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DETERMINATION OF A DISCRIMINANT FUNCTION
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DETERMINATION OF A DISCRIMINANT FUNCTION AS A PREDICTION MODEL FOR EFFECTIVENESS OF SPEED ZONING IN URBAN AREAS

By

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ABSTRACT

DETERMINATION OF A DISCRIMINANT FUNCTION AS A PREDICTION MODEL FOR EFFECTIVENESS OF SPEED ZONING IN URBAN AREAS

By

Fred Coleman, III

The critical task of controlling the speed of drivers in order to create a safe, yet efficient surface transportation system is found to be a mixture of policy, human behavior, and the physics of vehicles in motion. Speed zoning is the procedure utilized by traffic engineers to inform drivers of the required balance between safety and speed of travel appropriate for a specific section of a road. The objective of speed zoning is to convey an understanding of these factors in a manner consistent with environmental conditions and driver expectancies such that the overall safest driving environment can be achieved.

A review of the literature indicates traffic speed variation, traffic speed distributions, roadside friction, and human behavior are the primary factors in accidents.

The problem is that where states have procedures which quantify and use roadside development variables the empirical basis for their inclusion or exclusion has not been validated. Furthermore, the type and level of adjustment for these variables has not been substantiated as appropriate or meaningful.

Because of these limitations in the speed zoning procedure traffic engineers have no way of predicting if their speed zoning actions will result in better compliance to speed limits and most importantly, make the driving environment safer. As a result, analyses of speed zones have shown mixed results.

The hypotheses of this study is that a quantifiable relationship exists between accident parameters, speed parameters, roadside friction, and environmental/geometric variables such that it is possible to predict the effectiveness of speed zoning in urban areas. It is hypothesized that there exists specific variables which can serve as predictors of the effectiveness of proposed speed zoning actions.

In order to determine the effectiveness of speed zoning a set of treatment and control zones from the Michigan Department of Transportation files were matched in a before and after paired comparison experimental design. Those zones determined to be effective based on statistical tests utilizing a confidence coefficient of .95, in reducing accidents are analyzed. Discriminant analysis is used to determine which variables distinguish effective from non-effective speed zoning actions and therefore serve as predictors of the effectiveness of speed zoning actions.

Dedicated to
Jessie Mae Boyd Mack
1933-1971 (Mother)
and
Dillie James Boyd
1908-1989 (Grandmother)

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Chapter 1

Introduction

1.1 Speed and Safety

The relationship between speed and safety is characterized by the physics of vehicles in motion. Transportation Research Board Special Report 204 [1984] identified the following four reasons why reduced speeds are likely to yield safer driving:

1. When traveling at a higher speed, a car moves a greater distance during the fixed period of time that it takes for the driver to react to a perceived problem;

2. On highways lacking adequate superelevation, a driver's ability to steer safely around curves diminishes with speed;

3. The distance required to stop a vehicle by braking increases with speed; and,

4. Crash severity increases disproportionately with speed at impact.

Another factor in the speed-safety relationship is that concerning variation in speeds on the same highway segment. As reported by Solomon [1964] and Cirillo [1968] a wider variability in speeds increases the frequency of motorists passing one another which, in turn, increases the opportunities for multi-vehicle accidents to occur.

The authors of TRB 204 [1984] in discussing this topic add "speed variability contributes to the front-to-rear accidents prevalent on Interstate highways. These accidents are most common near intersections as motorists who slow down and change lanes to exit mix with motorists traveling at much higher speeds."

This relationship was also illustrated in West and Dunn's [1971] study. West and Dunn's data consisted primarily of rural two lane highway segments. Their study was able to identify the exact speed of travel for a large proportion of vehicles involved in accidents on the study segments. This is in contrast to police traffic investigators who estimate speed data from skidmarks and eyewitnesses to the accident. The ability to accurately pinpoint the travel speed of at least one of the vehicles as reported by West and Dunn [1971] just prior to the accident has provided the most accurate portrayal of the accident involvement rate by the deviation from average speed . Figure 1 illustrates these findings.

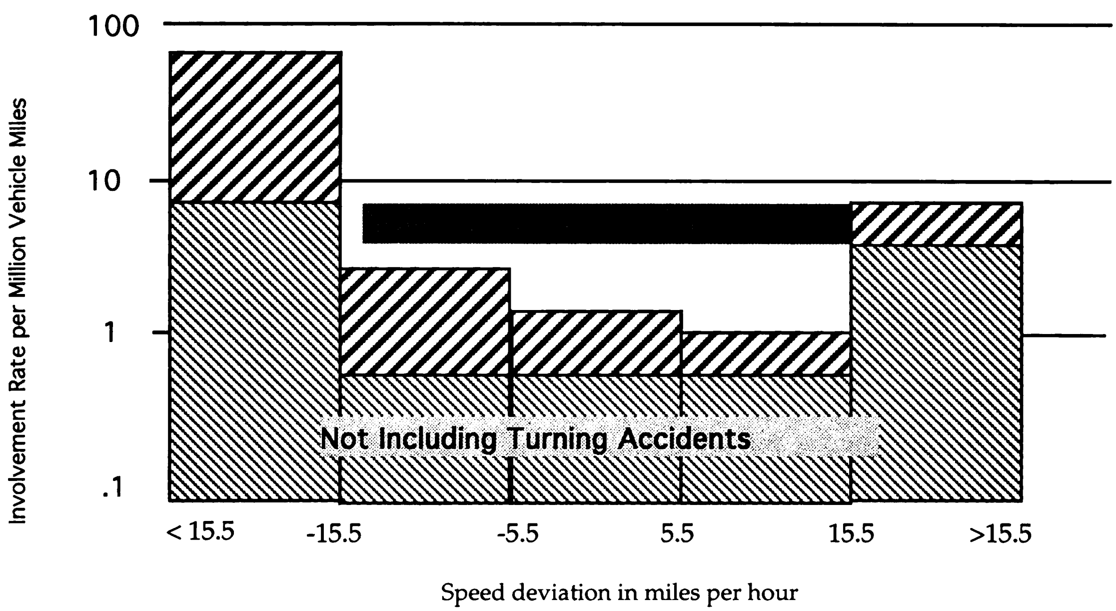

Figure 1. Accident Involvement Rate by Deviation from Average Speed

Source: West and Dunn [1971]

A key finding of West and Dunn [1971] was that slow drivers had higher accident involvement rates than fast drivers. Warren in a FHWA [1982] report on West and Dunn's findings, indicates when turning accidents were excluded the involvement rates for high and low speed drivers were very close and approximately six times higher than those of drivers close to the mean traffic speed. Warren explained the difference by noting the fact that cars stopping to turn or enter a road are naturally going to be deviating significantly from the mean traffic speed.

However it is not only vehicles stopping to turn that deviate from the average speed as documented in research conducted by G.G. Denton [1967]. His experiment on drivers directed to attain a series of pre-determined speeds

without use of a speedometer yielded results of substantial over and underestimation. Dentons' prior research on drivers use of a speedometer to monitor and control their speed indicated that drivers did not use the speedometer but evaluated their speed via sensory motion. His 1967 study concluded their ability to accurately select a speed by this technique was limited.

In summary, the relationship between speed and safety is one characterized by the physics of vehicles in motion. The speed at which it is safest for drivers to travel is within approximately (±) one standard deviation of the mean travel speed of the traffic stream. Low speed and high speed drivers are the most likely to become involved in accidents. The faster the speed of vehicles involved in accidents the greater is the likelihood of injury.

1.2 Speed and Accident Types

The relationship of speed to accidents by type is documented by Solomon's [1964] work. Using data from his study, figures 2, 3, and 4 represent his findings. Essentially, at low speeds the predominant accident types are rear end and angle. Figure 2 illustrates the similar trend in day and night occurrences of rear end and angle involvements as travel speed increases.

The overall pattern for rear end involvements is a high proportion of involvements at low speeds declining as speed increases. Rear end accidents as a percentage of total accidents range between 50% and 40% at speeds less than 22 mph up to 47 mph for both day and night occurrences. From 48 mph to 72 mph rear end accidents decline as a percentage of total accidents in both day and night to slightly above 20%. This trend indicates that rear end accidents as observed in this study are related to speed, however in a less significant manner as speed increases above 42 mph.

The substantially higher rear end involvements at low to moderate speeds are explained by Solomon in comparing the speed difference between the normal travel speed between pairs of vehicles and that of the two colliding vehicles. Solomon [1964] states "In summary, passenger car drivers involved in rear end collisions were more likely to have been traveling at a speed difference much greater than that for pairs of vehicles in normal traffic." Beatty [1972] studying similar mainline highway segments categorized as urban and rural locations found that 84 percent of two-vehicle accidents were reported as rear-end collisions or same-direction sideswipe. Beatty [1972] found that "40 percent of the two-vehicle accidents were in urban areas and only 27 percent of single-vehicle accidents occurred in these same areas. This would certainly imply the congested traffic conditions more typical of the urban areas." Beatty also confirmed Solomon's findings of speed difference and accident involvement. Beatty [1972] found "speed differences for two vehicles involved in an accident is, on the average 11.4 mph greater than for two randomly selected vehicles. The magnitude of the excess is almost twice the standard error even for single observations."

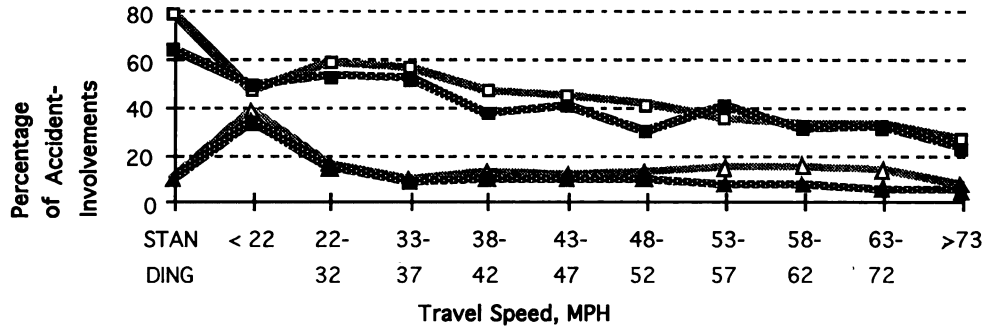

Figure 2. Percentage of Rear End and Angle Involvements Day vs. Night with Travel Speed

Source : D. Solomon [1964]

Angle accident involvements peak at a travel speed of less than 22 mph at about 38 percent for day and 33 percent for night. Angle accidents for both day and night range from 16% to 7%(day) to 14% to 4%(night) for the remainder of the speed categories. This leads to the conclusion that angle accidents as a percentage of total accident involvements are not related to increasing speed. Solomon's data indicates that at low speeds (5-25 mph) angle accidents are a significant share of accident involvements. Solomon points out "This is the speed of many vehicles at crossroads, driveways, and other points of access. However, the study sections were selected so that crossroads were at a minimum, and the data shown are typical of main rural highways having little roadside development. Main rural highways having considerable roadside development or many more intersections would have a higher proportion of angle collisions than shown here."

Figure 3 compares the same relationship of involvement for single vehicle accidents (day and night) with travel speed. A slightly increasing trend over the speed range from 33 to 72 mph is observed for daytime accident involvements. The lower end of the speed range for daytime occurrences constitutes a very low percentage of accident involvements. The range greater than 73 mph shows a moderate increase over the speed range of 33-72 mph.

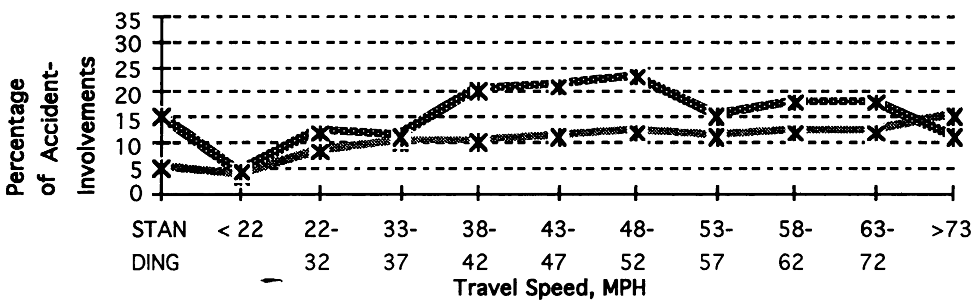

Figure 3. Percentage of Single Vehicle Involvements Day vs. Night with Travel Speed

SINGLE VEHICLE-DAY   SINGLE VEHICLE-NIGHT

Source : D. Solomon [1964]

The pattern is similar for night time occurrences with a higher percentage of involvements in the standing speed range. From less than 22 mph to 37 mph the day and night percentage of occurrences are mirrored. Beyond 37 mph night time occurrences are double the percentage in daytime over the speed range 38 to 52 mph. This disparity in accident involvements continues from 53 mph to 72 mph but at a reduced difference. At greater than 73 mph the night time percentage dips slightly below the daytime percentage accident involvement.

This data leads to the conclusion that night time single vehicle accident involvements are more likely to occur at speeds in the range from 37 mph to 72 mph in comparison to daytime single vehicle accident involvements in the same speed range. The rate of occurrence increases substantially between 38 and 52 mph, indicating a speed range where these accidents are increasing relative to daytime accident involvements of this type. This is in contrast to rear end and angle accidents which are declining as speed increases. This finding indicates a positive relationship between night time single vehicle accidents and increasing speed over a defined speed range.

Figure 4 derived from Solomon's data and re-compiled by Warren in a FHWA [1982] report represents the change in daytime percentage of accident involvements over various speed ranges. The data provides evidence that rear end and single vehicle accident types are related to speed of travel at the time of the accident. The percentage of accident involvements for rear ends decrease as speed increases. However, the percentage of accident involvements for single vehicle accidents increase as speed increases.

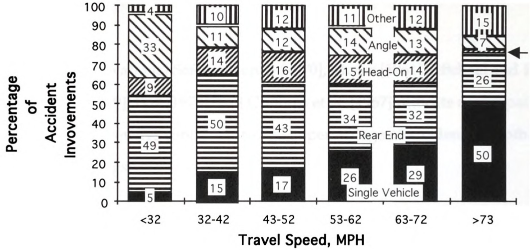

Figure 4. Variation of Accident Type with Speed

Source: D. Solomon [1964]

The predominance of rear end accidents in certain speed ranges is explained by Solomon [1964] as follows:

> "Pairs of passenger-car drivers involved in two-car rear end collisions were much more likely to be traveling at speed differences greatly in excess of those observed for pairs of cars in normal traffic. For example, fully one-third of accident-involved pairs of drivers were traveling at speed differences of 30 mph or more, compared to only 1 percent of pairs of cars in normal traffic."

1.3 Access Points and Roadside Development and Safety

The environmental conditions drivers face in navigating urban and rural roadways produces conflicts, some of which are a direct result of the access points available. The greater the intensity of access points the greater the likelihood of accidents resulting from these conflicts.

1.3.1 Driveways

Studies by the National Safety Council [1970], Marks [1961], Michael and Petty [1966], Box [1969], Box [1970], and Cribbins et al. [1967] indicate access points in the form of driveways contribute to a high percentage of accidents in both urban and rural settings.

Box [1970] conducted a study of driveway accidents in Skokie, Ill. by type of maneuver and collision. His statistics show that 58% of the total involve entering vehicles and 70% involve left turns. Of those involving entering vehicles rear ends were 65% of the accident type. Of those involving left turns, rear ends were 37%, right-angles were 34%, and head-on were 21%.

Glennon and Azzeh [1976] describe four types of accidents which they indicate are hard to identify and they believe are underrepresented in most if not all accident statistics concerning driveways:

(1) The rear end accident which happens upstream from the driveway because of a vehicle slowing down to enter the driveway;
(2) The sideswipe accident caused by vehicles changing lanes behind a vehicle preparing to enter a driveway;
(3) The rear end accident that happens downstream from the driveway involving a vehicle from the driveway that has not yet gained enough speed; and
(4) Collisions involving two vehicles using closely spaced adjacent driveways and collisions of driveway vehicles with intersection vehicles when the driveway is close to the intersection.

Glennon and Azzeh [1976] report that the most critical factor relevant to driveway accidents is relative speed. "Large speed differentials between through vehicles and maneuvering driveway vehicles create traffic inefficiency and its byproduct, increased accident potential." Stover et al. [1970] in their study found a distinct relation between driveway entrance speed and the efficiency and safety of driveway operations. They found that as driveway entrance speed increased from 2 mph-10 mph the traffic interference falls off rapidly. For the increase from 10 mph-15 mph some additional reduction is realized, but for higher entrance speeds, the additional change is small.

Glennon and Azzeh [1976] argue that for rural roadways and some urban roadways entrance speeds of 15 mph may be too low. Referring to Solomon [1964] they point to the "strong correlation between the involvement rate for two-car rear end collisions and speed difference for main rural highways. His findings indicate that for minimizing rear end collisions, a differential of less than 10 mph between through speed and driveway speed is desirable."

Stover et al. [1970] reports that " the kind and amount of medial and marginal access control bear heavily on the kind and amount of roadside development. In addition, the kind and amount of roadside development determine the kind and amount of vehicle traffic entering the traffic stream at any particular access point. The number of access points and the traffic entering the traffic stream at these points determines, in some measure, the over-all accident rate for any particular length of highway."

Kipp [1952] in his Minnesota study found no significant difference in accident rates for road sections having no access points and those having access points serving non-commercial purposes. Stover et al. [1970] summarized these findings as "this would seem to indicate that access points which are used relatively infrequently do not make a major contribution to the accident potential of a road section." The rate for sections with access points serving commercial activities was twice as great as the rates in the other two categories (no access points and non-commercial access points). When road sections were analyzed by traffic volume groups, correlation was found between the number of access points per mile and the accident rate. Road sections with commercial activities on abutting lands had relatively high accident rates. The rate for these sections was between two and three times the rate found on sections having no commercial development and nearly four times as great as the rate for strictly rural sections with few intersections.

Major and Buckley [1962] in their study of access point spacing along an arterial stream of traffic considered the problem from the abutting property viewpoint in evaluating arrangements to provide for minimum delay to and maximum capacity for entering traffic. In their study they found " a multiplicity of driveways or access points at close intervals produced undue conflict with the arterial and mutual conflict with each other, resulting in lower capacity and increased delays for traffic from abutting property entering the highway."

1.3.2 Intersections

Peterson and Michael [1965] in their Indiana study report that intersection accidents per 100 million vehicle-miles increased when:

(1) Percent green time on the bypass decreased
(2) Bypass or cross-street ADT increased
(3) Percent left turns from the bypass increased
(4) Maximum approach speed increased
(5) Number of intersection approaches increased
(6) Total width of driveways within 200 ft. of the intersection increased.

In their same study they found that for non-intersection study sections, accidents per 100 million vehicle-miles increased when:

(1) Total number of establishments per mile increased
(2) Total number of driveways per mile increased
(3) Total number of low volume intersections per mile increased
(4) Geometric modulus increased
(5) ADT increased
(6) Operating speed increased
(7) Total width of driveways per mile increased
(8) Length of intersection turning lanes in the section increased

1.3.3 Medians

Cribbins [1967] study in North Carolina of median openings, accidents and roadside development found that "as traffic volumes increase, use of median openings rapidly become more hazardous. "When combined with intensive roadside development, use of median openings under high-volume conditions becomes more hazardous. Signalization of median openings does not necessarily reduce the hazard of using openings under high-volume conditions; rather, it tends to make the traffic flow in a more orderly way by offering a more equitable time distribution for movements. Also as roadside development increases and crossovers of any type are permitted, accidents will increase." With regard to speed limit reduction, high volumes and roadside development the authors state: " the mere reduction in speed limit, when volumes are high and roadside development is intense, does not suffice to keep the accident rate at a low level. The increased hazards associated with turning movements under high volume conditions far exceed the benefits occasioned by reducing the speed limit."

Safety on a road is determined largely by freedom of interference with the free flow of traffic. Therefore highways with full access control are expected to have the lowest rate of accidents with partial and unlimited access being higher. Mulinazzi and Michael [1967] verified this in their study. They found " accident rates are lowest for highways with full access control and highest for no access control. On the other hand, the number of fatalities was highest under partial access control."

Essentially, the conclusions are that there is a strong relationship between roadside development and access points for accidents in general and accidents by type. Faithful [1959] has found a "definite correlation between accidents and ribbon development." Flaherty [1959] found a similar result in his Minnesota study between lineal feet of highway oriented uses and traffic volume. His analysis showed a correlation coefficient of .81.

Solomon [1964] presented data in a table format indicating type of accident involvement by day and night related to number of intersections per mile. This same data is presented here as Figure 5. Rear end accidents occurring during day and night indicate a trend of increasing frequency as the density of access increases. This relationship is also documented for angle accidents, with those occurring in the day showing the sharpest rate of increase as access density intensifies. Access points provide increased opportunity for variability in the speeds of vehicles in the form of entry and exit as well as crossing the traffic stream. The distance traveled when traveling at a higher speed and the distance required for braking increases with speed. The frequency of access points, the volume of traffic served by a variety of access points, and the acceleration/deceleration of through and merging traffic creates situations where constant evaluation of speed and distance are required by the driver.

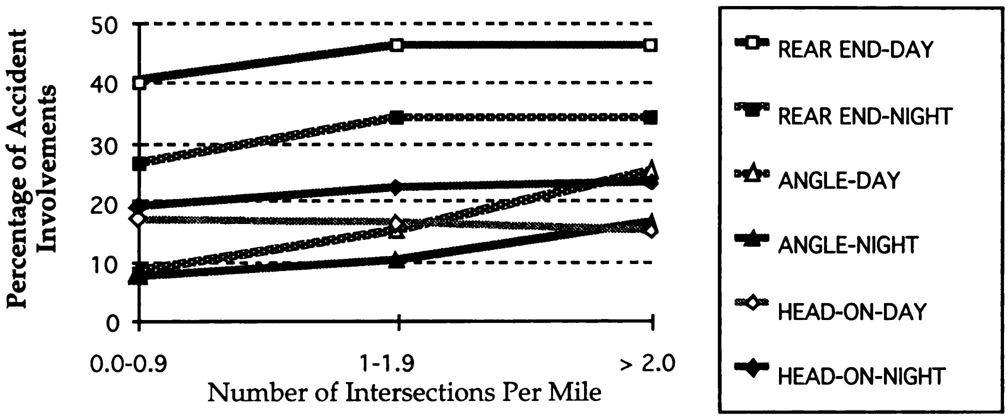

Figure 5. Number of Intersections Per Mile on Two Lane Highways Related to Type Of Collision

Source : D. Solomon [1964]

1.4 Driver Judgment

The prevalence of certain accident types(i.e. rear ends, angles, sideswipes) can be partially explained by known factors under which these involvements take place. Conditions such as the type of maneuver, traffic control (or lack thereof), and geometric conditions all provide meaningful clues to understanding the basis for certain accident types.

What is harder to ascertain is the judgment of drivers immediately before the accident. Seldom does a driver state the use of poor judgment to an investigating officer, probably because of the trauma of the accident as well as financial consequences if the driver is at fault. From a research perspective knowing the behavior exhibited by the driver and an accurate travel speed immediately prior to the accident is very important. Headways maintained between vehicles traveling in the same direction in the traffic stream provide one measurable variable to understand vehicle behavior. This variable along with travel speed provide the most direct measurements of driver judgment.

