceeds any of the thresholds given above should be given priority in safety improvement programs.

The selection of a countermeasure and its design is extremely site specific and should address the problems identified in the review of the accident experience. For urban areas the following three types of countermeasures are applicable: reconstruction to a T, channelization, signalization, or some combinations of these.

It should be noted that curved urban T-intersections have higher accident rates than curved Y-intersections for unsignalized intersections with two-way traffic on all legs. Thus, the redesign should not be a simple conversion to a T, but should be used together with channelization or signalization.

Rural Areas

Sites in rural areas that exceed the rural threshold rates should be candidates in a safety improvement program. An investigation of the accident patterns should precede any decision.

Overall Accident Rate Exceeded

If the overall accident rate threshold is exceeded, the prevailing accident type should be identified to select the appropriate countermeasure. For example:

If the prevailing accident type is a rear-end collision between vehicles on the main road, the treatment would be to provide a passing opportunity for through traffic. This could be accomplished with a fly-by lane (passing blister) or left turn lane at the intersection. If the intersection is modified to a T, the opportunity for passing left-turning vehicles should also be provided.

If the prevailing accident type is a rear-end accident on the side road, the site should be checked for problems with visibility. Specifically, it may be difficult for drivers on the side road to see traffic approaching from the left on the main road. If that is the case, the best treatment for this pattern of accidents would be to modify the intersection to a T.

If the prevailing accident pattern features collisions between vehicles leaving the side road and vehicles on the main road, visibility and the difficulty of seeing oncoming vehicles on the main road should be reviewed. The best treatment for this situation would be to modify the intersection to a T. A flasher could be considered as an alternative treatment or as an interim measure. However, visibility, line of sight, and traffic volumes have to be considered carefully before the flasher is used.

If the prevailing accident type is a collision with an animal (deer), reconstructing the intersection to a T will not help. Other than posting deer advance warning signs there are no countermeasures for this accident pattern.

Head-On Accident Threshold Exceeded

If the head-on accident threshold is exceeded, the signs and pavement markings at the site should be reviewed. If the signs and pavement markings are below MUTCD standards or in poor condition they should be improved. However, this study has found that small upgrades in signs have not had an effect on accidents at the sites that are already signed. Therefore, in most cases where the head-on collision threshold is exceeded, the intersection should be reconstructed to a T.

Run-off-Road Threshold

The threshold for run-off-road accidents given in Table 6-1 applies to sites with volumes over 5,000 ADT. For sites with volumes below 5,000 ADT the special right Y-sites should be grouped together with horizontal curves and the criteria used to select candidates for improvement from that set of road segments should be applied.

Run-off-road accidents at curved sites usually occur because the vehicle is travelling at speeds too fast for the curve. Signs and pavement markings that warn the driver of an upcoming curve, provide a speed advisory, and delineate the curve and guide the vehicle through it are standard treatments of such sites. Before any other treatments are considered a review of the signs and pavement markings should be made and brought up to MUTCD standards, if found to be lacking.

The rate of run-off-road accidents at curved T-sites was lower than for special right Y-intersections for all volumes categories. Furthermore, these accidents tended to be less severe at the curved T-sites than at the special right Y-sites. However, the curvature at the Y-sites tended to be greater than at the T-sites. This suggests that at sites with high rates of run-off-road accidents there may be safety benefits in modifying the special right Y-sites to T's, but the horizontal curve should also be modified in the reconstruction.

This research also found that a disproportionate percent of run-off-road accidents at special Y-intersections involve alcohol. Policy type countermeasures intended to remove impaired drivers from the road, especially in rural areas, would contribute to the reduction of this type of accident.

Routine Maintenance

The various findings about accident risks at special Y-intersections are based on data from sites with existing signs and pavement markings. The field studies and photolog review of the special Y-intersections conducted as part of this research found the signing and pavement markings to be in compliance with the MUTCD. Curves were marked with advance-warning signs and speed advisories when needed. Chevrons and target arrows were used on more severe curves. The side roads were controlled with stop signs, usually preceded by stop-ahead signs. The pavements were marked with centerlines and edgelines.

Y-Intersections

The field studies and other analyses conducted in this research indicate that the special Y-sites do not appear as perceptual traps because the pavement markings provide guidance as to the location of the main path. Good pavement markings counter the perceptual trap illusion. Good signing and pavement markings should not be considered as countermeasures at the special right Y-sites but rather as an integral part of the basic road system. They are essential for the operation of these intersections and must be maintained in good condition.

Conclusion

This study has examined the special right Y-intersection, where the main road curves to the right and the side road continues on a tangent, from many perspectives. The severe head-on accidents at these sites which led to this research were not found to be typical of the accident experience at such sites. In terms of accident patterns, the special right Y-intersection is similar to other types of Y-intersections on curves. Thus, the membership of an intersection in the set of Y-intersections where the main road curves to the right and the side road continues on a tangent is not sufficient to mark a site for immediate safety improvements. The criteria by which these sites are identified for safety improvements should be the same as those applied to all curved Y-intersections. However, even if the special right Y-sites do not exhibit safety problems it is very important that the signing, centerline, and pavement edgeline delineation be maintained in good condition.

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