Safety Improvements for Urban Arterials

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1. INTRODUCTION

In the year 2002, there were a total of 42,815 highway fatalities in the U.S. and another 2.9 million people were injured in highway crashes. The economic loss from traffic crashes resulting in fatalities, injuries and property damages (PD) is estimated at $230 billion per year nationally (1). Approximately 40% of these losses are attributable to urban highways. In Michigan, the economic losses resulting from highway crashes (comprising 1279 fatalities, 112,484 injuries and 314,000 PD accidents) were estimated at $10 billion in the year 2002 (2). The Detroit metropolitan area, which accounts for approximately 50% of the state population, comprises approximately 45% of the total crash loses in the state (3). Thus, the cost of highway crashes in the Detroit metropolitan area easily exceeds $4 billion annually.

The subject of this research project is urban arterials with a focus on signalized intersections on the 2,400 mile-long state trunk line in the Detroit metropolitan area, which comprises approximately 25% of the entire state trunk line system under the jurisdiction of the Michigan Department of Transportation (MDOT). Further, these 2,400 miles account for approximately 10% of the highway mileage in the Detroit metropolitan area. The state trunk line is the most heavily traveled in the region, accounting for more than 60% of the regional travel, measured in Vehicle Miles of Travel (VMT). Assuming a linear relationship between VMT and traffic crashes on urban arterials in the state trunk line, the cost of the losses is estimated at $2.5 billion annually in the Detroit metropolitan area. In brief, the research reported in this document addresses an estimated $2.5 billion dollar annual problem.

Clearly, an accurate assessment of the benefits from safety improvement projects is an important prerequisite to the realization of the optimal benefits from such investments. The intent of this project is the development of a toolbox or a set of guidelines that MDOT can use to select an appropriate countermeasure or a set of countermeasures designed to prevent future accidents and/or to reduce the severity of accidents at the subject locations. This research is based upon the premise that a majority of these highway accidents at these subject locations are preventable and that the installation of appropriate countermeasures will pay reduce the number of future accidents and improve operating conditions. Selection of the countermeasures should be based upon the economic justification of those countermeasures.

1.1 Problem Statement

MDOT invests significant funds every year to address the safety issues associated with urban arterials at signalized intersections and at mid-block crossings. A bulk of this investment is at urban arterials on the state trunk-line in the large metropolitan areas, as these locations are often very highly traveled, and account for a very large number of crashes. For example, there are a number of intersections in the Detroit area that have historically experienced approximately 100 crashes per year.

Typically, the process to address the safety hazard at urban intersections on a long term basis includes a number of steps:

- Identifying the most hazardous subject locations in the study area from historical accident and exposure data.
- Examining the accident records at these locations in conjunction with traffic, geometric and operational data.

- Identifying causal factors to the extent possible, associated with these accidents, with a focus on specific countermeasures that are likely to significantly reduce future traffic hazards.
- Identifying viable countermeasures for each subject location that will, either singly or in combination, prevent future accidents, or reduce severities thereof.
- Identifying either one or more mutually exclusive safety alternatives for each subject location where each project is a single countermeasure or a combination of countermeasures.
- Assessing the safety effect of the selected countermeasures through the use of Crash Reduction Factors (CRF) or Crash Modification Factors (CMF).
- Conducting a prior test to check if the projected savings in accidents are likely to be statistically significant.
- Estimating all costs and benefits associated with each project, where costs include the initial investment as well as periodic maintenance/operating and repair costs over the life of the project. Benefits include the anticipated savings in accidents derived through the implementation of countermeasures, salvage if any, as well as any operational benefit resulting from the countermeasures.
- Conducting a detailed economic analysis and developing economic Measures of Effectiveness (MOE) associated with each project.
- Selecting a specific project that is expected to provide the highest benefit to the user, or the highest yield to the taxpayer.
- Using capital budgeting to identify a set of optimal projects for different subject locations within the constraints of a given budget.

The set of procedures identified above is often very difficult to implement due to a number of factors including the lack of availability of data, lack of consensus among experts regarding the use of techniques, and the presence of conflicting information in the database. Typical problems are faced in:

- Identification of the most hazardous locations
- Use of CRFs/CMFs in estimating the likely effect of countermeasures in preventing future accidents.
- Use of the appropriate economic analysis technique to select the optimum set of countermeasures.
- Allocation of constrained resources to meet the safety needs of the study area.