Police officers investigating an accident are required to take statements from both parties involved. Where a fatality or serious injury has occurred, this is also supplemented in many states with an on-scene accident investigation where physical evidence such as skid marks, brake function, etc. are checked to determine how the accident occurred. One of the questions routinely asked by investigating officers to involved drivers is the speed they were traveling immediately prior to the accident. This speed can also be determined from skid marks if they are present. In property-damage or minor injury accidents evidence which would provide accurate information on the speed of vehicles involved in accidents is seldom collected. In most cases, the officer has to rely on the speed estimated by one or both of the involved drivers. Under the circumstances of stress and shock the accuracy of their statements concerning travel speed is questionable.

1.4.1 Driver Estimation of Speed of Travel

A more basic question is whether drivers can estimate their speed of travel or velocity in an automobile accurately. Denton [1965] in his research reports that "drivers tend not to use the speedometer as an aid to driving when carrying out maneuvers." Denton [1967] and Snider [1967] separately conducted experiments on drivers to determine how accurately they could estimate their driving speed.

Both experimenters used different approaches but arrived at the same conclusion. Drivers tend to underestimate their travel speed below 30-40 mph and overestimate it above this same range.

Denton [1967] found that "in a driving situation speed estimation by the driver is affected by initial speed of the vehicle and by the extent and direction of speed change." Denton found that in deceleration tests the initial speed (S) had little effect on the ability to achieve a certain speed, but rather the change in speed (R) was the dominant factor in achieving a desired final speed. Denton tested drivers required to decelerate to 1/4 to 1/2 to 1 (retain initial speed) of their initial speed. The results indicate that drivers consistently drove faster than the prescribed speed change requested in the test. Denton [1967] suggests the implication on actual driving is the following : " drivers on a motorway traveling at 80 mph and wishing to decelerate to exit at a speed of 20 mph, if judging subjectively would enter the ramp at 48 mph believing the sensation to be that of 20 mph. In other words he has committed a positive error of judgment of 140%." At 40 mph with a final speed objective of 20 mph Denton reported the error in judgment is approximately 40%.

The results for acceleration (R> 1) in contrast to deceleration indicate subjective error is significantly affected by both initial speed (S) and change in speed (R). Denton states "the subjective error is seen to be significantly affected by both (S) and (R), in such a way as to suggest that drivers accelerating from sliproads (*ramps*) onto the motorways will tend to think that they are traveling faster than they really are."

Figure 6 and 7 represent a graphical representation of the relationship between initial speed S, and change in speed R, for the deceleration and acceleration data respectively expressed as percentage error in final speed.

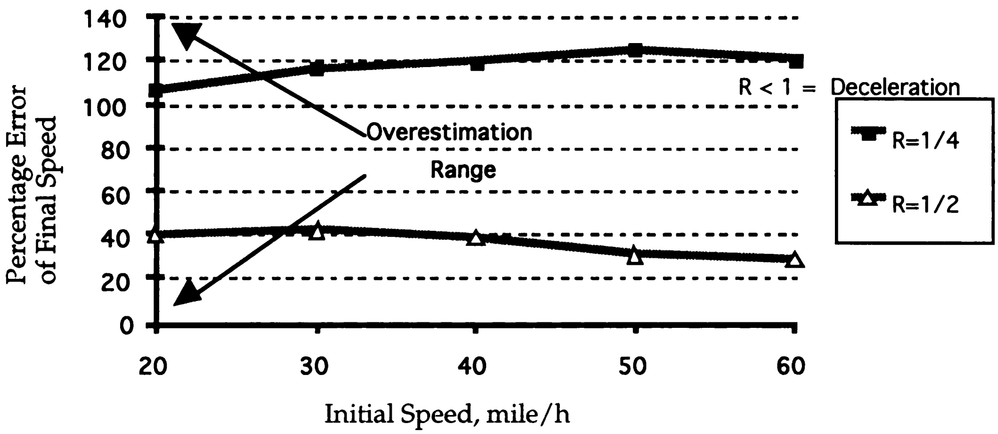

Figure 6. Percentage Error of Final Speed as a Function of Initial Speed, R< 1

Source : G.G. Denton [1967]

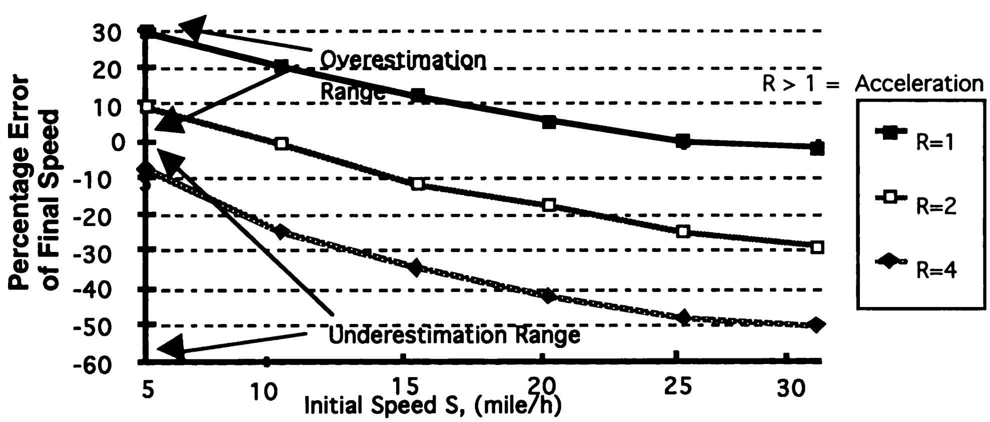

Figure 7. Percentage Error of Final Speed as a Function of Initial Speed, R > 1

Source : G.G. Denton [1967]

1.5 Human Factors

The driving task is a combination of interactions between humans, vehicles, and the roadway. Auditory, visual and perceptual cues are used by drivers to assist them in performing this task. The ability of drivers to see a change in distance in a car-following situation and apply the brakes to avoid a potential accident involves the drivers ability to judge distance and maintain a safe headway as well as sufficient brake reaction time. Colbourn et al. [1984] conducted a study to assess the headways drivers would choose to maintain a safe driving distance between vehicles at three different speeds: 30, 40, and 50 mph. Using three different driver experience levels tested under (1) improbable conditions of sudden deceleration and (2) highly probable conditions of deceleration, results on a closed test track yielded values very close to the "two second rule of thumb" which generates a distance that enables drivers to detect and react to drastic changes in the speed of a lead vehicle in a car-following situation. However, Colbourn [1984] reports "kinematically the critical distance separating vehicles varies with the square of the speed. As a result, drivers will maintain headways greater than necessary at low speeds but will tend to follow too closely at higher speeds." Colbourn took his drivers through a third set of conditions which focused on random unannounced panic stops to measure the length of headways maintained before and after the stop. His findings were that "drivers used headways which did allow them to stop safely behind the leading vehicle in an emergency situation and with a respectable margin." Colbourn reflected on these findings in regard to the real-world situation drivers find themselves in by stating:

> "On average, some 40% of the initial headway was lost during rapid braking. These conditions were fairly extreme in terms of

> severity of braking and optimal in terms of vehicle performance and road surfaces. Also the task was much simpler than that required on the road; subjects being fully aware of what would happen. Hence, it may not be surprising that performance was good. On the road there is a wealth of other information to process and reaction times will inevitably not be as fast as in a simple situation used experimentally.
>
> Thus, while it was observed here that drivers seemed to be using adequate headways in order to stop in an emergency situation, that situation was perhaps unrepresentative of highway driving conditions."

Being fully aware of the anticipated action was felt to have biased these results regarding maintenance of headways and headway choice in an experimental situation. One other impact of the anticipation effect was the measurement of brake reaction times. The range in the Colbourn [1984] data was .5 to 1.5 seconds. Using a correction factor developed by Johanssen and Rumar [1971] to estimate reaction times to an unexpected compared with an anticipated demand the corrected median reaction time was 0.9 seconds. Colbourn [1984] comments "again the situation considered was simple reaction, which is often radically different from that occurring on the road."

Colbourn [1984] concludes that "these findings suggest that under optimal conditions at least, and irrespective of their traffic experience, drivers can judge safe distances for vehicle following without perceptual-motor support devices. However, it is clear that such performance will rapidly deteriorate under conditions of poor visibility, bad weather, etc."

Probst et al. [1984] in his work on perceived self-motion and impairment of vehicular guidance also tested drivers brake reaction times. In an experiment involving vehicle following at different distances and speed while trying to maintain a constant gap he found that "reaction times were extremely slow, almost two seconds for a gap of 40 meters when the cars were traveling at 70 kilometers per hour." Using this data and other data from laboratory simulations Probst [1984] argues that additional reaction time over and above the normal reaction time range of .6 seconds to 1.0 seconds is needed in driving situations in the real world. Probst recommends that an additional .3 seconds be added because of the difficulty of determining the perception of motion while moving. In addition, .25 seconds if one is not already viewing the object and .15 seconds if ones' glance overshoots the object. Adding these values to the normal range leads to 1.30 seconds to 1.70 seconds for brake reaction times if all conditions are present. The upper value is approximately equal to values determined by Colbourn [1984].

Sivak [1982] conducted an experiment on drivers brake reaction times similar to Colbourn [1984], however with a data set of 1,644 data points. Taoka [1989] in estimating the statistical distribution of the Sivak [1982] data set postulates that "the measured reaction times published by Sivak and colleagues probably more closely estimates the true brake reaction time distribution of drivers than do the other three investigations. A car-following driver has less of an opportunity to anticipate the actions of the car ahead than a driver approaching a green signal at an intersection has in anticipating when the signal will turn to yellow." The 50th percentile (median) brake reaction time estimated by Taoka [1989] from Sivak [1982] is 1.07 seconds, 85th percentile is 1.78 seconds and 95th percentile is 2.40 seconds.

Data from Colbourn [1984] under optimal conditions suggest a brake reaction time between 1.8 and 2.0 seconds. Probst [1984] suggests a brake reaction time in the real world of 1.30 to 1.70 seconds. Taoka [1989] using data from Sivak [1982] suggests a brake reaction time of 1.78 seconds. All of these values provide an adequate safety cushion if drivers observe a two second headway rule of thumb if traveling at low to moderate speeds. In Colbourn [1984] the following is addressed to this "critical distance" :

> However, kinematically the critical distance separating vehicles varies with the square of the speed. As a result, drivers will maintain headways greater than necessary at low speeds but will tend to follow too closely at higher speeds.
>
> Rockwell's [1972] field studies showed that normal car-following results in a separation of 3-4 seconds between vehicles; 6 seconds was considered by most drivers to be appropriate for open-road driving. Minimum safe separations averaged 1-2 seconds, and headways preparatory to overtaking was about .5-1.0 seconds. British observational studies by Harms [1966] have shown that the percentage of vehicles close following (separations of less than 1 second) increases linearly with increasing traffic flow; from 5% at 150 vehicles per hour, to 25% at 1000 vehicles per hour.

Therefore if these observations and studies are correct it is possible to suggest that in general, under fairly optimal conditions most people drive at a reasonably safe distance in car-following situations. However, under increasing traffic density, poor visibility, or weather conditions, the optimal conditions under which drivers detect speed and distance changes is altered, and therefore place themselves at increased risk of accident involvement.

1.6 Methods of Controlling Speed

Methods for controlling speeds of drivers are achieved through three different means, design speed, speed laws, and speed limits. Design speed is a speed selected for a functional class of streets and roads to control the geometric design of the facility for basic safe operation. Speed laws are the legal definitions of laws regarding the type of speed limit which is implemented in a jurisdiction. While speed limits are the posted vehicle speeds determined through an engineering study of existing conditions and accident rates.

1.6.1 Design Speed

Design speed as defined by the American Association of State Highway and Transportation Officials (AASHTO) [1984] is "the maximum safe speed that can be maintained over a specified section of highway when conditions are so favorable that the design features of the highway govern."

Relative to arterial streets AASHTO states :

> "On arterial streets the design speed control applies to a lesser degree than on other high type highways. On rural highways or on high-type urban facilities, a certain percentage of vehicles are able to travel at or near the safe speed determined by geometric design elements, but on arterial streets the top speeds for several hours of the day are limited or regulated to that at which the recurring peak volume can be handled. Speeds are governed by the presence of other vehicles traveling en masse both in and across the through lanes and by traffic control devices rather than the physical characteristics of the street. During periods of low-to-moderate volume, speeds are governed by such factors as speed limits, midblock frictions, and intersectional frictions."

AASHTO [1984] recommends that arterial streets "be designed and regulated by control devices, where feasible, to permit running speeds of 20 to 45 mph." The lower range for local and collector streets through residential areas and the higher speeds for high-type arterials in outlying suburbs. Recognizing the transition from urban to suburban areas, AASHTO recommends the adoption of some form of speed zoning or control to prevent hazards associated with high speeds. The AASHTO basis is stated as follows: "although through traffic should be expedited to the extent feasible, it may be equally important to establish a ceiling speed to reduce hazard and serve local traffic."

1.6.2 Speed Laws

Speed control is implemented through three basic types of speed laws. The following are definitions from a FHWA [1985] report on speed zoning practices:

- Basic Speed Rule--specifies that regardless of any other speed limit that may be applicable at the time and place, the driver shall operate at a speed that is reasonable and prudent for existing conditions, taking into account actual and potential hazards encountered.

- Prima Facie Limits--any vehicles speed in excess of the established numerical limit is prima facie evidence that the driver is not operating at a reasonable and prudent speed. The law permits the driver the right to provide proof that the speed was not improper under existing conditions. Prima facie limits recognize the fact that no specific speed is particularly safe or unsafe at all times.

- Absolute limits--Absolute or fixed speed limits are always illegal to exceed regardless of whether the driver's speed was safe or reasonable and prudent for conditions.

The State of Michigan and many of it's municipalities use Prima Facie and Absolute Limits as the speed laws under which to govern vehicle speeds on designated sections of the road and street network. Based on these laws traffic engineers are required to perform an engineering study to determine the numerical speed limit that will apply to the road segment in question.

1.6.3 Speed Limits

Traffic engineers during the period from 1950-1970 gradually refined techniques utilized to determine a safe and reasonable speed limit (often in conjunction with police enforcement agencies) for motorists to travel on local, state and federal roadways. These techniques consist of measurements of traffic characteristics, land use, speed, and geometric factors existing at the time of the traffic engineering study. Their application and practice is oriented to the setting of speed limits in speed zones as opposed to speed limits on limited access facilities.

Accident frequency, severity, and accident type are the measures by which the safety of a roadway is determined. Accident statistics often serve as the variable of interest when a change is applied to a roadway (such as speed limits, signalization, or geometrics). Usually a "before and after" analysis is performed if other influencing variables such as traffic volume, land use characteristics, or construction have not independently altered the traffic characteristics of interest.

State and local transportation officials and the traffic engineering profession have practiced two similar procedures in determining a speed limit in a speed zone. The primary basis for both is the 85th percentile speed obtained in a spot speed sample. The major difference is to use "engineering judgment" to recognize and include other environmental and geometric factors ostensibly to reduce the limit below the 85th percentile speed if deemed necessary. In contrast, a small number of states and municipalities have adopted a policy which replaces engineering judgment with some form of quantification of environmental and geometric variables to reduce the speed limit below the 85th percentile speed.

A debate in the traffic engineering profession is underway fueled by recent state and federal research which seeks to determine which of the two policies of speed zoning leads to a safer driving environment for motorists.

1.7 85th Percentile Speed

Throughout the literature on speed zoning there is varied discussion as to which factors should be utilized in determining speed limits in speed zones. Carter [1949] may have been the first to suggest the value between the 80th and 90th percentile of the free-flowing speed plotted on a cumulative frequency curve. Matson, Smith and Hurd [1955] in their traffic engineering book state:

> "For any given road there is an optimum speed limit which will have the greatest effect on spot speed. This value is usually between the 80 and 90 percentile of the free-flowing speed as plotted on a cumulative frequency curve."

Johnston [1956] also suggested the 85th percentile. Baerwald [1957], Kessler [1959], and Avery [1960] provided additional support for the 85th percentile as the primary value to be used in setting speed limits. Kessler stated the justification as follows: "The 85th percentile speed is based upon the theory that the majority of motorists traveling upon a city street or highway are competent drivers and possess the ability to determine and judge the speed at which they may operate safely; further, that motorists are responsible and prudent persons who do not want to become involved in an accident and desire to reach their destinations in the shortest possible time."

In 1961, the Institute of Transportation Engineers Technical Committee 3-C published an article on "a valid statement of speed zoning principles and of the factors to be recognized in their application." The article "An Informational Report on Speed Zoning" suggests that speed limits should be based on prevailing vehicle speeds, physical features, accident experience, and traffic characteristics and control.

The institutionalization of the 85th percentile speed as the primary factor in the setting of speed limits in a speed zone was undertaken in 1969 by "Resolution of the Annual Meeting of the American Association of State Highway Officials" which states:

> "The review of existing practice revealed that most of the member departments use, primarily, the 85th percentile speed. Some agencies use the 90th percentile speed, and of secondary consideration are such factors as design speed, geometric characteristics, accident experience, test run speed, pace, traffic volumes, development along the roadway, frequency of intersections, etc."
>
> "On the basis of the foregoing review, the Subcommittee on Speed Zoning recommends to the AASHO Operating Committee on Traffic for consideration as an AASHO Policy on Speed Zoning that:
>
> The 85th percentile speed is to be given primary consideration in speed zones below 50 miles per hour, and the 90th percentile speed is to be given primary consideration in establishing speed zones of 50 miles per hour or above. To achieve the optimum in safety, it is desirable to secure a speed distribution with a skewness index approaching unity."

Further support of the 85th percentile criterion was provided by Research Triangle Institute [1969] stating:

> "The standard deviation of the speed distribution is from 5 to 7 mph. Approximately 85% of the drivers drive below the mean plus one standard deviation. The drivers having speeds between the mean and one standard deviation above the mean are definitely in a low involvement

> group. The region between one and two standard deviations above the mean speed encompasses approximately 10 percent of the drivers and does not have a significantly greater involvement rate than at mean speed. This region from the end of the first to the end of the second standard deviation is approximately the tolerance level allowed by police agencies."

Thus the 85th percentile speed is seen to be within one to two standard deviations of the mean speed which was found by Solomon [1964] and Cirillo [1968] to be the point at which there was the lowest accident involvement rates.

1.8 Evaluations of Speed Zone Effectiveness

A survey of highway officials on speed zoning practices was conducted in 1984 by the AASHTO Task Force on Speed Zoning and Control. Its' results along with a literature review were included in a report by Parker [1985]. The majority of respondents (82%) identified the highest priority research area as "determine the effects of altering the speed limits on speed and accidents." Kessler [1959] in his evaluation of 30 locations where speed limits were raised found the 85th percentile speeds unchanged, however, accidents decreased from 62 to 40. Parker [1992a] reports that Wenger [1960] examined accident experience at 25 locations in St. Paul, Minnesota and found that raising speed limits from 30 to 35 or 40 mph adversely affected accidents. Avery [1960] examined speed compliance in the same city at 18 locations where speed limits were raised from 30 to 35 or 40 mph and found no change in mean speed or 85th percentile speed. Dudek and Ullman [1987] examined six sites in rapidly developing urban fringe areas where speed limits previously posted at 55 mph were reduced to 45 mph. This change was not in accordance with prevailing 85th percentile speeds. They found no significant changes in speeds, speed distribution, or accident rates.

Parker [1992a] using 99 experimental and comparison sites in 22 states found where speed limits were raised accidents were reduced by 6.7 percent after implementation. Sites where speed limits were lowered, accidents increased by 5.4 percent. In both cases the change in accidents was not statistically significant. Also, Parker [1992a] found little change in the speed distribution as a result of raising or lowering the speed limits on urban and rural nonlimited access highways.

Parker [1992] in his study for the State of Michigan found that the 68 sites where speed limits changed, the overall reduction in accidents was 2.21 percent. He noted that before and after speed data were not collected at the Michigan experimental and comparison sites. Consequently, the effects of the posted speeds on driver behavior at the Michigan sites are not known.

1.9 Summary

The critical task of controlling the speed of drivers in order to create a safe, yet efficient surface transportation system is found to be a mixture of policy, human behavior, and the physics of vehicles in motion. Speed zoning is the procedure utilized by traffic engineers to inform drivers of the required balance between safety and speed of travel appropriate for functional classes of roads.

The literature review details the history of speed control, the apparent safe operating speeds, environmental conditions, as well as human decision-making which leads to safe operation at various speeds.

In summary, traffic speed variation, traffic speed distributions, roadside friction, and human behavior are found to be the primary factors in achieving effective speed control. The objective of speed zoning is to understand and apply these factors in a manner consistent with environmental conditions and driver expectancies such that the overall safest driving environment can be achieved with respect to the functional facility designated.

Michigan speed zoning procedure [1987, 1981] is based primarily on the 85th percentile speed with consideration for accident experience. Operating procedures agreed to in 1987 and prior draft procedures in 1981 confirm this practice. With a lack of empirical evidence to support a relationship to a speed limit change, the accident factor is relegated to subjective engineering judgment. Therefore, the results for the sites in this study reflect the variability of application of this factor in determining speed limits.

Parker [1992] in a study for the Michigan Department of Transportation (MDOT) found that while department policy suggested posting limits within 5 mi/h of the 85th percentile speed, due to political and community pressures and other nonquantitative considerations, this guideline is often waived. It was found in this study speed limits posted at nearly 31 percent of the experimental sites (21) and 23 percent of the comparison sites (20) were not within the 5 mi/h guideline. In nearly all [these] cases the limits were posted less than the 85th percentile speed.

In the same report Parker investigated errors associated with speed data collection. At a small sample of sites where data collected by the state was compared with automated equipment, he found the MDOT estimate of the 85th percentile speed is approximately 3 mi/h less than the speeds recorded by the automated equipment.

The errors found in speed data collection by the MDOT along with a significant lack of adherence to the suggested guidelines suggest that a number of sites have artificially low speed limits, which when compared to sites where this is not the case, the accident experience may be aberrant in comparison to similar signed zones.

Also, since typically little to no understanding of the empirically proven relationship demonstrated by Taylor [1965, 1965a] between speed distribution parameters such as skewness and accidents is employed in their speed zoning procedures, an opportunity is overlooked for setting consistent safe speed zone limits.

The results of the research conducted in speed zoning effectiveness indicate the results are mixed in regards to the relationship between setting speed limits at the 85th percentile speed and accident improvement. The purpose of this research is to identify additional factors involved and clarify their relationship to raising or lowering the speed limit based on generally accepted traffic engineering principles.

1.10 Statement of the Problem

In a 1985 Federal Highway Administration survey of state and local transportation officials four factors received the highest frequency response as part of their speed zoning procedure. In descending order they are : 85th percentile speed, accidents and pace speed tied for second, type and amount of roadside development was fourth. These four factors are measurable in quantitative units and are utilized by a number of states as part of a procedure to adjust the speed limit.

The problem is that where states have procedures which quantify and use roadside development variables the empirical basis for their inclusion or exclusion has not been validated. Furthermore, the type and level of adjustment of a variable in a procedure has not been substantiated as appropriate or meaningful.

Along with these limitations in the speed zoning procedure is the fact that traffic engineers have no way of predicting if their speed zoning actions will result in better compliance to speed limits and most importantly, make the driving environment safer resulting in a reduction in accidents. As a result, analyses of speed zones have shown mixed results.

In the Parker [1992] study of speed zones in Michigan he reported that 46 of the zones resulted in an increase in accidents while 19 resulted in a decrease. Taylor and Coleman [1988] report similar results for a study of speed zones in Muskegon County, Michigan. They found that 16 sites exhibited an increase in accidents following implementation of a speed limit, while 16 exhibited a reduction in accidents.

1.10.1 Statement of the Hypothesis

The hypotheses is that a quantifiable relationship exists between accident parameters, speed parameters, roadside friction, and environmental/geometric variables such that it is possible to predict the effectiveness of speed zoning in urban areas. It is hypothesized that there exists specific variables which can serve as predictors of effectiveness of proposed speed zoning actions.

CHAPTER 2

Methodology

2.1 Introduction

The literature review illuminated a number of factors that might be used to determine if speed zoning will be effective. In general, these were prior accidents, geometric and environmental conditions, speed parameters, and driver behavior.

The premise of this analysis is that it is possible to discriminate between effective speed zones and non-effective speed zones based on an accident analysis, by identifying the significant variables and characteristics of these road segments.

2.2 Site Selection

Several data bases were accessed to build the files used to conduct this analysis. MDOT staff provided a combined accident/geometric file for each speed zone for each year pre and post speed zoning action for all candidate sites. Candidate sites were selected based on an implemented Traffic Control Order (TCO) and/or a request for a Traffic Survey for an existing speed zone. The inventory of implemented zones was used to select candidate treatment (test) zones and the non-implemented zones resulting from a no change in speed limits decision were used to select control zones.

Zone matching of test and control zones for comparability was based on the criteria of speed limits (prior to change), volume, laneage, type (i.e. urban or transition to urban), and length. TCO maps for each speed zone were utilized along with the aforementioned data bases to assist in this process.

2.3 File Building

The specific technique to accomplish the merging of each accident in relation to environmental and geometric data, as well as speed data is to combine with each accident the respective variables that describe those conditions at the site of the accident. This was accomplished by utilizing the Michigan Department of Transportation (MDOT) Accident Master file for accidents, MDOT MIDAS III Road Segment file for geometric data, and MDOT Traffic Survey Request Speed file. In addition, to supplement the level of detail proposed for this analysis and capture conditions as close as possible to the time of accidents, the MDOT Photo-Log file for each speed zone was utilized to build a coded land use, laneage, driveway frequency, signal, and other geometric/environmental condition inventory for each tenth of a mile segment.

Using the ADD and MATCH commands in Statistical Package for the Social Sciences (SPSS) in each of the unique data sets, a record with accident, speed, and geometric data for each tenth of a mile that contained an accident in a speed zone was created. A single record for each accident including all the variables from each database is built. This created a new record which contained the accident data, geometric data provided by MDOT and manually collected photo-log data, and speed data. Spot speed data from speed data collection stations within each zone were utilized and is assumed to be representative of speeds throughout the segment in question. Typically MDOT chooses speed data stations free of interference from traffic signals and where free-flow speeds could be obtained.

In most cases the names of variables utilized by MDOT were used directly in the analysis. In some cases, names were slightly altered due to length restrictions. In order to utilize those variables which were qualitative as opposed to quantitative in nature, the researcher created codes and labels to identify them. These types of variables were identified as "coded" variables in the analysis and where appropriate will be identified as such. Typically, they were associated with data obtained from the photo-logs, such as land use types, laneage types, shoulder types, fixed objects, etc.

2.4 Determination of Effective vs Non-Effective Speed Zones

The experimental design utilized to determine effective versus non-effective speed zones is Before and After with comparison groups. Utilizing this design, the strength of findings and conclusions are improved if the comparison groups are shown to be comparable on those variables of interest in the before period. This analysis is performed on the accident variable since safety, as measured by accidents, is the primary measure of effectiveness (MOE).

Prior to complete accident/geometric/speed individual record-building, an analysis of the effectiveness of the speed zones was undertaken. The procedure involved converting accident frequencies to accidents per million vehicle miles (acc/MVM) for each year pre and post zoning action for each test and control zone. The year of the zoning action was excluded for both test and control zones. Each zone then had an accident rate per year pre and post speed zoning action calculated. The test and control zones were then identified by specific speed zoning action with a code, indicating test speed raised 5, test speed raised 10, control speed raised 5, etc. This code also included reference to a time period, before or after speed limit change. Therefore, in each zone an analysis record for each year pre and post speed zoning action was built which included accident rates. The groupings from the speed zoning action resulted in 16 unique groups, related to speed zoning action and time period. They are: Raised 10 Before, Raised 10 After, Raised 10 Control Before, Raised 10 Control After, Raised 5 Before, Raised 5 After, Raised 5 Control Before, Raised 5 Control After, Lowered 10 Before, Lowered 10 After, Lowered 10 Control Before, Lowered 10 Control After, Lowered 5 Before, Lowered 5 After, Lowered 5 Control Before, and Lowered 5 Control After.

One way Analysis of Variance (ANOVA) was performed to determine if there was a statistically significant difference in the change in the mean accident rate between the treatment groups and the control groups. If no difference is detected, this indicates the treatment (i.e. speed zoning action) had no effect on mean accident rates. The implication is that this specific change in speed limits had no effect on accident rate(s), and therefore did not improve safety.

Continuing the analysis of the speed zoning groups, comparison (i.e. contrasts) between two or more factor level means is conducted. The difference in mean accident rate between before to after periods is compared between treatment and control groups. The analysis determines if specific speed zoning actions have resulted in a statistically significant decrease in accident rates for treatment groups relative to their matched control counterparts. The single degree of freedom test is performed to make this determination. A finding of no difference (i.e. equality) indicates that the change in accident rates over time between treatment and control groups is not statistically different. This finding leads to the conclusion that the treatment groups performed the same as their control counterparts, and that accidents as a measure of safety was not improved by the speed zoning action.

2.5 Individual Zone Effectiveness Leading to Effective and Non-Effective Group Formation

The analysis of the effectiveness of speed zoning thus far has involved the overall effectiveness of speed zoning actions (ANOVA), and the effectiveness of specific speed zoning actions (contrasts). As a basis for determining if the individual treatment zone compared to its' matched control counterpart is effective in reducing accidents, accident frequencies are compared. The percentage reductions in accident frequency before to after for each treatment and control zone are calculated and these values are used to determine if a statistically significant reduction has occurred utilizing the Poisson test for accident reduction. The results of this analysis leads to identification of individual effective and non-effective treatment zones.

Each treatment zone is a specific speed zoning action, and with the determination of effective versus non-effective, the creation of specific groupings by speed zoning action is formed. These groupings by effective speed zoning action or non-effective speed zoning action forms the basis for the analysis groups to be utilized in discriminant analysis.

Accident type in the form of all accidents and rear end accidents was also conducted for each individual zone. This created two distinct data sets within each speed zone action grouping--effective all by respective speed zoning action and effective rear by respective speed zoning action.

2.6 Discriminant Analysis

Discriminant analysis is a multivariate statistical procedure which analyzes differences between mutually exclusive groups through linear relationships between variables to create the largest orthogonal space or distance between groups. It is employed on the effective speed zoning action groups and non-effective speed zoning action groups to determine how the effective groups differ from the non-effective. The analysis of the groups employing discriminant analysis is utilized to meet the following objectives:

(1) identify those variables that contribute to distinguishing between the groups,
(2) analyze the differences between these mutually exclusive groups, and
(3) develop a model to predict group membership for new cases whose group membership is desired, but unknown.

The limitation of no speed data for zones in the after period prevent the direct comparison of speed variables in the discriminant analysis between the before and after period. Motorists improved compliance with speed distribution parameters such as 85th percentile speed, mean speed, and skewness are often utilized as measures of effectiveness for speed zoning. However findings regarding their effectiveness are mixed when accidents after a speed zoning change are considered [Parker 1992a, Dudek and Ullman 1987, Taylor 1965, Avery 1960, Kessler 1959].

The determination of a procedure to predict speed zoning effectiveness is the overall objective of this effort. The variables identified, analyzed, and proposed for a procedure to predict group membership using the before period data for each specific speed zoning action is presented.

2.7 Speed Raised and Lowered Combined Effective Analysis

The merged records (i.e. cases) for each analysis group is the input data utilized in discriminant analysis. The initial approach is to analyze all effective groups combined versus their non-effective counterparts. The analysis is undertaken in two stages. The first being to examine the before period between effective versus non-effective, initially with all accident types and then rear end accidents. The analysis of the before period is expected to identify variables that characterize the conditions present before a speed zoning change is implemented which may allow the prediction of whether the intended change will be effective. The utilization of the combined speed raised and lowered effective groups in comparison with control counterparts is to determine what variables (regardless of speed zoning action) distinguish effective zones from non-effective zones. Analysis by all and rear accident type is conducted to determine whether variables change based on the accident type investigated.

The second stage analyzes the after period data. This analysis is conducted to determine if there had been a migration or shift in accident locations.

2.8 Variable Selection--Speed Raised and Lowered Combined Effective

Since over two hundred variables were created through the merging of data bases previously described, variable selection prior to beginning discriminant analysis was conducted. Correlation analysis was employed to eliminate highly correlated variables. Crosstabulation analysis was also utilized to discern relationships between "global" variables such as weather and lighting in relation to accident type, land use, laneage, and other variables expected to play a critical role in the discriminant function. These procedures identified 32 variables which met the criteria of not being highly correlated and providing insight into the relationships between variables.

Several measures of effectiveness (MOEs) are utilized to determine the best discriminant function. These are eigenvalue, Wilks' lambda, and percent correctly classified of those cases(i.e. records) for effective and non-effective groups. In terms of overall significance as an MOE, Wilks' lambda is generally considered superior. Its' range is between "1.0" and "0.0", with values close to zero indicating a function providing the best separation between groups. Thus, the minimization of Wilks' lambda, along with percent correctly classified become key determinants in the evaluation of discriminant functions.

Forward stepwise variable selection was then used to identify an initial set of variables which minimized Wilks' lambda in each comparison. Further analysis revealed that it was possible to identify a smaller number of variables which contributed approximately 80-85% of the total reduction in Wilks' lambda.

This set of variables was used to determine a discriminant function for each analyses based on stepwise variable selection. The discriminant functions and variables selected in this manner, along with the variable means and MOEs are indicated. Discussion of the difference in mean values between the effective and non-effective groups forms the characterization of effective speed zones by period and accident type.

Using speed zoning action and the determination of effective vs non-effective speed zone groups, the following group comparisons were utilized to determine those variables which produced a discriminant function which minimized Wilks' lambda:

Before Period Raised and Lowered Effective vs Before Period Raised and Lowered Non-Effective

Before Period Raised and Lowered Effective {Rear Ends} vs Before Period Raised and Lowered Non-Effective {Rear Ends}

After Period Raised and Lowered Effective vs After Period Raised and Lowered Non-Effective

After Period Raised and Lowered Effective {Rear Ends} vs After Period Raised and Lowered Non-Effective {Rear Ends}

2.9 Discriminant Analysis on Specific Speed Zoning Actions

The analysis of each primary speed zoning action--speed raised and speed lowered, begins by a variable selection process similar to the combined effective discriminant analysis. Correlation analysis and crosstabulation analysis were employed to eliminate highly correlated variables and understand the relationship of "global" variables in the data sets. Specifically it was determined that the before period and after period included many of the same variables. For specific speed zoning action analysis, each period was analyzed by the discriminant analysis forward variable selection process, identifying those variables which minimized 80-85% of Wilks' lambda. The before period data set variables and after period data set variables are then scrutinized for the same variables, as well as different variables. The question of how variables from the two time periods should be combined is resolved through consideration of the type of variable (i.e. direct or coded), its' potential role in determining an effective discriminant function, and the time period (one or both) in which the variable occurred. Based on this the following approach was used to generate four discriminant functions:

- All Direct Variables common to before period and after period,
- All Direct Variables common to before period and after period and in either the before period or after period,
- All Direct and Coded Variables common to before period and after period and,
- All Direct and Coded Variables common to before period and after period and in either the before period or after period

Each effective speed zoning data set by accident type was analyzed--yielding discriminant functions for all accidents and rear end accidents based on this typology.

The analysis at this point follows the same format as the combined effective analysis, first examining the before period with the same intent, and then the after period. A key difference from the combined effective analysis is that specific effective groupings as defined by accident type was also analyzed. This analysis was conducted for speed raised data sets (before and after). The speed lowered data sets was found not to have any differences from the total accident type effective data set(s).

As before, with the combined effective versus non-effective analysis, the primary MOEs to evaluate the resulting discriminant functions are minimization of Wilks' lambda and percent correctly classified.

After determination of the most effective discriminant function, evaluation of the variables remaining in this function occurs. This was conducted by: (1) assessing the degree of correlation between the pooled within-groups structure coefficients and the discriminant function, and (2) analyzing the difference in means between the effective group and non-effective group.

The evaluation of the variables in the discriminant function in this manner provides a characterization of how the effective zones are different than the non-effective zones. Utilizing the comparisons between before time periods for each primary speed zoning action allows conclusions to be reached regarding the conditions characteristic of effective speed zones.

Comparing results and characterizations between before and after time periods for primary speed zoning actions describes the shift in accident locations for each primary zoning action. More important, however, is that as a result of this analysis, speed zoning procedures which quantify and use roadside development variables now have evidence that suggests this approach is appropriate.

CHAPTER 3

Effectiveness of Speed Zones

3.1 Background

Speed zoning actions of raising or lowering the speed limit are undertaken with the expectation that accidents will be reduced in frequency after the zoning action has been in effect over some period of time. Normally this period of time for analysis purposes is no less than two years and may range as high as ten. In this analysis, the minimum range is two years before or after the zoning action and the maximum is seven years after.

Initially, in preparing the proposal and conducting the analysis, a zone-by-zone analysis of speed zoning effectiveness was to be undertaken. Chi-Square for Poisson Frequencies was to be the statistical method utilized. However, this procedure requires that each site or location have the same time period in the pre-zoning term and yet a different (but equal) time period (zone to zone) in the post zoning action term. This constraint could not be met at all sites. Also, the need to group the individual zoning actions later into homogeneous groups, such as limit lowered, limit raised etc., would not have been feasible under this procedure because of the different lengths of before and after time periods of analysis in numerous zones.

Since at this stage of the analysis, effectiveness of zoning action was of primary interest, using ONEWAY ANOVA as the statistical procedure was determined as a viable alternative. The objective of this test is to determine if there are significant differences in the group means under study. This technique permits the testing of all the groups at once through a calculated F statistic. The procedure also allows multiple comparisons between selected groups or combinations of groups. Both of these analyses were performed on the accident data set. ANOVA allows groups to be formed based on coding and a dependent and independent variable identification. In this case, ACC_RATE became the dependent variable and ZON_ACT became the independent variable. ACC_RATE is a numeric variable and ZON_ACT is an integer variable which identifies the zoning action.

3.2 Objectives

In general, the objective in performing statistical analysis on groups of speed zones based on the zoning action undertaken was to determine if, as expected, the zoning action resulted in a statistically significant reduction in accidents when compared to comparable matched control zones. Additionally, the statistical analysis was repeated for rear end accidents and the remaining accident types labeled "non-rear ends". The basic experimental design is Before/After with comparison group. While it is recognized that this design has serious threats to validity from local history, regression to the mean, and maturation, its strength is considerably improved if the comparability of the test and control groups are demonstrated. The matching process to address the comparability of the groups is discussed in the methodology section.

3.3 Matching of Test and Control Zones

The matching of test/control pairs was undertaken with the following variables as the key determinants: laneage, ADT, type of speed zone, one-way or bi-directional traffic, curvature and speed limit. Data on fixed objects, number of driveways, and other roadside or environmental factors were not used in matching, since a primary focus of this study is to determine their role in predicting the type and number of accidents. Thus these variables will be independent of the matching process in order to determine their contribution to the effectiveness of speed zones.

The control zones were matched on the before speed limit of the test zone in most cases. However, where there were constraints to matching based on the before period speed limit, the control zones were matched on the after period speed limit. Table 1 identifies these exceptions and their deviation from the preferred methodology.

Table 3.1
Non-Matching Speed Limits in Before Period in Control and Test Zones

District	Test Zone	Speed Change	Control Zone	Speed Limit
5	41-030-88T	R-10, 25 TO 35	41-030-88C	35
6	25-007-85T	R-5, 30 TO 35	25-007-85C	35
7	NONE	N/A	N/A	N/A
8	33-001-84TC	L-10, 45 TO 35	11-024-73C	35
8	81-023-84	L-10, 45 TO 35	81-023-84C	35
9	77-015-85T	L-5, 50 TO 45	77-015-85C	45
9	82-017-85T	R-5, 35 TO 40	82-017-85C	40

Note: N/A indicates "not applicable".

3.4 Data Preparation

Accident data received from the Michigan Department of Transportation (MDOT) were converted to spreadsheet format from a database format. The accident data contained basic information on accident type, time of day, ADT, hazardous action codes, etc. The accident data set for each zone were extracted from MDOT files for each year of interest, pre and post the zoning action. The set would range from 1981 to 1990, with the year of zoning action excluded from the accident analysis.

This data set was built for each test zone under study and its matching control zone. The zoning action which defines the major categories are speed limit raised and speed limit lowered, with further sub-categorization by the amount of change--5 or 10 miles per hour (mph). The final number of zones for each sub categorization is : 5 MPH Raised--9, 10 MPH Raised--4, 5 MPH Lowered--8, and 10 MPH Lowered--5. Resulting in a total of twenty-six test zones and twenty-six control zones. Table 2 provides a more informative breakdown by speed limits.

Table 3.2
Number of Zones by Zoning Action and Amount of Change

Lowered 5 MPH	Count	Lowered 10 MPH	Count	Raised 5 MPH	Count	Raised 10 MPH	Count
40 to 35	2	35 to 25	1	25 to 30	1	25 to 35	1
45 to 40	3	40 to 30	1	30 to 35	2	30 to 40	3
50 to 45	3	45 to 35	2	35 to 40	4		
		50 to 40	0	45 to 50	2		
		55 to 45	1				
Total	8		5		9		4

Statistical Package for the Social Sciences (SPSS) was used to read the spreadsheet files and produce a summary of total accidents, accidents per million vehicle miles (MVM) and accident type for each year pre and post zoning action. These accident rates were then compiled into a single spreadsheet composed of the columns: District, TCO Number, ZON_ACT, Year, REAR_END, ACC_RATE, NON_REAR, INIT_SPD and FIN_SPD. The rows are the accident rates for each year for each test zone and matching control zone, starting with district 5 and proceeding through district 9. The codes in the column ZON_ACT reflect the zoning action and status of the zone associated with that zone for each year. Table 3 lists the specific categorization(i.e. group) and its abbreviated name in the SPSS output.

Table 3.3
Group Name and Associated Accident Years with Mean

Categorization	Count	SPSS Output Name	Mean--All Acc. Types (Acc/MVM)
Raised 10 Before	18	RA 10 BEF	6.57
Raised 10 After	18	RA 10 AFT	8.55
Raised 10 Control Before	18	NC 10 RBEF	8.31
Raised 10 Control After	18	NC 10 RAFT	13.38
Raised 5 Before	39	RA 5 BEF	7.42
Raised 5 After	41	RA 5 AFT	6.81
Raised 5 Control Before	39	NC5 RA BEF	10.27
Raised 5 Control After	41	NC5 RA AFT	9.04
Lowered 10 Before	26	LOW 10BEF	7.98
Lowered 10 After	19	LOW 10AFT	5.28
Lowered 10 Control Before	26	NC 10LOBE	5.47

Table 3.3 (continued)

Lowered 10 Control After	19	NC 10LOAF	8.16
Lowered 5 Before	29	LO 5BEF	6.79
Lowered 5 After	35	LO 5AFT	6.90
Lowered 5 Control Before	29	NC 5 LOBE	4.38
Lowered 5 Control After	35	NC 5 LOAF	5.33
TOTAL	450		7.46

3.5 Analysis of Data

SPSS reads the file and performs those commands and subcommands assigned by the user to operate on the data. In this analysis, a oneway analysis of variance was performed on the accident rate data as the dependent variable and zoning action as the independent variable. The particular analysis undertaken on the accident data is a single factor study with sixteen treatment levels. The conclusions will extend only to the factor levels under study, and thus this type of analysis of variance model is a fixed effects model or Model I. The analysis of variance (ANOVA) is undertaken to analyze the effects of the independent variable, zoning action, on the dependent variable, accident rate. The factor level means are compared to each other to determine if they are equal. If they are found equal, the implication is that there is no relation between the factor (grouping of independent variables) and the dependent variable. Conversely, a finding of unequal factor level means indicates there is a relationship between the factor (treatment) and dependent variable. The F test is used to check for the equality of factor level means.

In order to determine if the factor level means are the same, the calculated F (F*) is compared to a table value with the appropriate degrees of freedom, in this case K (number of groups) -1 and N (number of observations) -K. The calculated F is the ratio of Between Groups Mean Squares and Within Groups Mean Squares contained in the output from an ANOVA table.

The procedure conducted was to compare the treatments by speed zoning action group for each period to their control counterparts. The table values for the F distribution at .95 confidence coefficient with appropriate degrees of freedom were compared to F* values obtained from ANOVA output. Results are presented in Table 3.4.

Table 3.4
Before Period and After Period F Test of Treatment vs Control by Speed Zoning Action ($\alpha = .05$)

	Before	After
Zoning Action		
Speed Raised 10	Accept H_o	Reject H_o
Speed Raised 5	Reject H_o	Reject H_o
Speed Lowered 10	Reject H_o	Reject H_o
Speed Lowered 5	Reject H_o	Accept H_o

With the exception of Speed Raised 10 in the before period and Speed Lowered 5 in the after period, the mean accident rates are found to not be equal to their control counterparts. An additional comparison between Speed Raised 10 and Speed Raised 5 combined for the before period with their control counterpart (combined) also yielded rejection of H_o.

Examination of whether the change in mean accident rates before to after for treatment zones are statistically significantly different than their control counterparts, was conducted and follows.

3.6 Determination of Effectiveness of Speed Zoning Action on Accidents

There are several tests which can be employed in the Before and After with comparison groups experimental design. The two most relevant here are:

(1) A test of the before period group mean (i.e. treatment vs control) values to determine how comparable the treatment (test) group is to the control group, and

(2) A test of the difference in mean accident rates from the before to after period, treatment compared to control.

3.6.1 Test of Comparability of Before Period Mean Accident Rate

The first test determines whether there are statistically significant differences in the before period mean accident rates for the treatment and control groups. The strength of the experimental design is improved if it can be demonstrated that the comparison locations are approximately equal before treatment. At this point with accidents as the variable under consideration, a finding of no difference would indicate that both treatment and control groups would be candidates for speed zoning action if no other variables were considered. Also, at least on this variable, it would indicate that both test and control groups belong to the same pool of zones. Thus, they should behave similarly over time to all internal threats to validity, as well as any treatment or lack thereof. Council [1980] states:

> "the strength of the (Before and After with comparison groups) design is directly proportional to how similar the treatment and control groups are. Thus in using this design, the evaluator should always carefully compare the measures for the two groups in the before period".

Using ANOVA the comparison of the test group means to their control group means addresses the issue of comparability and also the strength of the design. All the zones analyzed in this research were categorized as having undergone a zoning action (treatment) or no zoning action (control). The basis for inclusion in the test group may have been a procedural review (conducted every ten years), which produced a zoning action, or a series of complaints which may have led agency officials to a review and zoning action. Under either premise, agency policies and procedures should have led to speed zoning changes only if the change was supported by the data. Therefore, any speed zoning changes should be substantiated by the following data elements utilized by MDOT listed in approximate order of importance: 85th percentile speed, total accident history for previous 3-4 years, volume, number of driveways, existing speed limit, laneage, shoulders, width of lanes, adjacent land use, and functional classification of the facility.