1.2 Study Objectives

The specific objectives of this study are:

- To conduct a comprehensive review of CRFs/CMFs from the national database, and to compile a list of realistic CRFs/CMFs for various types of (location-specific) countermeasures.

- To review different economic analysis techniques for the evaluation of mutually exclusive alternatives, and to identify the most suitable technique(s) to be used by MDOT for the Detroit metropolitan region, considering factors such as: data availability, quality of the data, and intended use of the results.

- To develop a complete toolbox for MDOT to serve as a guide for implementing safety improvement programs for urban arterials in the Detroit metropolitan area.

- To conduct a minimum of 20 case studies at different subject locations to demonstrate application of the toolbox.

2. LITERATURE REVIEW

Relevant literature comprises three broad areas: **Development Accident Reduction Factors**, **Methods for Identifying High Accident Locations,** and **Methods for Economic Analysis**, as described below:

2.1 Crash Reduction Factors (CRFs)/Crash Modification Factors (CMFs)

The terms Accident Reduction Factor (CRF) and Crash Modification Factor (CMF) are used in estimating the expected reductions in crashes resulting from a given countermeasure. However, the two terms have different meanings. CRFs are expressed as a percent reduction in the number of accidents attributed to specific type of engineering improvement during its service life. CMFs, on the other hand, are designed to estimate the expected number of accidents after the installation of a countermeasure. CMFs when multiplied to number of accidents before improvement would result in the expected number of accidents after the improvement. CMFs have a base value of 1.0 for each improvement. An CMF value of less than 1.0 indicates a decrease in number of accidents resulting from a particular improvement, and vice-versa. Hence, both CRF and CMF, measure the effectiveness of the engineering improvement proposed to reduce the frequency and/or the severity of accidents at a given location. However, the results are expressed in different manners. For example, an CRF of 20% indicates that the proposed countermeasure should reduce accidents by 20%. Whereas, an CMF value for the same countermeasure would be 0.80, thereby signifying that future accidents should be reduced by 20% (1 minus 0.80), resulting from the improvement. Similarly, a negative value of CRF and an CMF exceeding unity indicates an increase in accidents. The term Accident Reduction Factor (ARF) is also used in the literature in the context of estimating safety benefits of engineering countermeasures and has the same meaning as CRF.

The need for development of CRFs/CMFs on a national level was first identified in the NCHRP Report 162 (4). Accident Reduction Factors constitute a critical component of evaluation of countermeasures to enable the traffic engineer to select the most economically viable project. The Federal Highway Administration (FHWA) has encouraged states to develop their own reduction factors in recognition of the possibility that there may be regional variations, as well as some degree of randomness in the effectiveness of countermeasures. Many states have developed their own CRFs/CMFs following a variety of means. The literature review conducted as a part of this study on CRFs appears to indicate some concerns among experts (5, 6).

- There seems to be some state-to-state variation on CRFs for similar types of countermeasures that might reflect regional disparities, or computational/modeling errors.

- The impact of countermeasures using CRFs may sometimes be exaggerated, as these factors often reflect changes at sites experiencing high accident rates (phenomenon often referred to as the regression to the mean).

- Reliability of CRFs based upon limited/incomplete database is an issue

- CRFs are originally designed for individual countermeasures. Yet, in many cases, there is a need to consider multiple countermeasures. Currently, there is not a consensus among practitioners and researchers on methods to combine the effects of multiple countermeasures to derive a composite CRF. These and other issues are discussed below

2.1.1 Development of CRF/CMF

Two broad categories of methods for developing CRFs are identified in the literature: Before and After Study Method and Cross-sectional Method. In the before and after method, CRFs are estimated as the difference between accidents occurring before the improvement and those occurring after the improvement, the implicit assumption being any change in the number of accidents is attributable to the improvement – an assumption that has come under some criticism over the years. On the other hand, a before and after study conforms to the scientific concept of controlled experiment. Cross-sectional methods are based upon a comparison of accidents data at various locations where design attributes vary systematically. Typically, regression techniques are used to estimate the incremental effect of the change in design attributes (e.g. safety improvement projects) on accident frequencies.