3.6.2 Hypotheses--Comparability of Before Period Mean Accident Rate

The hypothesis for this test is the following: H_o: $\mu_1 = \mu_2$ vs. H_a: $\mu_1 \neq \mu_2$

$$\text{Critical Region: } -t(1-\alpha/2), n_1 + n_2 - 2 < \frac{\overline{X} - \overline{Y}}{s_{\overline{X}-\overline{Y}}} < t(1-\alpha/2), n_1 + n_2 - 2, (\alpha = .05)$$

This is a two-tailed t-test which determines if the before period mean accident rate is approximately equal between the treatment and control groups.

Table 3.5 presents results of the test for total accidents, rear end accidents, and non-rear end accidents. The data set was grouped by speed zoning action. The analysis of variance was performed on the treatment and control group of each speed zoning action separately, thus the pooled standard deviation of the variance is only for the specific groups analyzed. In addition to the outcome of the t-test, labeled as "Outcome" in the top half of Table 3.5, the results of the F-Test for the treatment means is also indicated. In this case, the F-test and t-test are equivalent, if the t-test statistic is squared.

For comparison purposes, a non-parametric test, Wilcoxon Signed-Rank Test was also performed on the same data set using **accident frequencies** as opposed to accident rates per million vehicle mile. The results of this analysis is presented in the bottom half of Table 3.5. Both the analysis of variance and Wilcoxon Signed-Ranks Test utilize a confidence limit coefficient of .95.

Table 3.5
Test of Comparability in Before Period of Test Zone Mean Accident rate vs Control Zone Mean Accident Rate
$H_0: \mu_1 = \mu_2$ vs. $H_a: \mu_1 \neq \mu_2$ ($\alpha = .05$)

INDIVIDUAL GROUP POOLED VARIANCE ESTIMATE, d.f. = 30 TO 60

Accident Type	TOTAL				REAR				NON-REAR			
Group	$\|t^*\|$	$\|t\|$	Outcome	F-test Outcome	$\|t^*\|$	$\|t\|$	Outcome	F-test Outcome	$\|t^*\|$	$\|t\|$	Outcome	F-test Outcome
RA 10 Bef vs NC RA 10 Bef	1.45	2.03	Accept Null	Accept Null	.300	2.03	Accept Null	Accept Null	1.72	2.042	Accept Null	Accept Null
RA 5 Bef vs NC RA 5 Bef	2.21	2.00	Reject Null	Reject Null	2.22	2.00	Reject Null	Reject Null	1.86	2.00	Accept Null	Accept Null
LOW 10 Bef vs NC LOW 10 Bef	2.23	2.02	Reject Null	Reject Null	1.891	2.02	Accept Null	Accept Null	2.12	2.02	Reject Null	Reject Null
LOW 5 Bef vs NC LOW 5 Bef	3.74	2.01	Reject Null	Reject Null	2.44	2.02	Reject Null	Reject Null	3.506	2.01	Reject Null	Reject Null

WILCOXON SIGNED-RANKS TEST ($\alpha = .05$)

Accident Type	TOTAL				REAR				NON-REAR			
Group	Z	$-Z_{\alpha/2}$	$Z_{\alpha/2}$	Outcome	Z	$-Z_{\alpha/2}$	$Z_{\alpha/2}$	Outcome	Z	$-Z_{\alpha/2}$	$Z_{\alpha/2}$	Outcome
RA 10 Bef vs NC RA 10 Bef	-1.48	-1.96	1.96	Accept Null	-0.24	-1.96	1.96	Accept Null	-1.81	-1.96	1.96	Accept Null
RA 5 Bef vs NC RA 5 Bef	-2.41	-1.96	1.96	Reject Null	-2.42	-1.96	1.96	Reject Null	-1.86	-1.96	1.96	Accept Null
LOW 10 Bef vs NC LOW 10 Bef	-3.07	-1.96	1.96	Reject Null	-2.81	-1.96	1.96	Reject Null	-2.12	-1.96	1.96	Reject Null
LOW 5 Bef vs NC LOW 5 Bef	-2.93	-1.96	1.96	Reject Null	-2.39	-1.96	1.96	Reject Null	-2.48	-1.96	1.96	Reject Null

3.6.3 Findings

The Raised 10 Before results for the t-test involving total, rear, and non-rear accidents lead to the conclusion that the treatment and control accident rates are not significantly different. The results of the F-test indicate that the factor level treatment means have no significant effect on the dependent variable, accident rate.

The Raised 5 Before results for the t-test involving total and rear end accidents indicate that the accident rates are significantly higher in the test section than they were in the control sections. The opposite is found for non-rear accidents. The results of the F-test reflect the findings in the t-test by accident type.

The Lowered 10 Before results for the t-test indicate total and non-rear end accidents are also significantly higher in the treatment sections. This finding was not observed for the rear end accident type. The F-test results follow the pattern of the t-test.

The Lowered 5 Before results for the t-test also indicate total, rear end, and non-rear accidents are significantly higher in the treatment sections. Again, the F-test results reflect the findings in the t-test by accident type.

The findings from the non-parametric test reflect those from the analysis of variance. This is to be expected. Conover [1980] states:

> "the assumptions of the Wilcoxon test are easier to justify than the assumption of normality. If the data are discrete, we know right away that the distribution is nonnormal because the normal distribution is continuous. If the data have an occasional very large or very small observation called

"outliers", the power of the t-test drops considerably and should not be used. Unfortunately, this type of nonnormality is difficult to detect. If the normal distribution is required of the differences between the pairs, the asymptotic relative efficiency of the Wilcoxon test to the t-test is .955".

The Wilcoxon Signed-Rank test is applicable to the Before and After with comparison groups design which is essentially paired observations.

3.6.4 Significance of Findings: Comparability of Before Period Mean Accident Rate

The Raised 10 Before acceptance of the null hypothesis across all accident categories would indicate that the accident rates are the same between treatment and control zones in the before period. However, the sign of the difference between the means for all three accident types is negative indicating that the mean accident rates are less in the treatment group than the control group. A conclusion would be that, in comparison to their control counterparts, there may not be a priori justification for speed zoning based on the before period accident history.

The Raised 5 Before mixed results indicate that some of the accident rates are significantly different between treatment and control groups. The sign of the difference between the means for all three accident types is negative indicating that the treatment zone rate was less than the control zones. The mixed results may indicate that rear end accidents are more frequent in the control zones than the test zones, and is significant enough to influence the total accident finding.

The rejection of the null hypotheses for two out of three accident type categories when the treatment group mean accident rate is lower than the control group means that (1) either the control group is not appropriately matched to the treatment group, or (2) the treatment group may not have needed the speed zoning action relative to the matched control zones (at least based on accident experience).

The Lowered 10 Before findings are also mixed with acceptance of the null hypothesis on rear end accident types with all others rejecting the null hypothesis. This may indicate that the non-rear accident types influenced the total accident type outcome more than the rear ends in this case. It may also indicate that rear end accident types are at least not the primary problem for zones considered for this speed zoning action. The sign of the difference between the means for all three accident types is positive, indicating that the treatment zone rate was more than the control zone rate. This taken with the results of the t-test may indicate that this zoning action for the treatment group compared to the control group on the accident variable, identified a need for a change in the speed limit.

The Lowered 5 Before findings indicate that treatment accident rates for all accident types were larger than the control groups, meaning that relative to this comparison group there is a priori evidence for speed zoning action on the treatment zones.

Overall, the speed limit raised zones means were less than their control counterparts in the before period. For the Raised 10 grouping this led to acceptance of the null hypothesis across all accident types. Conversely, the Raised 5 grouping rejected on two of the three accident categories. However, since the difference in mean values were negative, it would appear that based on accident rates there was little justification for the zoning action. This finding is not surprising, as raising the speed limit often results from observing that the prevailing speed is higher than the speed limit then in effect, rather than an attempt to decrease accidents.

The pattern of findings was the opposite for the speed limit lowered category, with the treatment zones means greater than their control counterparts. The consistent findings of rejection of the null hypothesis in the Wilcoxon test results coupled with a positive difference in mean accident values, indicate for this speed zoning action there was an accident based a priori justification for speed zoning action.

The basic question addressed by this particular analysis was whether the treatment and control groups were similar in the before period at a confidence coefficient of .95 on one variable, accident rates. It is found that generally they are not, with one exception, Speed Limit Raised 10.

Although the remaining groups were generally determined not to be similar at the confidence level specified, the higher mean accident rates for accident types within treatment groups suggests that the accident experience may have been a factor leading to the speed limit change. Therefore, as one of the primary criterion leading to a speed zoning change, the higher rates compared to control groups is reasonable. The finding of non-comparability in the before period on the accident variable is not unjustified in this case.

3.7 Test of the Change in the Mean Accident Rate--Treatment Compared to Control

The results from Table 3.5 indicate that for a number of the treatment actions across all accident types there is an effect of the action on the dependent variable, accident rates. The principal question of interest here is to determine if the specific actions have resulted in a decrease in accident rates relative to their control groups. In order to test this hypothesis, the difference between the before to after period accident rates for treatment and control factors for each speed zoning action were compared. The null hypothesis is that the differences for the treatment and control groups are equal, indicating no effect by treatment.

3.7.1 Hypothesis--Test of the Difference in Before to After Period Mean Accident Rate--Treatment Compared to Control

The hypothesis for the second test to be performed at $\alpha = 0.05$ is:

$$H_o = (\mu_1 - \mu_2) - (\mu_3 - \mu_4) = 0 \quad \text{vs} \quad H_a = (\mu_1 - \mu_2) - (\mu_3 - \mu_4) \neq 0$$

alternatively: $H_o: \Sigma\, c_i\mu_i = c$ vs. $H_a: \Sigma\, c_i\mu_i \neq c$

where: u_i = factor level means (i.e. Raised 5 Before, Raised 5 After)
c_i = constants associated with the factor level means(i.e. in this case 1/2)
$\Sigma c_i = 0$

Neter, Wasserman, and Kutner [1985] indicate that to test the alternatives the t* test statistic is:

$$t^* = \frac{\sum c_i \overline{Y}_i - c}{\sqrt{MSE \sum \frac{c_i^2}{n_i}}}$$

which follows the t distribution with n_T - r degrees of freedom when H_0 holds.

Where: n_i = number of items in each group
r = number of groups
n_T = total items in all groups
MSE = Mean Square Error
$\overline{Y}_i$ = sample mean of the factor levels.

The test expressed in the t* statistic involves the linear combination of factor level means in the analysis. The test is called a single degree of freedom test. The question of interest is the comparison of the before period to after period difference in the treatment zone means compared to the before period to after period difference in matched control zones. Depending on the sign of the difference, the treatment may be considered effective in reducing accidents.

The single degree of freedom test is implemented here as a two-tailed test. Table 3.6 presents the results of this analysis with the respective speed zoning action groups further demarcated based on location of the zone in the urban environment. Transition, abbreviated to "Trans." in the table refers to speed zones on the city periphery which have an urban setting. However, because of both their speed reducing function (from a 50 or 55 mph limit to 45 or 40 mph limit) and their not being entirely in a residential, commercial, or industrial area , they are so categorized. Urban zones are just the opposite and normally have speed limits in the 25 to 40 mph range and are generally contained in areas with one or more typically urban land uses. The degrees of freedom shown for each speed zoning action represent the accident years in total for the before to after period comparison between the treatment and control groups involved for that speed zoning action. Only two groups, "Transition Raise 10" and "Transition Lower 10" which consisted of one treatment and control zone and no zones respectively, were not included in this analysis. All other zones were included in one of the groups.

Table 3.6
Single Degree of Freedom Test Difference in Before to After Period Accident Rate Treatment vs Control
Decision Rule: $|t^*| \leq t(.975, d.f.), H_o$; $|t^*| > t(.975, d.f.), H_a$

	All Accidents			Rear End Accidents			Non-Rear Accidents		
Speed Zoning Action	t*	d.f.	Decision vs. Null	t*	d.f.	Decision vs. Null	t*	d.f.	Decision vs. Null
Raised 10	1.40	68	Accept	.75	68	Accept	1.53	68	Accept
Urban Raise 10	1.80	50	Accept	.20	50	Accept	2.06	50	Reject
Trans. Raise 10	ISS	ISS	ISS	ISS	ISS	ISS	ISS	ISS	ISS
Raise 5	-0.39	156	Accept	-.55	156	Accept	-.21	156	Accept
Urban Raise 5	-.00	104	Accept	.23	104	Accept	-.25	104	Accept
Trans. Raise 5	-.29	48	Accept	-1.09	48	Accept	.43	48	Accept
Lower 10	3.13	86	Reject	2.51	86	Reject	3.14	86	Reject
Urban Lower 10	3.13	86	Reject	2.51	86	Reject	3.14	86	Reject
Trans. Lower 10	ISS	ISS	ISS	ISS	ISS	ISS	ISS	ISS	ISS
Lower 5	.74	124	Accept	4.12	124	Accept	.82	124	Accept
Urban Lower 5	.93	62	Accept	.71	62	Accept	1.01	62	Accept
Trans Lower 5	-.26	58	Accept	-.71	58	Accept	.04	58	Accept

Note: "ISS" indicates Insufficient Sample Size.

The results from Table 3.6 indicate that only one group, "Lower 10" and it's single related sub-group, "Urban Lower 10" reject the null hypothesis of equal differences in accident rate reduction for all accident types between the before to after periods, treatment compared to control. An observation is that the two groups are composed of the same zones, as reflected in the results and the lack of zones in the Transition Lower 10 category. The results of the F test for rear end accidents indicate that the factor level means are equivalent at the confidence coefficient of .95. Meaning that there is very small chance that there is a relationship between the treatment levels and the dependent variable rear end accident rate. The t* test results for Lower 10 means that the absolute reduction in accident rates for the test zones when compared to the control zones were found to be significantly greater at the .95 confidence level.

The results of Table 3.6 for "Lower 10" is significant given that Table 3.5 results indicate that the rejection of the null hypothesis for the t* test took place on both the total and non-rear accident types, and was accepted on rear ends. All three accident types had positive differences in mean accident rates in the before period, indicating the treatment zones had higher accident rates than the control zones. Table 3.6, however, indicates that the difference in rates between before to after periods were significant. A review of the means for total, rear end and non-rear indicate a trend toward lower accident rates in the treatment after period compared to the before period. This finding for "Lower 10" indicates that for all accident groupings, the action of lowering the speed limit is shown to be statistically significant in reducing accident rates.

The results of Table 3.6 are significant also for the remaining speed zoning actions. Cumulatively, a conclusion is that speed zoning was not effective in the aggregate in reducing accidents at the .05 level of significance, for most types of speed zones.

These results are consistent with past experience which also show mixed results from speed zoning. In Michigan as in other locations, simply changing the speed limit does not always result in a decrease in accidents.

3.7.2 Family Confidence Intervals for Speed Zoning Actions

The individual tests in Table 3.6 use a confidence coefficient of .95. In order to draw conclusions about the major speed zoning actions with an overall confidence level, multiple comparison procedures are employed.

Utilizing Scheffe´ and Bonferroni multiple comparison procedures creates a confidence coefficient that assures in $(1- \alpha) \times 100$ repetitions the same approximate range of confidence intervals would be found for the family of statements. Both methods were used to construct confidence intervals with a family confidence level of 95 percent with the following results in Table 3.7:

Table 3.7
Family Confidence Intervals for Speed Zoning Actions, All Accident Types
($\alpha = .05$)

Speed Zoning Action	Scheffe´	Bonferroni
Raised 10 All	$-1.622 \leq L_1 \leq 4.718$	$-1.211 \leq L_1 \leq 4.308$
Raised 5 All	$-2.574 \leq L_2 \leq 1.952$	$-2.340 \leq L_2 \leq 1.718$
Lowered 10 All	$1.194 \leq L_3 \leq 4.198$	$1.349 \leq L_3 \leq 4.043$
Lowered 5 All	$-1.200 \leq L_4 \leq 2.043$	$-1.033 \leq L_4 \leq 1.8759$

Note: The values in the table are accidents per million vehicle miles. Negative values denote an increase in accidents, while positive values indicate a decrease in accidents.

The conclusion from both techniques is : (1) There is no overall effect for the speed zoning actions of Raised 10, Raised 5, and Lowered 5 on the accident rate, since the confidence intervals contain zero; (2) For Lower 10, the effect at the .95 confidence level is that the accident rate decreased between 1 and 4 accidents per million vehicle miles (acc/mvm) in the treatment zones relative to the control zones.

3.8 Test of Individual Zone Accident Reduction Effectiveness

Each speed zone was analyzed for its' effectiveness in reducing accidents after treatment, in this case a speed zoning change of raising or lowering the speed limit. The methodology was to use the treatment and control zones before and after accident frequencies, along with the number of years in the treatment after period to produce an expected accident frequency for the treatment zones. A percentage improvement was derived based on the difference between the expected and actual divided by the actual, multiplied by 100. This percentage improvement (if positive) reflects a decrease in accidents. Poisson curves [Box and Oppenlander 1976] based on expected after accident frequencies without treatment and percentage improvement were used to determine a significance level. This procedure was applied to each zone and groups of zones based on speed zoning action and type of zone. The primary focus of this effort was to determine which zones were individually effective in comparison to their matched control zone in reducing accident frequencies. The results of this analysis is presented in Table 3.8--Individual Zone Effectiveness by Type of Zone and Accident Categories, Table 3.9--Zoning Action and Accident Categories, Table 3.10--Zoning Action by Land Use and Accident Categories, Table 3.11--Comparison of Zoning Action and Accident Categories, and Table 3.12--Listing of Effective Zones by Zoning Action and Accident Categories.

The selection of zones for the effective zones listing in Table 3.12 is based on the **All Accidents** and **Rear End Accidents** at the 85% level of significance. Normally a 95% level of significance would be utilized as the level of significance, however since the total number of zones in this study was small (total 26) and the majority of effective sites were greater than 95% level of significance, it was concluded that the additional two sites this change allowed would not jeopardize the results. **Non-Rear End** accident category was not used in the selection of effective zones, since they are not a primary focus of this study. However, their data is provided in all three tables for comparison purposes.

3.8.1 Discussion of Findings--Individual Zone Accident Reduction Effectiveness

Table 3.8 presents a listing of the accident data for all the test and treatment zones. Negative values under the "% Difference" column indicate there were more accidents in the after period than would be expected. Collectively, the set of zones in this study are shown to have achieved a reduction in accident frequencies at the 99% level of significance. This result was also obtained for these zones when only rear end accidents were identified and analyzed. Only an 80% level of significance was achieved when non-rear end accidents were analyzed.

A conclusion is that the zoning actions undertaken individually may vary, however as a total group they are effective at the 99% level of significance for total and rear end accidents. The matching of test and control zones and the general finding of their comparability on the accident variable further strengthens these results.

Table 3.8
Individual Zone Effectiveness by Type of Zone and Accident Categories

			All Accidents		Rear End Accidents		Non-Rear End Accidents	
Districts	ZONE	ZONE TYPE	% Difference	Significance Level	% Difference	Significance Level	% Difference	Significance Level
District 5	61-025-87TA	TR-10, 30 TO 40	-49%	N/A	-5%	N/A	-71%	N/A
District 5	41-030-86T	UR-10, 25 TO 35	-26%	N/A	-14%	N/A	-36%	N/A
District 5	61-001-87T	UR-5, 25 TO 30	3%	0%	9%	85%	-1%	N/A
District 5	61-025-87TB	UL-10, 40 TO 30	-16%	N/A	-19%	N/A	-1%	N/A
District 6	25-003-88TB	TL-5, 50 TO 45	-87%	N/A	-100%	N/A	-57%	N/A
District 6	25-007-85T	UR-5, 30 TO 35	12%	90%	-1%	N/A	22%	80%
District 6	25-003-88TA	UL-5, 40 TO 35	1%	0%	-62%	N/A	52%	90%
District 7	08-024-85T	TR-5, 45 TO 50	44%	99%	0%	0%	63%	95%
District 7	08-025-85TA	UR-5, 35 TO 40	29%	99%	-8%	N/A	47%	90%
District 7	08-025-85TB	TR-5, 45 TO 50	2%	0%	-24%	N/A	23%	80%
District 7	11-010-86T1	UR-5, 35 TO 40	53%	99%	50%	99%	58%	95%
District 7	13-030-89TB	UR-5, 35 TO 40	4%	0%	33%	95%	-9%	N/A
District 7	11-010-86T2	UR-5, 30 TO 35	47%	99%	112%	99%	25%	80%
District 7	11-010-86T3	UR-10, 30 TO 40	156%	99%	155%	99%	152%	99%
District 8	23-030-88T	UL-5, 45 TO 40	-19%	N/A	-46%	N/A	11%	80%
District 8	33-001-84TA	UL-5, 40 TO 35	-1%	N/A	40%	99%	-43%	N/A
District 8	33-001-84TB	TL-5, 50 TO 45	90%	99%	7%	70%	170%	99%
District 8	33-001-84TC	UL-10, 45 TO 35	148%	99%	172%	99%	130%	99%
District 8	81-024-83T	UR-10, 30 TO 40	11%	70%	13%	70%	-8%	N/A
District 8	81-003-85T	UL-5, 45 TO 40	47%	99%	71%	99%	13%	80%
District 8	23-030-88T2	UL-10, 55 TO 45	-62%	N/A	-63%	N/A	-59%	N/A
District 8	81-023-84	UL-10, 45 TO 35	145%	99%	83%	99%	250%	99%
District 8	33-028-88T	UL-10, 35 TO 25	25%	99%	67%	99%	-15%	N/A
District 9	77-015-85T	TL-5, 50 TO 45	-15%	N/A	-36%	N/A	0%	0%
District 9	82-049-85TA	TL-5, 45 TO 40	-16%	N/A	51%	99%	-43%	N/A
District 9	82-017-85T	TR-5, 35 TO 40	-30%	N/A	-32%	N/A	-25%	N/A
ALL ZONES AVERAGE			25%	99%	42%	99%	11%	80%

* Zone Type Legend; UR = Urban Raised, TR = Transition Raised, UL = Urban Lowered, and TL = Transition Lowered.
† Negative values in "% Difference" indicate an increase in accidents as opposed to a decrease.
‡ N/A indicates the value obtained is "not applicable".

Table 3.9
Zoning Action and Accident Categories

	All Accidents		Rear End Accidents		Non-Rear End Accidents	
Zoning Action	**Percent Change**	**Significance Level**	**Percent Change**	**Significance Level**	**Percent Change**	**Significance Level**
Raised 5 (9)	1%	0%	-8%	N/A	10%	80%
Raised 10 (4)	41%	99%	46%	99%	38%	99%
Raised Total	9%	85%	2%	0%	15%	90%
Lowered 5 (8)	31%	99%	55%	99%	6%	75%
Lowered 10 (5)	39%	99%	56%	99%	22%	95%
Lowered Total	33%	99%	55%	99%	9%	80%
All Zones	25%	99%	42%	99%	11%	80%

Note: N/A indicates "not applicable".

Table 3.10
Zoning Action by Land Use and Accident Categories

	All Accidents		Rear End Accidents		Non-Rear End Accidents	
Zoning Action	**Percent Change**	**Significance Level**	**Percent Change**	**Significance Level**	**Percent Change**	**Significance Level**
Urban Raised (9)	30%	99%	30%	95%	31%	99%
Urban Lowered (9)	38%	99%	60%	99%	10%	90%
Transition Raised (4)	-25%	n/a	-27%	n/a	-17%	n/a
Transition Lowered (4)	0%	0%	11%	80%	5%	0%
All Zones	25%	99%	42%	99%	11%	80%

* N/A indicates "not applicable".