While before and after studies analyze the effect of changes in safety at a given location over time, cross-sectional methods analyze the effect of changes or improvements on safety in different locations at the same time. A major disadvantage of the cross-sectional approach is its inability to take into account the effect of factors not included in the model. This simply attests to the importance of selecting the different locations in a manner that allows the analyst to study the effect of the desired improvements only. The major advantage of cross sectional methods, on other hand, is that this method, if carefully planned, can be used to examine the sensitivity of the sites to alternative highway improvements.

2.1.1.1 Before and After Methods

Five types of before and after methods are found in the literatures:

1. The simple before and after study method
2. The before and after study with control site method
3. The before, during and after study method
4. The comparative parallel study method
5. The before and after study with Empirical Bayes (EB) method

2.1.1.1.1 The Simple Before and After Study Method

This method is the most widely used and serves as the basis of most CRFs developed by many states. This method is based on the assumption that any difference in accident experience before and after the improvement period is solely the result of the improvement. The basic formula to obtain CRF is given below:

$$ARF = 1 - \frac{N_A}{N_B} \qquad (2.1)$$

Where, N_A and N_B are the number of accidents before the improvement and those after the improvement, respectively.

For example, if the average annual accident frequencies at a signalized intersection before and after the implementation of a safety improvement project are 40 and 30 respectively, the CRF of that particular improvement can be computed as below:

$$ARF = 1 - \frac{30}{40} = 1 - 0.75 = 0.25 = 25\%$$

CRF's for any other Measure of Effectiveness (MOEs), such as accident rate, number of injury accidents, number of fatalities, etc., can be measured by replacing the corresponding MOE.

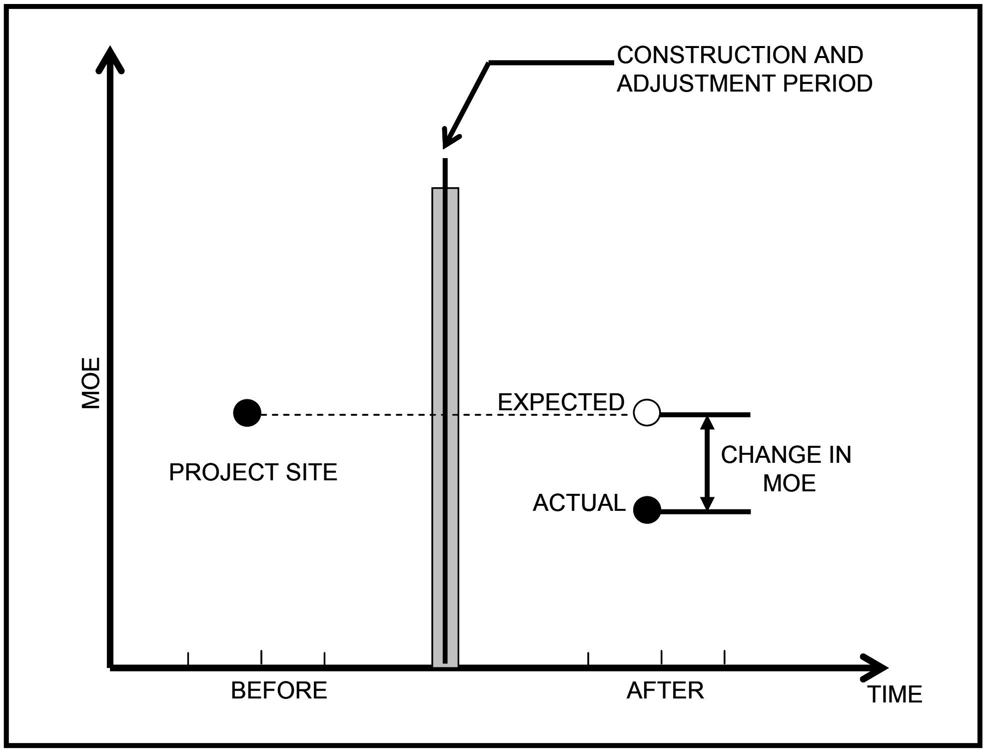


Figure 2.1 shows a simple schematic of a before and after experimental design. *(Source Ref: 23)*

Despite its simplicity, a before-after design has been found to suffer from certain problems such as effect of regression to mean, accident migration, maturation and external causal factors. The exact implications of these terms are explained below.