† Negative values in "Percent Change" indicate an increase in accidents as opposed to a decrease.

Table 3.9 groups the zones by zoning action and accident categories. The analysis was used to determine how individual zones grouped by common zoning actions were or were not effective in reducing accident frequencies. The values in parentheses behind each group name indicates the number of zones in that group. Another important consideration related to the strength of the findings is the comparability of each group with its' control group. Using the results from Table 3.5 and the data from Table 3.9, a comparison of results is shown in Table 3.11.

The results indicate that in the zones where the speed limit was raised or lowered by 10 mph the before period accident rate was comparable to the control zone. However this is not true where the speed limit was raised or lowered by 5 mph. It would appear that the majority of the inconsistency is in the 5 mph lowered category. Keep in mind that the data in Table 3.5 is only for before period comparability and not zoning category effectiveness.

Table 3.11

Comparison of Zoning Action and Accident Categories

	All Accidents		Rear End Accidents		Non-Rear End Accidents	
Zoning Action	Table 5 H_o Outcome	Table 9 Sig. Level	Table 5 H_o Outcome	Table 9 Sig. Level	Table 5 H_o Outcome	Table 9 Sig. Level
Raised 5 (9)	Reject	0%	Reject	N/A	Accept	80%
Raised 10 (4)	Accept	99%	Accept	99%	Accept	99%
Lowered 5 (8)	Reject	99%	Reject	99%	Reject	75%
Lowered 10 (5)	Reject	99%	Accept	99%	Reject	95%
All Zones	N/A	99%	N/A	99%	N/A	80%

Note: N/A indicates "not applicable".

Table 3.12
Listing of Effective Zones by Zoning Action and Accident Categories

			All Accidents		Rear End Accidents		Non-Rear End Accidents	
Districts	ZONE	LIMIT RAISED	% Difference	Significance Level	% Difference	Significance Level	% Difference	Significance Level
District 6	25-007-85T	UR-5, 30 TO 35	12%	90%	-1%	N/A	22%	80
District 7	08-024-85T	TR-5, 45 TO 50	44%	99%	0%	0%	63%	95
District 7	08-025-85TA	UR-5, 35 TO 40	29%	99%	-8%	N/A	47%	90
District 7	11-010-86T1	UR-5, 35 TO 40	53%	99%	50%	99%	58%	95
District 7	11-010-86T2	UR-5, 30 TO 35	47%	99%	112%	99%	25%	80
District 7	11-010-86T3	UR-10, 30 TO 40	156%	99%	155%	99%	152%	99
District 7	13-030-89TB	UR-5, 35 TO 40	4%	0%	**33%**	**95%**	-9%	N/A
District 5	61-001-87T	UR-5, 25 TO 30	3%	0%	**9%**	**85%**	-1%	N/A

			All Accidents		Rear End Accidents		Non-Rear End Accidents	
Districts	ZONE	LIMIT LOWERED	% Difference	Significance Level	% Difference	Significance Level	% Difference	Significance Level
District 8	33-001-84TA	UL-5, 40 TO 35	-1%	N/A	**40%**	**99%**	-43%	N/A
District 8	33-001-84TB	TL-5, 50 TO 45	90%	99%	7%	70%	170%	99
District 8	33-001-84TC	UL-10, 45 TO 35	148%	99%	172%	99%	130%	99
District 8	81-003-85T	UL-5, 45 TO 40	47%	99%	71%	99%	13%	80
District 8	81-023-84	UL-10, 45 TO 35	145%	99%	83%	99%	250%	99
District 8	33-028-88T	UL-10, 35 TO 25	25%	99%	67%	99%	-15%	N/A
District 9	82-049-85TA	TL-5, 45 TO 40	-16%	N/A	**51%**	**99%**	-43%	N/A

* N/A indicates "not applicable".

† Negative values in "% Difference" indicate an increase in accidents as opposed to a decrease.

Table 3.12 provides a listing of those zones with a significance level of ≥ 85% for the accident categories of total and rear end. In Table 3.9, the data is demarcated by zoning action of raising or lowering the speed limit. These zones form the grouping of "effective zones". They are to be analyzed in comparison to their non-effective counterparts to determine the contribution and significance of roadside friction and speed variables to their effectiveness. Table 3.13 below presents the number of effective zones and non-effective zones by speed zoning action based on the listing in Table 3.12.

Table 3.13
Number of Effective Zones versus Non-Effective Zones
by Speed Zoning Action--All and Rear End Accident Types

Speed Zoning Action	No. of Effective Zones			No. of Non-Effective Zones			Total
	All	Rear		All	Rear		All
Raised 5	5	4		4	5		9
Raised 10	1	1		3	3		4
Lowered 5	2	3		6	5		8
Lowered 10	3	3		2	2		5
Total	11			15			26

CHAPTER 4

Combined Effective Speed Raised and Speed Lowered Analysis vs Combined Non-Effective Speed Raised and Speed Lowered Analysis

4.1 Discriminant Analysis

The process of determining mutually exclusive groups is the primary methodological requirement for discriminant analysis. The determination of effective speed zones versus non-effective as previously indicated is now utilized to form the groups for discriminant analysis. The primary intent of this effort is to:

(1) identify those variables that contribute to distinguishing between the groups,
(2) analyze the differences between these mutually exclusive groups.

Since both lowering and raising the speed limit are combined in this section of the report, the development of a model to predict group membership is reserved for a later section.

4.2 Variable Selection

The literature review identified a number of speed parameters such as 85th percentile speed, skewness, percentile in the pace, upper and lower limit of the pace, etc., used to establish speed limits. The literature also identified roadside friction variables, such as driveway density, land use type, and fixed objects as parameters to be considered in establishing speed zone limits. Driver behavior variables which can also be considered because they are represented in the data set are hazardous action codes identified by accident investigators as well as circumstances such as weather, other contributing circumstances, lighting, etc.

A single data base including these variables was built for each speed zoning action and its control counterpart combining the accident, speed, and geometric files. Using the ADD and MATCH commands in SPSS, and matching on each tenth of a mile in each of the unique data sets, a record with accident, speed, and geometric data for each tenth of a mile that contained an accident was created. These data were then used to create speed zoning action(i.e. Speed Raised) effective and non-effective groups. Through appropriate utilization of the ADD files procedures, larger groups were built such as Before Period Effective Speed Raised and Lowered. Appropriate counterparts were also developed in this same manner.

The analysis of these newly formed groups involved determining frequencies of direct and coded variables. "Direct" variables are those where their values are directly interpretable, such as SKEWNESS or KURTOSIS. "Coded" variables are those where a value has been assigned to a qualitative level, and thus are not directly interpretable from their numerical values. Examples would be FIXOB_E, where values were developed for the number of utility poles, trees, fire hydrants, etc.

The coded variable and direct variable frequencies are a combination of the accident milepoint they occurred at and the frequency of accidents which occurred at that milepoint. Each group is therefore composed of the matching of the accidents at milepoint occurrences with the features of the geometric, speed, and environmental conditions present in the approximate timeframe and in the one tenth mile section where the accident occurred.

Correlation analysis and crosstabulation analysis were techniques used to select variables for discriminant analysis. The procedure employed was to use correlation analysis to identify and eliminate highly correlated variables. Crosstabulation analysis was used to identify and understand the distribution of variables within ubiquitous or "global" variables such as road type as well as specific variables such as hazardous action or land use.

Using both techniques allowed identification of variables which were minimally correlated and were distributed throughout the data set. This second point is important from the perspective of understanding the relationship and distribution of "coded" variables such as land use, laneage, and hazardous actions across accident types within locations and environments.

This core set of variables identified in this manner were then used in all initial discriminant analyses in a stepwise variable selection process. The specific criteria for variable selection was the minimization of Wilks' lambda. While other methods such as Rao's V and Mahalanobis' Distance were available, Wilks' lambda was selected due to its' close theoretical underpinnings to Analysis of Variance, using the ratio of the within-groups sum of squares to the total groups sum of squares. As such, it is the proportion of the total variance in the discriminant scores not explained by differences among groups. Norusis [1990] indicates "Small values of lambda are associated with discriminant functions that have much variability between groups and little variability within groups". This characteristic builds cohesive groups while still measuring the separation between groups. Thus, in a variable selection technique, one is able to select variables which improve group cohesiveness while maintaining good group separation over a variable which reduces group cohesiveness while also maintaining good group separation. Wilks' lambda has a range with a maximum value of 1.0 which indicates poor performance, to a value close to 0.00 which indicates very good performance. The ability to convert Wilks' lambda to a Chi-Square distribution and obtain a multivariate F statistic and a partial F statistic as each variable is entered facilitates the analysis of variable selection.

Proceeding in this manner, and using parameter settings for partial F-statistics for entry and exit of variables into the discriminant function, as well as a tolerance level which prevents linear combinations of variables to be included above a minimum, analyses were performed on combinations of effective and non-effective speed zone groups.

4.3 Analysis Categories

Using speed zoning action and the listing of effective vs non-effective speed zone groups, the following group comparisons were utilized to determine those variables which produced a discriminant function which minimized Wilks' lambda:

> Before Period Raised and Lowered Effective vs Before Period Raised and Lowered Non-Effective (BP2 RAISLOW EFF ALL vs BP2 RAISLOW NON-EFF ALL)

Before Period Raised and Lowered Effective {Rear Ends} vs Before Period Raised and Lowered Non-Effective {Rear Ends} (BP2 RAISLOW EFF ALL vs BP2 RAISLOW NON-EFF ALL--REAR END ACCIDENTS ONLY)

After Period Raised and Lowered Effective vs After Period Raised and Lowered Non-Effective (AP2 RAISLOW EFF ALL vs AP2 RAISLOW NON-EFF ALL)

After Period Raised and Lowered Effective {Rear Ends} vs After Period Raised and Lowered Non-Effective {Rear Ends} (AP2 RAISLOW EFF ALL vs AP2 RAISLOW NON-EFF ALL--REAR END ACCIDENTS ONLY).

The before period effective vs non-effective comparisons identify those variables which separate effective and non-effective groups prior to changing the speed limit. Thus, if statistical measures of the discriminant function and the function itself are reasonably significant, information needed to predict whether speed zoning actions would be effective based on the characterization of the zone is available.

The after period analysis provides another opportunity to characterize the effective vs non-effective speed zoning groups by comparing variables differentiating the effective vs non-effective speed zones after the speed limit change. Through the variables selected, the agency establishing the speed zone can predict the success (or lack of success) in reducing accidents through the implementation of the speed zone. If there is a change in variables selected from the before period to the after period this would indicate a shift in accident locations within the zone.

Variables selected and the value of their means provide an overall characterization of how the effective and non-effective groups differ.

Segmentation of the comparison files by all accidents and rear end accidents was performed to determine if major accident types significantly changed the selection of variables and therefore the characterization of how the groups differ.

4.4 Initial Variables in Discriminant Analysis

Thirty-two variables were identified from the output of the correlation analysis and crosstabulation analysis and are presented as follows: ADT AREA_CO2 CONT_CI1 CONT_CI2 DRYWAYE DRYWAYW DST_CRS EIGHT5_P FIXOB_E FIXOB_W HAZ_ACT1 HAZ_ACT2 HWY_TYPE KURTOSIS LANEAG_E LANEAG_W LANUSE_E LANUSE_W LIGHTING OBJ_HIT1 OBJ_HIT2 PERC_IN_ PRK_LEFT PRK_RIGH RDSIDE_D ROAD_CON ROAD_TYP SIGNAL_E SIGNAL_W SKEW SKEWNESS TRAF_CON. Their meaning is described in Table 4.1 which follows:

Table 4.1
Identification and Description of Variables in the Discriminant Analysis

Variable Name	Variable Meaning	Variable Name	Variable Meaning
ADT	Average Daily Traffic	LANUSE_E	Type of land use in eastbound* direction
AREA_CO2	Highway Area Code and Highway Type Combined	LANUSE_W	Type of land use in westbound direction
CONT_CI1	Contributing Circumstances, Vehicle 1	LIGHTING	Type of light under which the accident occurred
CONT_CI2	Contributing Circumstances, Vehicle 2	OBJ_HIT1	Object hit by vehicle 1

Table 4.1 continued

DRYWAYE	Number of driveways eastbound direction	OBJ_HIT2	Object hit by vehicle 2
DRYWAYW	Number of driveways westbound direction	PERC_IN_	Percentile of vehicle speeds in the 10 mph pace range
DST_CRS	Distance from accident location to nearest crossroad	PRK_LEFT	On-street parking on the left side
EIGHT5_P	85th percentile speed	PRK_RIGH	On-street parking on the right side
FIXOB_E	Number and type of fixed objects in eastbound direction	RDSIDE_D	Roadside Development Code
FIXOB_W	Number and type of fixed objects in westbound direction	ROAD_CON	Road Surface Condition
HAZ_ACT1	Violation (Hazardous Action), Driver 1	ROAD_TYP	Roadway type
HAZ_ACT2	Violation (Hazardous Action), Driver 2	SIGNAL_E	Number and type of traffic signals in eastbound direction
HWY_TYPE	Specific highway area type	SIGNAL_W	Number and type of traffic signals in westbound direction
KURTOSIS	Measure of distribution distortion, in comparison to the normal distribution, there is an over or under concentration of observations at the center in relation to the tails	SKEW	Measure of distribution distortion, in comparison to the normal distribution, there is a shift of the central value to the right or to the left

Table 4.1 continued

LANEAG_E	Type and width of laneage in eastbound direction	SKEWNESS	Same as skew, however the skewness index uses a value of 1.0, as opposed to 0.0 to indicate normality
LANEAG_W	Type and width of laneage in westbound direction	TRAF_CON	Type of traffic control, including signage, if any.

Note: * Where eastbound and westbound are specified this can also represent northbound and southbound as well.

Stepwise variable selection was used to identify an initial set of variables which minimized Wilks' lambda within each test section. Further analysis was then conducted to identify a smaller number of variables which contributed approximately 80-85% of the total reduction in Wilks' lambda. Each separate test situation was processed in this manner.

The use of the eigenvalue as a measure of the effectiveness of the discriminant function has no direct scalar interpretation. It is the ratio of the between group Sum of Squares divided by the within group Sum of Squares. Since discriminant analysis is based on creating the largest difference between groups from the linear combinations of independent variables, the larger the numerator and smaller the denominator, the better (in a general sense) is the discriminant function. Therefore, in general, large eigenvalues are associated with good functions. However since no scale exists, the comparison is relative. The eigenvalue is used to gain an understanding of which variables best distinguish between effective and non-effective speed zones.

The discussion of each speed zoning comparison will focus initially on the variable values determined for the before period. The measures of effectiveness (MOEs), the relationship between the discriminant function and its variables, and means and distribution of variables will be presented and discussed.

The results of the before period analysis by accident type with and without speed variables is presented in Table 4.2.

Table 4.2
Before Period Raised and Lowered Effective All and Rear End Accidents
vs
Before Period Raised and Lowered Non-Effective All and Rear End Accidents
Measures of Effectiveness

Effective All Actions	Accident Type: ALL			
Analysis Type	EIGENVALUE	WILKS Lambda FINAL	Correct Classification Group 1	Correct Classification Group 2
Analysis w/Speed Variables	1.44	.41	88.8%	84.2%
Analysis w/o Speed Variables	.57	.64	90.4%	67.6%
Effective All Actions	Accident Type: REAR END			
Analysis Type	EIGENVALUE	WILKS Lambda FINAL	Correct Classification Group 1	Correct Classification Group 2
Analysis w/Speed Variables	1.57	.39	94.4%	87.0%
Analysis w/o Speed Variables	.71	.59	93.2%	73.7%

The findings indicate that for both accident groupings inclusion of speed variables improves all the measures of effectiveness with the exception of Correct Classification for Group 1, which is the effective zones grouping. The significance of this finding is that: 1) The importance of speed variables in distinguishing between effective and non-effective zones is confirmed, and 2) Even without speed variables, the models correctly classify a high percentage of the zones.

Tables 4.3 and 4.4 contain the correlation coefficients also known as pooled within-group structure coefficients. These structure coefficients are simple bivariate correlations with the discriminant function and are unaffected by relationships with other variables. Also included in these tables are standardized coefficients. These coefficients indicate the relative importance of the variable and its contribution to the discriminant score.

Table 4.3
Before Period Raised and Lowered Effective Structure Coefficients and Standardized Coefficients with Speed Variables
Accident Type: All and Rear End

Accident: All						Accident: Rear End
w/Speed						w/ Speed
Variables						Variables
	Structure Coefficients	Standardized Coefficients		Structure Coefficients	Standardized Coefficients	
SKEWNESS	.42	.93		.44	.33	SIGNAL_W
SIGNAL_W	.41	.29		-.43	-.12	DRYWAYE
DRYWAYE	-.38	-.12		.42	.90	SKEWNESS
EIGHT5_P	.36	.60		.34	.55	EIGHT5_P
ADT	.21	.63		.25	.73	ADT
RDSIDE_D	.16	.49		.16	.27	SIGNAL_E
KURTOSIS	.04	.48		.03	.55	KURTOSIS

Unlike structure coefficients, Klecka [1980] states "standardized coefficients take into consideration the simultaneous contributions of other variables". Norusis [1990] also regarding standardized coefficients adds "the actual signs of the coefficients are arbitrary. The negative coefficients...could just as well be positive if the signs of the other coefficients were reversed". Klecka [1980] indicates that in discriminant analysis "structure coefficients are a better guide to the meaning of the canonical discriminant functions than the standardized coefficients are". Where the sign of the structure coefficients are concerned, Norusis [1990] indicates "exercise care when attempting to interpret the coefficients, since correlations between variables affects the magnitudes and signs of the coefficients".

Starting with Table 4.3 the structure coefficient sizes indicate weak correlations with the discriminant function. The groupings of variables based on the magnitude of the structure coefficients indicates that four of the variables have the most significant role in analyzing all and rear end accident types. They are SKEWNESS, SIGNAL_W, DRYWAYE, and EIGHT5_P. While their order changes based on accident type their magnitude remains approximately the same.

Table 4.4
Before Period Raised and Lowered Effective Structure Coefficients and Standardized Coefficients without Speed Variables
Accident Type: All and Rear End

Accident: All w/o Speed Variables						Accident: Rear End w/o Speed Variables
	Structure Coefficients	Standardized Coefficients		Structure Coefficients	Standardized Coefficients	
SIGNAL_W	.65	.45		-.66	.33	SIGNAL_W
DRYWAYE	-.60	-.57		.64	.68	DRYWAYE
LANUSE_E	.37	.36		-.38	-.29	ADT
ADT	.34	.14		.24	.18	LANUSE_W
LANUSE_W	-.27	-.22		.17	.38	PRK_RIGH
RDSIDE_D	.25	.37		.03	-.40	PRK_LEFT
FIXOB_E	-.20	-.14				

Results shown in Table 4.4 where speed variables are not included in the analysis finds slightly stronger correlations, although still considered weak, for SIGNAL_W and DRYWAYE. There is a sizable reduction in magnitude compared to SIGNAL_W and DRYWAYE for other variables included in the function. The size of the correlations of these two variables with the discriminant function creates a distinctive grouping containing these two variables and the remainder of the variables. This pattern occurs across all and rear end accidents. A reversal of signs occurs on SIGNAL_W, DRYWAYE, and ADT between the all accident and rear end accident grouping. This is attributed to the difference in variables included for rear end accidents, PRK_RIGH and PRK_LEFT. A check for correlations in the variable sets by each accident type found no highly correlated values.

Table 4.5
Before Period Raised and Lowered Effective Means with Speed Variables
vs
Before Period Raised and Lowered Non-Effective Means with Speed Variables, Accident Type: All and Rear End

	All		Rear End		
Variables	Effective w/Speed (Mean)	Non-Effective (Mean)	Effective w/ Speed (Mean)	Non-Effective (Mean)	Variables
SIGNAL_W	5.7	17.7	6.5	20.3	*SIGNAL_W*
DRYWAYE	3.1	1.03	3.2	.80	DRYWAYE
SKEWNESS	.56	1.03	.52	1.02	SKEWNESS
EIGHT5_P	42.2	46.3	42.2	46.1	EIGHT5_P
ADT	23907	27815	24753	29286	ADT
RDSIDE_D	2.8	3.00	12.3	17.9	*SIGNAL_E*
KURTOSIS	3.14	3.19	3.13	3.17	KURTOSIS

Table 4.6
Before Period Raised and Lowered Effective Means without Speed Variables
vs
Before Period Raised and Lowered Non-Effective Means without Speed Variables, Accident Type: All and Rear

	All		Rear End		
Variables	Effective w/o Speed (Mean)	Non-Effective (Mean)	Effective w/o Speed (Mean)	Non-Effective (Mean)	Variables
SIGNAL_W	5.7	17.7	6.5	20.3	*SIGNAL_W*
DRYWAYE	3.1	1.03	3.2	.80	DRYWAYE
LANUSE_E	19.2	28.1	24753	29286	ADT
ADT	23907	27815	20.5	14.9	*LANUSE_W*
LANUSE_W	20.3	14.8	.22	0.0	*PRK_RIGH*
RDSIDE_D	2.8	3.00	.13	.10	*PRK_LEFT*
FIXOB_E	14.7	10.5			

4.5 Discussion--Before Period All and Rear End Accident Types

The mean values for the variables shown in Table 4.5 are a weighted value, composed of the value of the variable multiplied by the frequency of accidents. Thus, a road section with a large value for one of the variables and a moderate accident frequency will contribute equally to the mean value as a section with moderate variable values and a high accident frequency.

4.6 Speed Variables Included

Starting with the review of data in Table 4.5 where speed variables are in the discriminant function, and analyzing the all accidents and rear end grouping together, the two coded variables [of significance] are SIGNAL_W and RDSIDE_D. For RDSIDE_D, there are three variable levels, rural(1), strip-fringe(2), and urban(3). Both data sets are composed primarily of urban sites, thus the value of this variable is 2.79 and 3.00 respectively. The SIGNAL_W variable represent(s) the frequency of accidents which took place at or near signalized intersections in the westbound direction. The non-effective zones for all accidents and rear end accidents had 62% and 63% of their accidents respectively near signalized intersections, while effective zones had 26% and 23% of their accidents respectively near signalized intersections. This finding indicates that candidate locations which have most of their accidents at or near signalized intersections are not good candidates for speed zoning.

The DRYWAYE mean values indicate that in non-effective zones for both accident categories, over two-thirds of the accidents were at locations where no driveways were in the immediate vicinity. The effective zones accidents were distributed throughout the range of driveway frequencies with two drive and five drive locations having the largest proportion. Therefore, locations with a high frequency of driveway accidents are good candidates for speed zoning.

The mean SKEWNESS value is an average of the skewness index values for the speed distribution nearest to each accident in the respective data sets. The mean value for effective zones is negatively skewed, indicating that a majority of drivers are driving faster than the mean speed. A normal curve would contain about 50% of the drivers above and below the mean speed. Since fewer drivers (percentage-wise) are traveling below the mean speed, there is less deviation in the speed profile, possibly leading to a safer driving environment.

The mean skewness value for the non-effective zones in both accident categories indicate a normal curve. Approximately 33% of the values for all accidents and 27% for rear ends are negatively skewed, with the remainder in the normal range between 1.0 and 1.17.

These findings indicate that speed zoning is found to be effective where the speed distribution prior to implementing the speed zone has a negative skewed distribution. This indicates that locations with an existing negative skewness index are good sites for speed zoning.

Mean values for ADT are lower in the effective zones for both accident categories than non-effective zones. The difference is about 5,000 vehicles per day. A review of the frequency values for effective zones found groupings in the 12,000, 19,000, and 29,800 values. For non-effective zones groupings were found at 13,500 and 35,500. The range for the effective zones was between 7,000 and

29,800 compared to 6,200 to 37,590 for the non-effective. Because of the overlap of ranges in ADT, it is not considered to be a good predictor of success in speed zoning.

Kurtosis for both data sets were mesokurtic, and thus this does not appear to be a good "predictor" variable.

The effective zones 85th percentile speed was approximately 4 miles per hour less than the non-effective zones. The difference is substantial from a speed limit setting perspective, allowing a change of 5 miles per hour higher or lower, since both speed raised and speed lowered zones comprise the data set. However, because of the overlap of ranges in 85th percentile speed, it is not considered to be a good predictor of success in speed zoning.

4.7 Speed Variables Excluded

Review of Table 4.4 and Table 4.6 indicates that the only variables which have not been discussed and have a structure coefficient of note is LANUSE_E for all accidents and LANUSE_W for rear ends. Starting with LANUSE_W the accident distribution for effective zones is characterized by two land use types. One is a retail-oriented land use with high vehicular interaction such as gasoline stations, malls, and sit-down style restaurants, and the second is single family residential development. The retail land use accident distribution (percentage-wise) for accidents in effective zones is 43% and 46% for all and rear end accidents respectively. For residential land use the distribution of accidents by all and rear end accidents is 30% and 33% respectively. The distribution of accidents for the two land uses in combination is 73% and 79% for all accidents and rear ends respectively. For non-effective zones LANUSE_W is dominated by retail land uses, with 82% and 88% for all and rear end accidents respectively.

Similar to the westbound land use, the accident distribution for LANUSE_E is also characterized by retail-oriented land use and single family residential development. The distribution of accidents at or near retail land uses in effective zones is 48% and 54% for all and rear end accidents respectively. Similarly the distribution of all accidents and rear end accidents at or near single family residential land uses in effective zones is 36% and 32% respectively. These two land uses in combination total 84% and 86% for all and rear end accidents respectively.

For LANUSE_E in non-effective zones, residential land use comprises a very low percentage of accident locations for all and rear end accidents. The distribution of accidents in non-effective zones is dominated by retail land uses and undeveloped land use. For retail the distribution of accidents is 44% and 42% for all and rear end accidents respectively. For undeveloped land use the distribution is 33% and 38% for all and rear end accidents respectively.

These findings for LANUSE_E indicates that retail land uses and undeveloped land use are not good sites for speed zoning to be effective. However, zones with retail land uses mixed with single family residential development are good candidates for speed zoning.

The findings for LANUSE_W are similar to those for LANUSE_E. However the accident distribution is found to be more highly concentrated at retail land use sites. Retail land uses mixed with single family residential are once again found to be good candidates for speed zoning.

4.8 Validity of the Discriminant Means and their Distributions

Unfortunately discriminant analysis procedures do not allow a frequency distribution to be generated from the cases used to generate the discriminant function. The discriminant analysis procedure also drops any case with a missing value on a variable chosen to be in the discriminant function.

A reasonable question is how representative are the discriminant function data sets compared to the total data sets used to generate the frequency distributions. To minimize any possible difference, traffic volume (ADT), laneage, and segment length were matched as close as possible for each test and control zone. The percentage of the available accidents utilized by the discriminant analysis procedure for each data set is indicated in Table 4.7.

Table 4.7
Percentage of Cases Utilized in Discriminant Analysis Per Data Set

Data Set	Percent Utilized
BP RAISLOW EFF ALL	85%
BP RAISLOW NON-EFF ALL	71%
BP RAISLOW EFF REAR	59%
BP RAISLOW NON-EFF REAR END	45%
AP RAISLOW EFF ALL	80%
AP RAISLOW NON-EFF ALL	63%
AP RAISLOW EFF REAR END	58%
AP RAISLOW NON-EFF REAR END	39%

A t-test was performed on the means for the variables with the largest difference between the complete data set and the data set used to produce the discriminant values. Those variables from discriminant data sets which use a high proportion of cases from the all inclusive data sets were found to have no difference from the population means at the .95 confidence limit. The differences became increasingly more significant as the proportion of accidents decreased. These results are shown in Table(s) 4.8 and 4.9.

Based on the results in Table(s) 4.7, 4.8, and 4.9, it appears that the mean value of variables in the all accident data sets are equal at the .95 confidence limit coefficient. This does not hold for the mean values in the rear end accident data sets. The variable distributions described for rear end accidents therefore may be different than the distributions used in the discriminant analysis. However, the mean values provide a perspective on the differences between effective versus non-effective groups.

Table 4.8
Comparison of Selected Before Period Variables Population Means vs Discriminant Data Set Means with Results for Null Hypothesis ($\alpha = .05$)

Variable	BP RAISLOW EFF ALL	BP RAISLOW NON-EFF ALL	BP RAISLOW EFF REAR END	BP RAISLOW NON-EFF REAR END
ADT	ACCEPT	REJECT	REJECT	REJECT
DRYWAYE	ACCEPT	ACCEPT	ACCEPT	REJECT
EIGHT5_P	ACCEPT	ACCEPT	REJECT	ACCEPT
LANEAG_E	ACCEPT	ACCEPT	REJECT	REJECT
LANEAG_W	ACCEPT	ACCEPT	REJECT	REJECT
SKEWNESS	ACCEPT	ACCEPT	REJECT	REJECT
SIGNAL_E	ACCEPT	REJECT	REJECT	REJECT
SIGNAL_W	ACCEPT	REJECT	REJECT	REJECT

Table 4.9

Comparison of Selected After Period Variables Population Means vs Discriminant Data Set Means with Results for Null Hypothesis (α = .05)

Variable	AP RAISLOW EFF ALL	AP RAISLOW NON-EFF ALL	AP RAISLOW EFF REAR END	AP RAISLOW NON-EFF REAR END
DRYWAYE	ACCEPT	ACCEPT	ACCEPT	REJECT
EIGHT5_P	ACCEPT	ACCEPT	REJECT	ACCEPT
LANEAG_E	ACCEPT	ACCEPT	REJECT	ACCEPT
LANEAG_W	ACCEPT	ACCEPT	REJECT	ACCEPT
SKEWNESS	ACCEPT	ACCEPT	REJECT	ACCEPT
SIGNAL_E	ACCEPT	ACCEPT	REJECT	ACCEPT
SIGNAL_W	REJECT	ACCEPT	REJECT	REJECT

4.9 Summary--Before Period All and Rear End Accident Types with and without Speed Variables

Analysis of the combined effective data sets found SIGNAL_W and DRYWAYE to be the most important discriminating variables. They appeared in the discriminant functions for all and rear end accidents with and without speed variables in the discriminant function. When speed variables were included, SKEWNESS and EIGHT5_P had structure coefficients with a magnitude that indicated a significant correlation to the discriminant function.

When speed variables were not included LANUSE_E (all accidents) and LANUSE_W (rear end accidents) were identified as additional significant variables.

The conclusion from this analysis is that speed zoning can be expected to be effective where:

- most accidents do not occur at or near signalized intersections,
- the frequency of driveways is high (ranging from two to five per .1 mile segment),
- the skewness index is negatively skewed, and
- land use is a mixture of retail and single family residential

Based on the findings and conclusions, if the objective was to determine where speed zoning would be effective in reducing accidents prior to a speed limit change, the sites would contain these characteristics.

4.10 Discussion--After Period All Accident Types

The analysis of after period data is undertaken to determine if there is a shift in the location of accidents after the speed limit is changed. Starting with the comparison of MOEs between the after period and the before period, the MOEs in Table 4.10 (after period) compare favorably with those in Table 4.2 (before period).

Table 4.10
After Period Raised and Lowered Effective All and Rear End Accidents
vs
After Period Raised and Lowered Non-Effective All and Rear End Accidents
Measures of Effectiveness

Effective All	Accident Type: ALL			
Analysis Type	EIGENVALUE	WILKS Lambda FINAL	Correct Classification Group 1	Correct Classification Group 2
Analysis w/o Speed Variables	.62	.62	85.2%	80.0%
Effective All	Accident Type: REAR END			
Analysis Type	EIGENVALUE	WILKS Lambda FINAL	Correct Classification Group 1	Correct Classification Group 2
Analysis w/o Speed Variables	.80	.55	88.4%	79.5%

Eigenvalues and Wilks lambda are also comparable, and the percentage of cases classified correctly is similar. The ability of the discriminant functions to classify the effective zones (Group 1) and non-effective zones (Group 2) is noteworthy.

Table 4.11
After Period Raised and Lowered Effective Structure Coefficients and
Standardized Coefficients without Speed Variables
Accident Type: All and Rear End

Accidents All w/o Speed Variables					Accidents Rear End w/o Speed Variables
	Structure Coefficients	Standardized Coefficients	Structure Coefficients	Standardized Coefficients	
LANEAG_W	-.59	-1.84	-.64	-1.84	LANEAG_W
LANEAG_E	-.53	1.09	-.61	1.08	LANEAG_E
DRYWAYE	.49	.60	.55	.68	DRYWAYE
RDSIDE_D	-.20	-.32	.11	.43	LANUSE_W
LANUSE_W	.19	.44	-.11	-.26	RDSIDE_D
FIXOB_E	.15	.27	.10	.21	FIXOB_E
ADT	.03	.60	.01	.51	ADT

Table 4.11 presents the structure and standardized coefficients from the combined effective zones vs non-effective zones without speed variables. The magnitude of the structure coefficients for all and rear end accidents are close, with almost the same variable lists. Therefore, for all and rear end accidents, the variables most highly correlated with the discriminant function are LANEAG_W, LANEAG_E, and DRYWAYE.

Comparing the results to Table 4.4 for the before period, SIGNAL_W (signalization westbound) has the largest structure coefficient with both accident types. In the after period it is replaced by LANEAG_W and LANEAG_E under both accident types.

DRYWAYE in the before period has the second largest structure coefficient after SIGNAL_W. The magnitude of the structure coefficient in the after period is slightly smaller than in the before period, the decrease is attributed to the inclusion of the LANEAG_E variable.

LANUSE_E (all accidents) and LANUSE_W (rear end accidents) ranked third and fourth respectively in the before period based on the magnitude of their structure coefficients. In the after period, LANUSE_W is included in the discriminant function, however, the magnitude of the structure coefficient is small causing it to rank fourth with rear ends and fifth in all accidents.

Table 4.12
After Period Raised and Lowered Effective Means without Speed Variables
vs
After Period Raised and Lowered Non-Effective Means without Speed Variables, Accident Type: All and Rear End

	All		Rear End		
Variables	Effective w/o Speed (Mean)	Non-Effective (Mean)	Effective w/o Speed (Mean)	Non-Effective (Mean)	Variables
LANEAG_W	40.9	58.2	42.7	62.9	LANEAG_W
LANEAG_E	41.9	58.0	43.1	62.8	LANEAG_E
DRYWAYE	3.1	1.0	3.2	.62	DRYWAYE
RDSIDE_D	2.8	3.0	22.7	18.9	LANUSE_W
LANUSE_W	22.3	17.0	2.9	3.0	RDSIDE_D
FIXOB_E	14.9	11.5	13.8	11.2	FIXOB_E
ADT	27549	27015	29271	29225	ADT

Table 4.12 lists the mean values for those variables retained in the discriminant function without speed variables. LANEAG_W, LANEAG_E and DRYWAYE were determined to have the largest correlations with the discriminant function.

LANEAG_E and LANEAG_W accident distributions are within one or two percentage points of each other for both effective and non-effective groups and by accident type. The after period combined effective zones finds that the accident distribution occurs primarily on 5 LN 2 WAY 12 FT LNS with 74% for all accidents and 65% for rear ends. The after period combined non-effective accident distribution for all accidents occurs primarily on 4 LN 1 WAY 12 FT LNS with 44%, and the remainder distributed approximately equally between 5 LN 2 WAY 12 FT LNS and 4 LN 2 WAY 12 FT LNS. The distribution for rear ends for non-effective finds 58% in the 4 LN 1 WAY 12 FT LNS category, with the remainder distributed equally between the same two categories for all accidents.

These findings indicate that 5 lane highways are good candidates for speed zoning to be effective, while 4 lane highways are not good candidates.

Laneage variables were not selected for the discriminant function in the before period. However, a large number of accidents in the combined before period effective occur on 5 LN 2 WAY 12 FT LNS. This finding further substantiates that speed zoning will be effective at 5 lane sites.

In the after period the presence of driveways near the accident location was noted for effective zones. Non-effective zones accidents occur where there were no driveways, with 73% for all accidents and 74% for rear end accidents respectively.

The after period combined effective distribution was found to have the same type of accident distribution as the before period. The consistency of the findings for DRYWAYE in the before and after period indicates that driveway frequency is a good predictor of speed zoning effectiveness, but the location of accidents relative to driveway location is not altered by changing the speed limit.

Accident distribution based on land use follows the same pattern as was found in the before period for effective zones.

4.11 Summary--After Period

The analysis of discriminant functions and their variables in the after period is found not to be significantly different than findings in the before period.

- Driveway frequency was found to be a consistent roadside friction variable indicating that the presence of driveways is a good indicator that speed zoning will be effective.

- Specific laneage types are found to distinguish where speed zoning is effective. The facility associated with effective speed zoning is 5 LN 2 WAY 12 FT LNS, and 4 LN 1 WAY 12 FT LNS where speed zoning is not effective.

- A mixture of retail and residential land uses were found to provide the environment where speed zoning is effective.

These findings for combined effective raised and lowered speed zones in comparison to combined non-effective zones characterize effective speed zoning in an urban environment. Importantly, the role of skewness (index) as a predictor variable for speed zoning effectiveness is confirmed, and the specific characteristics and role of laneage type, driveway frequency, and land use characteristics which determine where speed zoning will be effective are identified.

CHAPTER 5

Analysis of Speed Limit Raised Zoning Actions

5.1 Before Period Speed Limit Raised Zoning Action

There are eight zones out of a total of thirteen that were found to be effective in reducing accident rates after their speed limits were raised. The type of zone and the amount which the speed limit was raised is presented in Table 5.1 below.

Table 5.1
Listing of Speed Limit Raised Effective Zones

Districts	Zone	Zone Type
District 5*	61-001-87	UR-5, 25 TO 30
District 6	25-007-85T	UR-5, 30 TO 35
District 7	08-024-85T	TR-5, 45 TO 50
District 7	08-025-85TA	UR-5, 35 TO 40
District 7*	11-010-86T1	UR-5, 35 TO 40
District 7*	11-010-86T2	UR-5, 30 TO 35
District 7*	11-010-86T3	UR-10, 30 TO 40
District 7*	13-030-89TB	UR-5, 35 TO 40

These eight zones formed the speed limit raised effective group and were analyzed in comparison to the five speed limit raised non-effective zones. A subset of these eight zones were also effective in reducing rear end accidents. Those identified with an asterisk (*) comprised this set. This set of zones was analyzed with the same procedures utilized on the all accident list.

5.2 Variable Selection

Similar to the combined effective speed raised and lowered analysis, correlation analysis and crosstabulation analysis were conducted on the two data sets to select variables for discriminant analysis.

A compilation of the variables for the before period and accident type are shown in Table 5.2. Those variables which are italicized indicate they are "coded" variables, meaning that their values are not directly interpretable from the discriminant integer output because of their qualitative nature.

Table 5.2

Before Period Raised Variable Identification

BP RAISED EFF ALL	BP RAISED EFF ALL
ACCIDENT TYPE: NO SELECT DATA SET: ALL	ACCIDENT TYPE: REAR END DATA SET: ALL
LANEAG_W PERC_IN_ KURTOSIS EIGHT5_P	*LANEAG_W* KURTOSIS PERC_IN_
BP RAISED EFF REAR ENDS	**BP RAISED EFF REAR ENDS**
ACCIDENT TYPE: NO SELECT DATA SET: REAR	ACCIDENT TYPE: REAR DATA SET: REAR
ADT KURTOSIS *DRYWAYE* *FIXOB_W* SKEWNESS *PRK_RIGH* *SIGNAL_E* *PRK_LEFT* *DRYWAYW*	ADT KURTOSIS *DRYWAYE* *FIXOB_W* HAZ_ACT2 SKEWNESS *LANEAG_E*

Table 5.3 combines the variables from both accident type analyses for the before time period and separates the "direct" and "coded" variables. The double listing of variables in Table 5.3 identifies the variable as being selected in both the all zones effective and rear end zones effective data sets.

Table 5.3
Before Period Raised Variable Identification
Coded and Direct Variables

BP ALL & REAR	BP ALL & REAR
DIRECT VARIABLES ACCIDENT TYPE: NO SELECT	DIRECT VARIABLES ACCIDENT TYPE: REAR END
ADT EIGHT5_P KURTOSIS PERC_IN_ SKEWNESS	ADT KURTOSIS PERC_IN_ SKEWNESS
BP ALL & REAR	**BP ALL & REAR**
CODED VARIABLES ACCIDENT TYPE: NO SELECT	*CODED VARIABLES* ACCIDENT TYPE: REAR END
DRYWAYE *DRYWAYW* *FIXOB_W* *LANEAG_W* *PRK_LEFT* *PRK_RIGH* *SIGNAL_E*	*DRYWAYE* *FIXOB_W* *HAZ_ACT2* *LANEAG_E* *LANEAG_W*

Various combinations of these variables were tested to determine how they performed on discriminating between the effective zones and non-effective zones. Wilks' lambda, eigenvalues, and the classification of the effective and non-effective cases were the measures of effectiveness used to determine if a combination of values had high discriminating power. The determination of combinations with high discriminating power provides an indication of which variables may be used to determine if a speed zone will be effective in carrying out its' intended purpose, which is a safer driving environment.

5.3 Discriminant Analysis--Before Period Effective All and Effective Rear: All and Rear End Accidents

The analysis was carried out on both effective all and effective rear data sets. The variable groupings consisted of the following typology:

- All Direct Variables common to the before period and after period,
- All Direct Variables common to the before period and after period or appearing in either the before period or after period,
- All Direct and Coded Variables common to the before period and after period and,
- All Direct and Coded Variables common to the before period and after period or appearing in either the before period or after period

As an example, the variable list for the before period effective all and effective rear are as follows:

Analysis 1: KURTOSIS, PERC_IN_, SKEWNESS
Analysis 2: ADT, KURTOSIS, PERC_IN_, DRYWAYE, DRYWAYW, SKEWNESS, and EIGHT5_P
Analysis 3: KURTOSIS, PERC_IN_, FIXOB_W, LANEAG_W, PRK_RIGH, SKEWNESS
Analysis 4: KURTOSIS, PERC_IN_, SKEWNESS, FIXOB_W, LANEAG_W, PRK_RIGH, ADT, DRYWAYE, DRYWAYW, EIGHT5_P, PRK_LEFT, and SIGNAL_E

Discriminant analysis operations between the effective zones and non-effective zones were repeated through each of the variable sets and discriminant functions along with associated statistics were obtained for each analysis.

5.3.1 Before Period Raised Effective All and Effective Rear Analysis: All Accidents

Since the same sets of variables defined the effective all and effective rear data sets, a comparison of the measures of effectiveness was undertaken to determine how the variable groupings performed in discriminating between the effective and non-effective zones. The results are presented in Table 5.4.

Table 5.4

Before Period Effective All and Rear End Comparison of Measures of Effectiveness: All Accidents

Effective All	Accident Type: ALL ACCIDENTS			
	Eigenvalue	Wilks' Lambda	Correct Classification	Correct Classification
			Group 1	Group 2
Analysis 1	.16	.86	57.8%	76.1%
Analysis 2	5.72	.15	100.0%	100.0%
Analysis 3	3.30	.23	94.5%	92.7%
Analysis 4	11.47	.08	100.0%	100.0%
Effective Rear End	Accident Type: ALL ACCIDENTS			
	Eigenvalue	Wilks' Lambda	Correct Classification	Correct Classification
			Group 1	Group 2
Analysis 1	.43	.70	57.2%	93.3%
Analysis 2	2.69	.27	100.0%	82.0%
Analysis 3	4.28	.19	93.4%	98.1%
Analysis 4	6.69	.13	97.5%	99.2%

Based on the eigenvalue, Wilks' lambda, and correct group classification for the cases used in the analysis, the variables used to form Analysis 4 were most effective on both the before period effective all data and effective rear data sets. However, each of the analyses except Analysis 1 was successful in discriminating between the two categories (successful and non-successful).

Table 5.5 which follows, contains the correlation coefficients and standardized coefficients of variables for the discriminant function in Analysis 4.

Table 5.5
Before Period Raised Effective All and Rear End Variable Correlations with respective Discriminant Functions, All Accidents

Effective All			Effective Rear End		
Variable	Correlation Value	Standardized Coefficient	Variable	Correlation Value	Standardized Coefficient
LANEAG_W	.29	-.39	ADT	.42	.63
PRK_RIGH	-.27	-.82	EIGHT5_P	.39	.50
EIGHT5_P	.26	2.92	LANEAG_W	.38	.35
PERC_IN_	.06	.89	SKEWNESS	.23	1.15
DRYWAYE	-.04	.38	KURTOSIS	.15	.30
FIXOB_W	-.04	-.64	PRK_RIGH	-.11	-1.71
KURTOSIS	.03	1.87	DRYWAYE	-.08	.59
SIGNAL_E	.01	.14	PRK_LEFT	-.05	.60
			DRYWAYW	-.04	.13
			PERC_IN_	-.04	.14
			SIGNAL_E	-.04	.39
			FIXOB_W	-.02	-.77

The effective all data set utilizes eight of the possible twelve variables to build its discriminant function. The effective rear end utilizes all twelve variables. The effective all correlations indicate weak association with the discriminant function. This means no single variable or small set of variables represents a large proportion of the power of the discriminant function.

The effective rear end data set variable correlations are slightly larger than the effective all. However they too are generally considered weak. The sign of the largest correlations are all positive indicating they are acting in concert with the discriminant function. The conclusion is that although the individual correlations are weak, the discriminant function is strengthened through the breadth of variables. Their positive correlation indicate that ADT, 85th percentile speed, laneage, and skewness can be used to distinguish between effective and non-effective zones.

This was not the case for the effective all variables where the correlations were weaker, there were fewer variables, and a negatively correlated variable was among the largest. A significant finding is that 85th percentile speed is among the top three variables in both groups. This indicates that this speed parameter is important as a predictor variable. The same appears to be true for the coded geometric variable, laneage westbound which appears in both lists with one of the larger correlations with the discriminant function.

5.3.2 Mean Values for Coded and Direct Variables

Table 5.6 contains the mean values of variables used in the before period raised effective all and rear end analysis, compared with the non-effective data set. The mean values for the coded variables and direct variables are a weighted value, composed of the value representing the characteristics of each analysis zones .10 mile segment and the frequency of accidents occurring in that segment. Thus, a variable with a large value and moderate accident frequency may have a considerable influence on the mean value. This would also be true of the opposite situation.

Table 5.6
Mean Values of the Variables in the Before Period Raised
Effective All and Rear End vs
Before Period Raised Non-Effective All and Rear End,
All Accidents

	All		Rear End	
Variables	Effective (Mean)	Non-Effective (Mean)	Effective (Mean)	Non-Effective (Mean)
KURTOSIS	3.6	3.8	3.2	3.8
PERC_IN_	75.5	77.1	78.3	77.1
SKEWNESS	1.08	1.03	.41	1.03
FIXOB_W	22.0	17.3	18.5	17.3
LANEAG_W	26.9	61.6	32.6	61.6
PRK_RIGH	2.09	0.00	.70	0.00
ADT	14485	26864	12714	26864
DRYWAYE	2.2	1.6	2.3	1.6
DRYWAYW	3.5	2.7	3.4	2.7
EIGHT5_P	38.9	44.9	34.6	44.9
PRK_LEFT	1.04	.29	.61	.29
SIGNAL_E	2.6	3.1	1.5	3.1

5.3.3 Coded Variables

The coded variables which were determined to be most highly correlated with the discriminant function will be the primary focus of discussion. Referring to Table 5.6, for the effective all and effective rear data set, for LANEAG_W the only distinguishing characteristic is that one way streets represent a higher percentage of non-effective zones than effective zones. However, this characteristic does not dominate this category.

PRK_RIGH in the effective all data set had parking availability distributed on a 60/40 basis with exclusive parking comprising the higher value. Conversely, 100% of the streets in the non-effective data set had no parking allowed. It appears speed zoning is more effective where on street parking is allowed than on streets where it is prohibited. Generally, parking is not allowed on state trunklines except in the central business district.

5.3.4 Direct Variables

The direct variables found to be the most highly correlated with the discriminant function for each effective data set will be the focus of this discussion.

Referring to Table 5.6, the EIGHT5_P speed variable was identified in both the effective data sets as a significant variable in the discriminant function. For effective all, the mode of this variable is 38 mph, with a median of 39 mph. The mode and median for non-effective was 48 mph. For effective rear, the mode was 34 mph and the median 34 mph. A difference of approximately 10-14 mph exists between the mode and median of the effective zones versus the non-effective zones.

SKEWNESS (skewness index) for the effective all zones and non-effective zones indicates a positive value. Effective rear exhibits a negatively skewed value with a median of 0.00 and a mode of 0.00. A normal distribution would have a skew value of approximately 1.0 and one standard deviation above the mean would be very close to the 85th percentile speed. A negatively skewed distribution indicates the majority of drivers are traveling above the mean and grouped close to the 85th percentile speed. This also means there are a number of drivers traveling below the mean, and thus there is potentially a large speed difference between successive vehicles in the traffic stream.

This analysis leads to the conclusion that a negatively skewed speed distribution in the before condition may be an indication that the speed zone will be effective in reducing rear end accidents. Given the laneage, parking, and 85th percentile speed values for effective rear data sets, this finding would seem to indicate that skewness may be an important variable in determining the predicted effectiveness of raising the speed limit.

ADT is one of the direct variables playing a role in defining the best discriminant function for the effective rear data set. The correlation with the function was not strong, however it was the strongest of all the direct variables. The primary difference between the effective and non-effective data sets is the mean value. Median and mode values also reflect this large difference, contributing to the selection of ADT as a significant discriminating variable.
A conclusion is that streets with low to moderate ADT are more likely to realize a reduction in accidents when the speed limit is raised.

Table 5.7
Before Period Raised Effective All--All Accidents
Comparison of Coefficient Sign and the Magnitude
of the Effective and Non-Effective Means

VARIABLE	Structure Coefficient	Standardized Coefficient	Effective Mean	Non-Effective Mean	Larger Mean-Effective vs Non-Effective	Sign of Structure and Standardized Coefficient
LANEAG_W	.29	-.39	26.9	61.6	Non-Effective	Mixed
EIGHT5_P	.26	2.92	38.9	44.9	Non-Effective	Positive
PERC_IN_	.06	.89	75.5	77.1	Non-Effective	Positive
KURTOSIS	.03	1.87	3.6	3.8	Non-Effective	Positive
SIGNAL_E	.01	.14	2.6	3.1	Non-Effective	Positive
PRK_RIGH	-.27	-.82	2.09	0.00	Effective	Negative
DRYWAYE	-.04	.38	2.2	1.6	Effective	Mixed
FIXOB_W	-.04	-.64	22.0	17.3	Effective	Negative

Table 5.8
Before Period Raised Effective Rear End--All Accidents
Comparison of Coefficient Sign and the Magnitude
of the Effective and Non-Effective Means

VARIABLE	Structure Coefficient	Standardized Coefficient	Effective Mean	Non-Effective Mean	Larger Mean-Effective vs Non-Effective	Sign of Structure and Standardized Coefficient
ADT	.42	.63	12714	26864	Non-Effective	Positive
EIGHT5_P	.39	.50	34.6	44.9	Non-Effective	Positive
LANEAG_W	.38	.35	32.6	61.6	Non-Effective	Positive
SKEWNESS	.23	1.15	.41	1.03	Non-Effective	Positive
KURTOSIS	.15	.30	3.2	3.8	Non-Effective	Positive
PRK_RIGH	-.11	-1.71	.70	0.00	Effective	Negative
DRYWAYE	-.08	.59	2.3	1.6	Effective	Mixed
PRK_LEFT	-.05	.60	.61	.29	Effective	Mixed
DRYWAYW	-.04	.13	3.4	2.7	Effective	Mixed
PERC_IN_	-.04	.14	22.0	17.3	Effective	Mixed
SIGNAL_E	-.04	.39	1.5	3.1	Non-Effective	Mixed
FIXOB_W	-.02	-.77	18.5	17.3	Effective	Negative

In regards to Table(s) 5.7 and 5.8, the finding is that when the structure coefficient is signed positive, the mean values of the variable is larger in the non-effective zones than in the effective zones. The opposite is true when the structure coefficient is signed negative.

Thus, in the operation of the discriminant function, increasing the value of variables (holding all other variables constant) when their structure coefficients are signed positive would tend to increase the separation between the effective and non-effective groups. The opposite would hold true for variables with their structure coefficients signed negative. Therefore, a direct interpretation of the discriminant function for all accidents would be that lower values of the 85th percentile speed, increased parking (higher values), and a high frequency of driveways would be good predictors of effective speed zoning.

5.3.5 Summary Effective All and Rear End: All Accident Types

Using the size of the structure coefficients and the difference in mean values between effective and non-effective data sets, variables were identified for in-depth analysis. For effective all, the coded variables were LANEAG_W and PRK_RIGH. The direct variables were ADT, EIGHT5_P, and SKEWNESS.

The effective all data set was characterized by two lane and four lane facilities with travel in both directions. Parking was available in both directions where accidents occurred. The volume characteristics were low to moderate, skewness values were negative, and the 85th percentile speeds were slightly below 40 mph.

The non-effective data set was characterized by a single direction multi-lane facility. Parking was not available, the volume levels were double those of the effective zones, skewness values were normal, and 85th percentile speeds were a 6-10 mph higher.

5.3.6 Before Period Raised Effective All and Effective Rear End Analysis Rear End Accidents

In Table 5.9, a screening procedure is used in the discriminant analysis to select only rear end accident records. The variables determined for this analysis were those associated with rear end accidents through the variable selection procedures described earlier. Therefore, the variables are highly specific to rear end accidents.

Table 5.9
Before Period Effective All and Rear Comparison of
Measures of Effectiveness,
Rear End Accidents

Effective All	Accident Type: REAR END			
	Eigenvalue	Wilks' Lambda	Correct Classification	Correct Classification
			Group 1	Group 2
Analysis 1	.35	.74	66.3%	82.4%
Analysis 2	1.74	.36	95.9%	82.9%
Analysis 3	2.53	.28	95.9%	90.2%
Analysis 4	3.22	.24	95.9%	92.7%
Effective Rear	Accident Type: REAR END			
	Eigenvalue	Wilks' Lambda	Correct Classification	Correct Classification
			Group 1	Group 2
Analysis 1	.55	.64	63.6%	94.5%
Analysis 2	3.60	.22	99.5%	82.9%
Analysis 3	5.93	.14	97.2%	97.6%
Analysis 4	9.99	.09	99.1%	100.0%

Variables utilized in each analysis are as follows:

Analysis 1: KURTOSIS, PERC_IN_, SKEWNESS
Analysis 2: ADT, PERC_IN_, SKEWNESS, DRYWAYE, and KURTOSIS
Analysis 3: SKEWNESS, PERC_IN_, KURTOSIS, FIXOB_W, LANEAG_E, and LANEAG_W
Analysis 4: DRYWAYE, PERC_IN_, SKEWNESS, FIXOB_W, ADT, LANEAG_E, LANEAG_W, SKEW, KURTOSIS, and HAZ_ACT2

Analysis 4 (based on the measures of effectiveness previously identified) defines the discriminant function which performs best in distinguishing effective zones from non-effective zones. It is not surprising that when each effective data set is constrained to rear end accidents, the effective rear data set discriminant output are superior to the effective all data set for rear end accidents. As in the previous section, all of the analyses except Analysis 1 classify nearly all of the zones correctly.

Referring to Table 5.10, seven of the possible ten variables for Analysis 4 were utilized in determining the discriminant function for the effective all grouping. The two laneage variables have the strongest correlations with the discriminant function. However, the strength of the correlation for these two variables is still considered weak.

Table 5.10
Before Period Effective All and Rear End Variable Correlations with respective Discriminant Functions, Rear End Accidents

Effective All			Effective Rear End		
Variable	Correlation Value	Standardized Coefficient	Variable	Correlation Value	Standardized Coefficient
LANEAG_W	.52	2.77	ADT	.35	2.58
LANEAG_E	.32	-1.33	LANEAG_W	.31	1.23
PERC_IN_	.20	.19	LANEAG_E	.22	-2.94
FIXOB_W	-.10	-.22	SKEWNESS	.22	1.62
DRYWAYE	-.08	.56	KURTOSIS	.14	.30
SKEW	-.04	.76	DRYWAYE	-.07	.31
HAZ_ACT2	-.04	-.22	SKEW	-.05	.49
			HAZ_ACT2	-.05	-.24
			FIXOB_W	-.01	-.56

Analysis 4 contained nine of the ten possible variables for determining the discriminant function for the effective rear end grouping. ADT and LANEAG_W have the largest correlations with the discriminant function. LANEAG_E and SKEWNESS tie for third with a smaller correlation value.

The geometric variables of laneage in both eastbound and westbound directions are prominent in both data sets. Speed variables continue to play a role, although they differ for each data set. This seems to indicate that speed variables are important to the discriminant function.

Again, the effective rear end data set involved more variables than the effective all data set. In both cases, the sign of the correlations were positive for the most highly correlated variables.

To characterize the effective zones in comparison to the non-effective zones, analysis of the variables which determined the best overall discriminant functions were undertaken.

The same process utilized in the all accident analysis was employed here. The analysis which determined the most effective discriminant function was Analysis 4. Therefore, an examination of variables from this analyses will provide the comparison base. Table 5.11 identifies all ten variables that were initially involved in determining the most effective discriminant function for Analysis 4 in both effective data sets.

Table 5.11
Before Period Raised Effective All and Rear End vs
Before Period Raised Non-Effective All and Rear End,
Rear End Accidents

	All		Rear	
Variables	Effective (Mean)	Non-Effective (Mean)	Effective (Mean)	Non-Effective (Mean)
DRYWAYE	1.95	1.43	2.1	1.43
PERC_IN_	74.5	77.1	78.2	77.1
SKEWNESS	1.08	1.02	.35	1.02
FIXOB_W	23.9	12.4	18.3	12.4
ADT	14138	27287	12921	27287
LANEAG_E	36.5	61.4	36.9	61.4
LANEAG_W	28.1	62.2	32.7	62.2
SKEW	.19	.17	.24	.17
KURTOSIS	3.7	3.9	3.1	3.9
HAZ_ACT2	2.90	2.50	3.65	2.50

5.3.7 Coded Variables

The distinguishing difference between the effective data sets and the non-effective data sets is the bi-directionality of the laneage for effective zones, as opposed to one way facilities for non-effective zones. The laneage data type distribution comparison continues to confirm that speed zoning is less likely to be effective on one way multi-lane facilities.

5.3.8 Direct Variables

Again referring to Table 5.10, ADT is identified as one of the direct variables playing a role in defining the best discriminant function for the effective rear data set. The correlation was strongest overall among the direct variables. The primary difference between the values obtained in comparing the effective and non-effective data sets is the large difference in mean ADT values. Median and mode values also reflect this large difference, contributing to the selection of ADT as a significant discriminating variable.

SKEWNESS in the effective data sets controlling for rear end accident type exhibits a pattern similar to when no accident type was selected. Effective rear zones exhibit a negative skewness index. The value is slightly more negatively skewed than the effective rear with no control for accident type.

KURTOSIS for both effective all and effective rear is found to be different between the effective data sets. Effective all value is much closer to the non-effective value and both values are leptokurtic. However for effective rear, the value is close to the normal value of 3.0 and is considered mesokurtic.

In summary, for rear end accidents, moderate volumes, a negatively skewed speed distribution, and a mesokurtic kurtosis are representative of speed zones that are likely to be effective.

Table 5.12
Before Period Raised Effective All--Rear End Accident Select
Comparison of Coefficient Sign and the Magnitude
of the Effective and Non-Effective Means

VARIABLE	Structure Coefficient	Standardized Coefficient	Effective Mean	Non-Effective Mean	Larger Mean-Effective vs Non-Effective	Sign of Structure and Standardized Coefficient
LANEAG_W	.52	2.77	28.1	62.2	Non-Effective	Positive
LANEAG_E	.32	-1.33	36.5	61.4	Non-Effective	Mixed
PERC_IN_	.20	.19	74.5	77.1	Non-Effective	Positive
FIXOB_W	-.10	-.22	23.9	12.4	Effective	Negative
DRYWAYE	-.08	.56	1.95	1.43	Effective	Mixed
SKEW	-.04	.76	.19	.17	Effective	Mixed
HAZ_ACT2	-.04	-.22	2.90	2.50	Effective	Negative

Table 5.13
Before Period Raised Effective Rear--Rear End Accident
Comparison of Coefficient Sign and the Magnitude
of the Effective and Non-Effective Means

VARIABLE	Structure Coefficient	Standardized Coefficient	Effective Mean	Non-Effective Mean	Larger Mean-Effective vs Non-Effective	Sign of Structure and Standardized Coefficient
ADT	.35	2.58	12921	27287	Non-Effective	Positive
LANEAG_W	.31	1.23	32.7	62.2	Non-Effective	Positive
LANEAG_E	.22	-2.94	36.9	61.4	Non-Effective	Mixed
SKEWNESS	.22	1.62	.35	1.02	Non-Effective	Positive
KURTOSIS	.14	.30	3.1	3.99	Non-Effective	Positive
DRYWAYE	-.07	.31	2.1	1.43	Effective	Mixed
SKEW	-.05	.49	.24	.17	Effective	Mixed
HAZ_ACT2	-.05	-.24	3.65	2.50	Effective	Negative
FIXOB_W	-.01	-.56	18.3	12.4	Effective	Negative

Similar to the effective all and effective rear data sets with no accident type selected, the sign of the structure coefficients and comparison of means of variables yields the same finding. If the structure coefficient is signed positive, the mean value of the non-effective variable is larger than the mean of the effective variable, the opposite being true when the structure coefficient is signed negative.

Interpretation of the effective versus non-effective variables in Table 5.12 indicates two lane and four lane bi-directional facilities, increasing frequency of various fixed objects, and higher frequency of driveways are indicators of effective zones.

The interpretation of Table 5.13 suggests that lower values of ADT, two lane and four lane bi-directional facilities, a negatively skewed speed distribution, and higher frequency of driveways are indicators of effective speed zones.

5.3.9 Summary Effective All and Rear End: Rear End Accident Types

The coded variables and direct variables identified with effective zones indicates that bi-directional two and four lane facilities, a higher frequency of driveways, and a negatively skewed speed distribution determine whether the speed zoning action will be effective. A lower range of ADT volume is also found to be important for the effective rear data set.

5.3.10 Summary--Before Period Raised

Based on the correlation of coded and direct variables to the most effective discriminant function obtained, and the comparison of the mean values of these variables, it was determined that effective speed zones can be characterized as containing bi-directional two lane and four lane streets, ADT volumes in the range of 6,000 to 9,000, and a speed distribution which is negatively skewed. These characteristics were found to be present generally across both effective data sets and with analysis for all and rear end accident types.

5.4 Analysis of After Period Speed Raised Zoning Action

As indicated in Chapter 2, Methodology, speed data were not available in the after period and therefore could not be used in the discriminant analysis. Consistent with the approach outlined in the methodology, the after period data will be utilized to compare the change in variable levels between effective and non-effective groups between the before and after period. The complete data set is used to determine the mean values for each variable, as opposed to the means generated from the cases utilized in discriminant analysis. This provides a much broader spectrum of cases for effective and non-effective data sets, and would give a complete representation of the data since no cases would be dropped as in discriminant analysis for missing variables.

5.4.1 Comparison of the Change in Mean Values Between Time Periods for Location Sensitive Variables-Effective All (All Accidents)

Table(s) 5.14 and 5.15 below compares the mean values of the six parameters that vary by location within a given zone. These are: DRYWAYE, DRYWAYW, FIXOB_E, FIXOB_W, SIGNAL_E, and SIGNAL_W. Table 5.14 contains the values for the effective and non-effective data set(s) for all accidents, while Table 5.15 contains the mean values for the effective and non-effective data set(s) with rear end accidents.

A t-test was performed on the effective data between the after period mean values and the before period mean values. The null hypothesis is that the means of the variables for the before and after data sets are the same, indicating that no statistically significant change at the .95 confidence level has occurred in the value of the variable within the .10 mile segment (weighted) where accidents occurred. A change in this case is the result of a shift in the location of accidents from the before period to after period, leading to a different mean value in the after period.

Table 5.14
Comparison of the After Period Means with Before Period Means of Location Sensitive Variables in Discriminant Analysis, Effective All Data Set--All Accidents

	EFFECTIVE			NON-EFFECTIVE		
Variable	BP	AP	t-test @ α = .95	BP	AP	t-test @ α = .95
DRYWAYE	2.1	2.3	ACCEPT	1.6	1.0	REJECT
DRYWAYW	3.5	3.3	ACCEPT	2.7	2.1	REJECT
FIXOB_E	21.6	20.2	ACCEPT	13.2	12.5	ACCEPT
FIXOB_W	22.0	19.0	REJECT	17.3	19.2	REJECT
SIGNAL_E	2.6	4.2	REJECT	3.1	3.5	REJECT
SIGNAL_W	1.7	2.8	REJECT	11.5	14.0	REJECT

The results of the t-test for driveway frequency across effective and non-effective data sets indicate that approximately the same number of driveways in both time periods were at locations where accidents occurred in the effective zones, however, the number of driveways were significantly less in the after period for non-effective zones. This finding is consistent with earlier findings that non-effective zones have fewer driveway related accidents.

For both effective and non-effective data sets the signalization variables reject the null hypothesis. In both data sets there is an increase in accidents in the after period. The larger increase in accidents for the effective data set may be attributed to drivers adjusting to the new speed limits, while in the non-effective data set, the speed limit increase caused minimal driver adjustments since they were already driving faster than the existing speed limit.

Table 5.15
Comparison of the After Period Means with Before Period Means
of Location Sensitive Variables in Discriminant Analysis
Effective All Data Set--Rear End Accidents

	EFFECTIVE			NON-EFFECTIVE		
Variable	BP	AP	t-test @ α = .95	BP	AP	t-test @ α = .95
DRYWAYE	1.9	2.2	ACCEPT	1.4	0.6	REJECT
DRYWAYW	3.6	3.6	ACCEPT	1.9	1.6	ACCEPT
FIXOB_E	22.6	23.9	ACCEPT	12.4	11.5	ACCEPT
FIXOB_W	23.8	22.4	ACCEPT	17.4	20.9	REJECT
SIGNAL_E	3.4	4.3	ACCEPT	2.9	2.9	ACCEPT
SIGNAL_W	2.0	2.1	ACCEPT	12.9	16.8	REJECT

Table 5.15 confirm that speed zoning is least effective in reducing rear end accidents where there is a pre-existing high accident frequency at or near signalized intersections.

5.4.2 Summary--Change in Mean Values Between Time Periods for Location Sensitive Variables--Effective All (All Accidents)

A comparison of the findings between the effective data sets and non-effective data sets mean values across time periods finds that the conclusions from the before period regarding characteristics of effective speed zoning are validated using the after period data sets. Where rejection of mean values in the effective data set occurred, the differences were minimal.

5.4.3 Summary--Analysis of After Period Speed Raised Zoning Action

The findings indicate that the before period location or environmental conditions predicting effectiveness of speed zoning are found to be consistent with the location and conditions in the after period. This indicates that: (1) there has not been a statistically significant shift in accident locations within the speed zone, and (2) the consistency in the results suggests that the methodology undertaken here to characterize effective and non-effective zones is valid.

CHAPTER 6

Analysis of Speed Limit Lowered Zoning Actions

6.1 Before Period Speed Limit Lowered Zoning Action

There are seven zones out of a total of thirteen that were found to be effective in reducing accident rates after their speed limits were lowered. The type of zone and the amount which the speed limit was lowered is presented in Table 6.1 below.

Table 6.1
Listing of Speed Limit Raised Effective Zones

Districts	Zone	Zone Type
District 8*	33-001-84TA	UL-5, 40 TO 35
District 8	33-001-84TB	TL-5, 50 TO 45
District 8*	33-001-84TC	UL-10, 45 TO 35
District 8*	81-003-85T	UL-5, 45 TO 40
District 8*	81-023-84	UL-10, 45 TO 35
District 8*	33-028-88T	UL-10, 35 TO 25
District 9*	82-049-85TA	TL-5, 45 TO 40

A subset of these seven zones were also effective in reducing rear end accidents. Those identified with an asterisk (*) comprised this set. This set of zones effective in reducing rear end accidents are not analyzed separately for speed lowered zoning actions because their results in discriminant analysis indicated no difference with the effective all data set restricted to rear end accidents.

6.2 Variable Selection

Similar to the analysis performed on the before period speed limit raised zones, a variable selection process was conducted which led to an initial set of variables utilized in a stepwise discriminant analysis. The stepwise variable selection process was performed to identify variables which contributed the majority of the minimization of Wilks' lambda. As before, variables which contributed approximately 80% to 85% of the minimization of Wilks' lambda were identified and used in the analyses. Also, accident type was investigated in conjunction with variable selection to determine if certain variables were related to accident type in discriminating between effective and non-effective zones.

For the before period lowered effective analysis, the effective all data set is analyzed for all and rear end accidents. Table 6.2 displays the results of the variable selection process from the stepwise discriminant analysis.

Table 6.2

Before Period Lowered Variable Identification

BP LOWERED EFF ALL	BP LOWERED EFF ALL
ACCIDENT TYPE: ALL ACCIDENTS DATA SET: ALL	ACCIDENT TYPE: REAR END DATA SET: ALL
DRYWAYE EIGHT5_P *ROAD_TYP* SKEWNESS *SIGNAL_W*	ADT *DRYWAYE* *SIGNAL_E* *SIGNAL_W* SKEWNESS
BP LOWERED EFF REAR	**BP LOWERED EFF REAR**
ACCIDENT TYPE: ALL ACCIDENTS DATA SET: REAR	ACCIDENT TYPE: REAR END DATA SET: REAR
DRYWAYE *SIGNAL_W* PERC_IN_ SKEW SKEWNESS	*DRYWAYE* PERC_IN_ *SIGNAL_W* SKEW SKEWNESS

6.3 Discriminant Analysis--Before Period Effective All: All and Rear End Accidents

Accident types of interest consisting of all and rear end were identified for each discriminant run with each combination of variables. The variable groupings generally consisted of the following typology:

- Analysis 1: All Direct Variables common to before period and after period,
- Analysis 2: All Direct Variables common to before period and after period and in either the before period or after period,

- Analysis 3: All Direct and Coded Variables common to before period and after period and,
- Analysis 4: All Direct and Coded Variables common to before period and after period and in either the before period or after period

As an example, the variable list for the before period effective all is as follows:

Analysis 1: PERC_IN_, SKEWNESS
Analysis 2: EIGHT5_P, PERC_IN_, SKEWNESS, and SKEW
Analysis 3: DRYWAYE, PERC_IN_, SKEWNESS, ROAD_TYP, and SIGNAL_W
Analysis 4: DRYWAYE, EIGHT5_P, PERC_IN_, SKEW, SKEWNESS, ROAD_TYP, and SIGNAL_W

Discriminant analysis operations between the effective zones and non-effective zones were repeated through each of the variable sets and discriminant functions obtained for each analysis along with associated statistics.

6.3.1 Measures of Effectiveness--Before Period Lowered Effective All Analysis: All Accidents

A comparison of the measures of effectiveness was undertaken to determine how the variable groupings performed in discriminating between the effective and non-effective zones. The results are presented in Table 6.3.

Table 6.3
Before Period Effective All Comparison of
Measures of Effectiveness: All Accidents

Effective All	Accident Type: ALL ACCIDENTS			
	Eigenvalue	Wilks' Lambda	Correct Classification	Correct Classification
			Group 1	Group 2
Analysis 1	.39	.72	73.9%	100.0%
Analysis 2	.55	.64	83.9%	96.5%
Analysis 3	1.47	.40	87.8%	86.4%
Analysis 4	1.68	.37	87.2%	85.5%

Based on the eigenvalue, Wilks' lambda, and correct group classification for the cases used in the analysis to derive the discriminant function, the variables used to form Analysis 4 were slightly more effective on the before period effective all data set with no specific accident type analyzed.

Table 6.4 which follows, contains the correlation coefficients as previously defined for the discriminant function in Analysis 4.

Table 6.4
Before Period Lowered Effective All Structure Coefficients and Standardized Coefficients

Effective All		
Variable	Structure Coefficients	Standardized Coefficients
SIGNAL_W	.48	.54
SKEWNESS	.46	.63
DRYWAYE	-.45	-.34
EIGHT5_P	.26	.56
SKEW	-.19	-.19
PERC_IN_	-.17	-.21
ROAD_TYP	-.10	-.84

Table 6.5
Mean Values of the Variables in the Before Period Lowered Effective All vs Before Period Lowered Non-Effective--All Accidents

	All	
Variables	Effective (Mean)	Non-Effective (Mean)
SIGNAL_W	7.4	23.3
SKEWNESS	.47	1.03
DRYWAYE	3.4	.72
EIGHT5_P	42.9	46.3
SKEW	.06	.03
PERC_IN_	76.9	72.9
ROAD_TYP	2.06	2.00

6.3.2 Coded Variables

SIGNAL_W has a relatively large positive structure coefficient indicating that it acts in concert with the discriminant function to discriminate between the effective and non-effective groups. The sign of the standardized coefficient is also positive.

Large values on *SIGNAL_W* would increase the function value. The desire is to have the largest distance or space possible between the two data sets. The mean values indicate that the frequency distribution of coded values is such that the mean is larger for non-effective zones. Review of the specific codes and their percentages within each data set reveals that effective zones have approximately 70% of their accident locations where there was no signalization in the westbound direction, compared to 37% for non-effective zones.

This fact, along with the positive sign of the standardized coefficient, indicates that larger values on the variable will lead to large function values. The absence of a strong correlation with any other variables except *SIGNAL_E* tends to support the belief that the coefficient is accurate and not compromised. This lends strong support to the conclusion that zones with fewer accidents at signalized locations will more likely benefit from speed zoning

DRYWAYE has a negative sign on both the structure coefficient and standardized coefficient. For the structure coefficient this indicates a negative correlation with the discriminant function. The size of the structure coefficient is not large, and in general, correlation values of this magnitude would be considered weak. The sign indicates that the variable acts against or inverse to the discriminant function attempting to achieve the largest space between the effective and non-effective data sets. The presence of a large number of driveways would tend to decrease the size of the discriminant function value.

The standardized coefficient is not correlated with other variables, leading to the conclusion that this coefficient is not sharing its' contribution on the discriminant function with other variables to a meaningful degree. Although there are no large correlations, *DRYWAYE* has its' largest correlation with *LANEAG_E* and *LANEAG_W* at -.43 for both. Since this correlation is not positive and large it does not appear that the magnitude and sign would be affected for *DRYWAYE*. The size of the standardized coefficient places it second among those with a negative sign, and fifth among all such coefficients regardless of sign. This denotes its' overall weak role in determining the discriminant function value.

For *DRYWAYE* analysis of the distribution for effective all indicates 82% of accidents in effective zones occurred where driveways were present. In comparison, for non-effective zones, this percentage for all driveway frequencies was 25%. The remaining 75% were locations where no driveways were present. Driveway frequency for this data set is associated with decreasing the discriminant function value. In this case, the high frequency values are associated with effective zones. However, since the correlation of the structure coefficient is described as weak and the standardized coefficient absolute magnitude is small, the descriptive impact of the coefficients is minimized. Instead, the means and distributions of the effective and non-effective data sets are clear in their description of the characterization of effective vs non-effective speed zones.

6.3.3 Direct Variables

The structure coefficient for SKEWNESS indicates a weak positive correlation with the discriminant function. The positive sign indicates that increasing values for skewness will serve to increase the discriminant function value.

The standardized coefficient is also positive. However, the variable was found to be moderately negatively correlated (-.53) with ADT. This relationship is interpreted to mean that SKEWNESS does not share the same information as ADT. The moderate degree of correlation is also interpreted to mean that the likelihood of the magnitude and sign of the standardized coefficient being very different is unlikely. Values found in the distribution of each data set for SKEWNESS and factored by the standardized coefficient for SKEWNESS are expected to contribute to maximizing the function value.

Review of the distribution of values for skewness for the effective all data set indicate that 77% of accident locations occurred where the speed was negatively skewed. For non-effective zones, this percentage was 45%. The negatively skewed speed distribution indicates that drivers were selecting speeds which were spread less throughout the speed distribution and were generally clumped together at or near the 85th percentile speed. The opposite behavior would lead to a positively skewed distribution, meaning a greater variation in driver speeds throughout the speed profile and from various findings a recognition that this is a more unsafe driving condition because of the speed variation in the traffic stream. The finding in relation to speed zoning effectiveness is that locations which have a speed profile in the before period which tends to be negatively skewed are found to be a precursor of effective speed zones. This fact may indicate that this variable may be used to predict the effectiveness of speed zoning prior to the speed limit change.

An interesting finding involves the signs of the structure coefficients and standardized coefficients and whether the means of the effective zones were less than or greater than the means of the non-effective zones. Table 6.6 separates the variables and related coefficients first by sign of the coefficients and then ordered by structure coefficient size.

Table 6.6
Before Period Lowered Effective All--All Accidents
Comparison of Coefficient Sign and the Magnitude of
the Effective vs Non-Effective Means

VARIABLE	Structure Coefficient	Standardized Coefficient	Effective Mean	Non-Effective Mean	Larger Mean-Effective vs Non-Effective	Sign of Structure and Standardized Coefficient
SIGNAL_W	.48	.54	7.4	23.3	Non-Effective	Positive
SKEWNESS	.46	.63	.47	1.03	Non-Effective	Positive
EIGHT5_P	.26	.56	42.9	46.3	Non-Effective	Positive
DRYWAYE	-.45	-.34	3.4	.72	Effective	Negative
SKEW	-.19	-.19	.06	.03	Effective	Negative
PERC_IN_	-.17	-.21	76.9	72.9	Effective	Negative
ROAD_TYP	-.10	-.84	2.06	2.00	Effective	Negative

6.3.4 Summary--Before Period Effective All:

A review of those variables with significant structure coefficients and a comparison of their means and distributions indicate that for the effective all data set, speed zoning effectiveness was characterized by zones with fewer accidents at signalized intersections, a negatively skewed speed distribution, and a high driveway density as compared to non-effective zones where speed limits had been lowered.

6.3.5 Before Period Effective All Analysis--Rear End Accident Select

In comparing the measures of effectiveness and mean values for variables used in the most effective analysis, the selection of rear end accidents as the accident type was conducted for both the effective all data set and the non-effective data set. Therefore, the results are specific to rear end accidents in both effective and non-effective data sets.

Table 6.7
Before Period Effective All Comparison of
Measures of Effectiveness: Rear End Accident Type Selected

Effective All	Accident Type: REAR ENDS			
	Eigenvalue	Wilks' Lambda	Correct Classification	Correct Classification
			Group 1	Group 2
Analysis 1	.39	.72	79.0%	96.7%
Analysis 2	.46	.69	83.9%	96.7%
Analysis 3	1.51	.40	95.3%	83.6%
Analysis 4	1.66	.38	95.3%	84.8%

For effective all zones where rear end accident types are selected and analyzed as a group, the measures of effectiveness (MOE) identify the variables used in Analysis 4 as the most effective. The specific variables used in this analysis are:

Analysis 4: DRYWAYE, EIGHT5_P, PERC_IN_, SKEW, SKEWNESS,
ROAD_TYP, and SIGNAL_W

Table 6.8 which follows, contains the correlation coefficients of variables for the discriminant function in Analysis 4. Similar to effective all with all accident types, variables that formed Analysis 4 are displayed with their structure coefficients and standardized coefficients.

Table 6.8

Before Period Lowered Effective All Structure Coefficients and Standardized Coefficients: Rear End Accidents

Effective Rear		
Variable	Structure Coefficients	Standardized Coefficients
DRYWAYE	-.54	-.43
SIGNAL_W	.54	.71
SKEWNESS	.39	.43
EIGHT5_P	.28	.56
PERC_IN_	-.22	NI
SKEW	-.17	-.17
ROAD_TYP	-.07	-.50

Table 6.9
Before Period Lowered Effective All vs
Before Period Lowered Non-Effective--Rear End Accidents

	All	
Variables	Effective (Mean)	Non-Effective (Mean)
DRYWAYE	3.38	.39
SIGNAL_W	7.8	25.8
SKEWNESS	.49	1.02
EIGHT5_P	42.4	45.9
PERC_IN_	78.3	72.9
SKEW	.06	.03
ROAD_TYP	2.0	2.0

Table 6.10
Before Period Lowered Effective All--Rear End Accident Selected
Comparison of Coefficient Signs and the Magnitude of
the Effective vs Non-Effective Means

VARIABLE	Structure Coefficient	Standardized Coefficient	Effective Mean	Non-Effective Mean	Larger Mean-Effective vs Non-Effective	Sign of Structure and Standardized Coefficient
SIGNAL_W	.54	.71	7.8	25.8	Non-Effective	Positive
SKEWNESS	.39	.43	.49	1.02	Non-Effective	Positive
EIGHT5_P	.28	.56	42.4	45.9	Non-Effective	Positive
DRYWAYE	-.54	-.43	3.4	.39	Effective	Negative
PERC_IN_	-.22	NI	78.3	72.9	Effective	Negative
SKEW	-.17	-.17	.06	.03	Effective	Negative
ROAD_TYP	-.07	-.50	2.00	2.00	Tie	Negative

6.3.6 Coded Variables

DRYWAYE has a relatively large negative structure coefficient, indicating that it is not acting in concert with the discriminant function. The negative correlation indicates that in this case driveway frequency has an inverse relationship with the discriminant function. The standardized coefficient is also negative, however its' magnitude relative to all other standardized coefficients is not very large and therefore the impact on the function value is minimal relative to the other coefficients. In general, the impact of the negative sign would tend to decrease the discriminant function value, thereby diminishing the separation between the data sets.

In the non-effective category 82% of the accident occurrences were where there were no driveways. In comparison to the effective zones, the category with the largest percentage is five driveways with 36%. The effective category had 89% of its' accident occurrences where at least one driveway was present. This cumulative percentage value is comparable to the effective all no accident select data set which was 82%. For the non-effective data set no accident select, the accident locations with driveways was 25% compared to the effective all rear end accident select of 18%. For DRYWAYE, it is concluded that a high frequency of driveways characterizes effective speed zoning where the speed limit is lowered.

SIGNAL_W is similar to the select all accident data set and has relatively large positive values for the structure and standardized coefficients. The difference here is that the standardized coefficient is the largest among these coefficients, where for select all it was third in magnitude. The magnitude of the coefficient in this data set may indicate that signalization plays a more important role in identifying zones where rear end accidents are reduced than in identifying those where all accidents are reduced.

It was found that 68% of accident occurrences took place where there was no signalization present in effective zones compared to 27% in the non-effective zones. The percentages for no signalization present are very similar between the effective zone for all and rear end accidents. However, the percentages for no accident occurrence in the comparison of non-effective zones for all and rear accidents indicate that rear end accidents occur somewhat more frequently (73% vs 63%) at signalized intersections. This finding may indicate that speed zones may exhibit minimal differences in accident involvement near signalized intersections by all and rear end accident types. In conclusion, for *SIGNAL_W*, the lack of accidents at or near signalized intersections is found to characterize effective speed zoning where the speed limit is to be lowered.

6.3.7 Direct Variables

The structure coefficient for skewness is positive and in overall magnitude is third behind *SIGNAL_W* and *DRYWAYE*. The positive sign on the coefficient indicates that values for the variable will lead to increasing the overall discriminant function value.

The comparison between data sets indicate that for effective all rear end accident select, 80% of the accidents occurred where there was a negatively skewed speed profile compared to non-effective with 55%. The vast majority (54%) of accident occurrences in the effective all rear end select data base were associated with a

skewness index value of 0.0. The largest skewness index value for effective all (rear end accidents) was 1.09 with 7.0% of all occurrences. This compares to a skewness index value of 1.17 at 23.0% for non-effective all.

Comparing the two effective data sets, reveals that the percentage of accidents occurring where negative skewed profiles were obtained are fairly close, 77% for effective all no accident select and 80% with rear end accident select. The difference between non-effective values is 10% with non-effective all at 45% and non-effective rear with 55% for negatively skewed speed profiles. The key difference appears to be that a larger proportion of rear end accidents occurred where the speed profile was negatively skewed prior to implementing the speed zone. The conclusion is an existing negatively skewed speed profile is a characteristic for effective speed zoning where the speed limit is lowered.

6.3.8 Summary--Before Period Effective All Analysis-Rear End Accidents

The variables found to be effective in discriminating between the effective and non-effective data sets are essentially the same found for the all accident analysis. For rear end accidents the structure coefficient sizes were marginally smaller than the all accident analysis. However, the mean values were consistent with related findings in the all accident case. Therefore, the characteristics for effective speed zoning when speed limits are lowered and rear end accidents analyzed are essentially no different than the all accident case.

6.4 Analysis of After Period Speed Lowered Zoning Action

Similar to the analysis conducted in the after period speed raised discussion, the means of variables which reflect a change in the location of accidents would indicate if the conditions and locations predicted for effective zones are confirmed in the after period. The same variables of : DRYWAYE, DRYWAYW, FIXOB_E, FIXOB_W, SIGNAL_E, and SIGNAL_W will be compared between the before and after time periods for effective all data sets, as well as non-effective, for all and rear end accident type. As with speed raised, the complete data set is used to determine the mean values for each variable, as opposed to the means generated from the cases utilized in discriminant analysis.

6.4.1 Comparison of the Change in Mean Values Between Time Periods for Location Sensitive Variables

Again, similar to the after period raised analysis, a comparison of the mean values between the before and after time periods for effective all and rear data sets with non-effective data sets is undertaken. Table 6.11 below compares the mean values of the effective all data set for all accident types with the non-effective data set, also including all accident types.

Table 6.11
Comparison of the After Period Means with Before Period Means
of Location Sensitive Variables in Discriminant Analysis,
Effective All Data Set--All Accidents

	EFFECTIVE			NON-EFFECTIVE		
Variable	BP	AP	t-test @ α = .95	BP	AP	t-test @ α = .95
DRYWAYE	3.3	3.3	ACCEPT	.90	1.1	ACCEPT
DRYWAYW	2.0	2.2	REJECT	1.5	1.9	REJECT
FIXOB_E	12.9	13.8	REJECT	9.6	9.9	ACCEPT
FIXOB_W	14.9	17.1	REJECT	11.9	11.2	ACCEPT
SIGNAL_E	11.5	13.3	REJECT	17.6	13.9	REJECT
SIGNAL_W	6.9	8.9	REJECT	19.9	15.3	REJECT

Reviewing the results for driveways indicates that although the null hypothesis was not accepted in both directions, the actual differences are small. The important factor is that there is no substantial change in number of driveways in the effective data set and that the values are not decreasing. In the non-effective data set the values increased in the after period, indicating a shift toward locations with more driveways. The results are consistent with earlier findings, which predicted that the level of driveway frequency in the before period would be higher than that found in non-effective zones. The results indicate that this is also true for the after period when compared to the non-effective zones.

The null hypothesis for fixed objects is rejected for the effective data set and accepted for the non-effective. This finding indicates that the location of accidents in relation to type and frequency of fixed objects has changed for the effective data set. The increase in the mean value indicates an increase in types of objects associated with an urban environment. Where for the non-effective data set, acceptance of the null hypothesis indicates no change between time periods. The significance of this finding for non-effective zones is that no change in fixed objects indicates accidents are occurring in approximately the same locations identified with non-effective zones and rejection of the null hypothesis is further substantiation of the predicted characteristics for effective speed zoning.

Signalization results for effective data sets finds the null hypothesis is rejected primarily because of the increase in values. Where for non-effective the opposite is true. These results indicate that for effective zones there may be a slight increase in accidents at or near signalized intersections, where for non-effective there is a more substantial shift in location away from signalized intersections. Overall, the finding for effective zones is still valid for signalized intersections, which is that their mean values are less than for non-effective zones. However, here it appears that the action of lowering the speed limit in non-effective zones has an impact on the distribution of accidents away from intersections.

The results of the t-test for the comparison of mean values between time periods for the effective all and non-effective data sets confirms the findings from the discriminant analysis regarding the location of accidents in the effective and non-effective zones.

Table 6.12 presents the results of the t-test for the effective all data set with rear end accidents and the non-effective data set restricted to rear end accidents.

Table 6.12
Comparison of the After Period Means with Before Period Means
of Location Sensitive Variables in Discriminant Analysis
Effective All Data Set--Rear End Accidents

	EFFECTIVE			NON-EFFECTIVE		
Variable	BP	AP	t-test @ α = .95	BP	AP	t-test @ α = .95
DRYWAYE	3.3	3.3	ACCEPT	.60	.65	ACCEPT
DRYWAYW	1.9	2.3	REJECT	1.7	2.3	REJECT
FIXOB_E	12.4	12.9	ACCEPT	9.4	10.7	ACCEPT
FIXOB_W	15.7	17.8	REJECT	13.2	12.8	ACCEPT
SIGNAL_E	13.3	13.4	ACCEPT	20.9	17.4	REJECT
SIGNAL_W	7.3	9.8	REJECT	22.6	15.5	REJECT

The mean values for driveways and the results of the t-test are not substantially different than the effective all case. The findings indicate that there is no substantial change between time periods for either effective all or non-effective data sets. The important point being that the values indicate that the locations are essentially the same for both data sets, with values for both consistent with predictions from discriminant functions.

Fixed objects for the effective data set are found to either not change or increase, while for the non-effective essentially no change is registered. Importantly, the consistency in results again conforms earlier findings of the location of accidents for effective and non-effective data sets relative to roadside friction elements.

Therefore, the agreement provides additional confirmation that effective data sets would have a higher mean value relative to non-effective data sets.

The t-test results for signalization for effective all finds no change or a slight increase in mean values. Where for non-effective the decrease in mean values is also found here, leading to rejection of the null hypothesis. Similar to the effective all and all accident case, the substantial lack of change in locations is found for rear ends. And, the pattern for non-effective is repeated, with values indicating a shift in locations away from signalized intersections. The consistency of the locations for the effective zones is confirmed. The shift in locations for the non-effective indicates the action of lowering limits has had a limited effect on shifting accident locations relative to signalized intersections. The conclusion however is that the predicted locations of accidents in discriminant analysis relative to signalized intersections for effective zones and non-effective zones is upheld.

CHAPTER 7

Summary and Conclusions

7.1 Basis and Objectives

An analytical study was performed on twenty-six speed zones to determine those factors which are associated with the effectiveness of speed zoning in urban areas. The sites are located in the state of Michigan and the zones were implemented between 1983 and 1989.

The objectives of this research were to: (a) determine if the speed zoning actions undertaken by the state were effective in reducing accidents, and, (b) to develop a model to predict the conditions under which a speed zoning action would be effective.

7.2 Conduct of the Research

The research project was performed in three phases: (1) an analysis of the accident history in the subject sites and matched control sites to determine which zones had been effective in achieving a statistically significant reduction in accidents, (2) an analytical investigation of speed related, roadside friction, and roadway related factors to determine which characteristics are associated with effective and non-effective speed zones, and (3) an investigation of the consistency of the characteristics associated with effective and non-effective speed zones after implementation.

7.3 Summary and Conclusions of Each Phase of Research

A summary of each phase of the research undertaken with conclusions derived at each phase are presented below.

(1) **Effectiveness of Speed Zones:** The results in this study indicate that speed zoning was not effective in the aggregate in reducing accidents at the .05 level of significance for speed zones where the speed limit was raised, in speed zones where the speed limit was lowered, and in all speed zones.

These results are consistent with past experience which also show mixed results from speed zoning. In Michigan as in other locations, simply changing the speed limit sometimes results in a decrease in accidents and other times results in an increase or no change in accidents.

(2) **Predicted Characteristics of Effective Speed Zoning:** The derivation of mutually exclusive groups (i.e. effective and non-effective speed zones) utilized in discriminant analysis procedures permitted the identification of variables that distinguish between the groups.

In the analysis, the most significant variables identified by the discriminant functions were: skewness index, signalization, driveway frequency (density), and 85th percentile speed. In general the following was found for effective zones:

- The speed distribution is negatively skewed,
- Relatively few accidents occur at or near signalized intersections,
- Driveway frequency is higher by a factor of three (compared to non-effective zones), and
- 85th percentile speeds were lower.

When speed variables were omitted from the analysis the role of signalization and driveways were unchanged, and land use and ADT became prominent variables.

In the sites studied, using these variables to define a discriminant function model, over 90% of the speed zones were correctly classified as effective or non-effective.

(3) **Temporal Stability of Predicted Characteristics of Effective Speed Zoning:** Analysis of the characteristics and variables in the period of time after implementation of the zoning action was undertaken. The analysis focused on those variables which would indicate if there had been a significant change in the location of accidents in the after period. The variables utilized for this analysis are: driveway density, fixed object density, and the presence of a signalized intersection within .10 miles of each accident.

The results of the analysis indicate the accident locations did not shift significantly. In general, the change in mean values from the before period to the after period were not statistically significantly different. Where this was not the case, the difference was not significant in practical terms.

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