"Regression to the Mean" can be defined as the tendency of the response variable to fluctuate about the long term mean value and as that which occurs predominantly at sites with high accident frequencies (8). Thus, it signifies that an observed decrease in the accident frequency in the "after" period cannot necessarily be attributed to the improvements made at the site. The argument is that a reduction in accidents would have occurred irrespectively of the improvement, due to of the tendency of the data to 'converge' toward the mean. The term "Accident Migration" refers to the phenomenon of the transfer of accidents from the treated site to surrounding sites. Sometimes, it also refers to a shift of severity levels and/or accident patterns to adjoining sites, as a consequence of improvements at the candidate location. Thus, an observed reduction in accidents at the specific site may be accompanied by a similar increase in accidents at an adjacent site, thereby nullifying the improvement at the candidate site. The term "Maturation" signifies trends in accident occurrence behavior due to temporal changes in factors such as weather, economy, traffic volume, etc (8). A before and after study with trend analysis, as shown in figure 2.2, is performed to accommodate such trends. If the data for the before period exhibits a definable trend, then it is assumed that without the introduction of the improvement, the MOE would have continued to increase or decrease at the same rate as it was in the before period. The change in the MOE measured after project implementation is attributable to the improvement.

Sometimes, external causal factors, such as traffic volume, economic conditions, vehicle fleet, etc., affect calculation of CRF and therefore, those factors should be considered in the analysis.

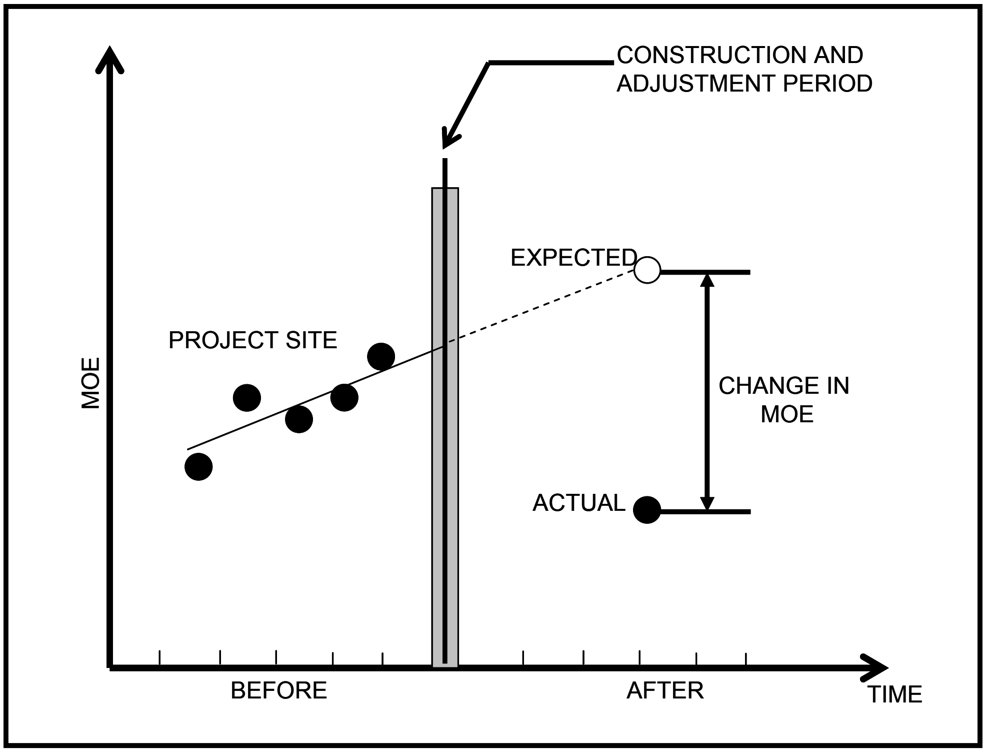


Fig. 2.2 Experimental Design of a Before and After Study with Trend Analysis. *(Source Ref: 23)*

For example, the following formula can be used to account traffic volume growth (9, 10).

$$ARF_{adj} = 1 - \left(\frac{N_A}{N_B}\right)\left(\frac{V_B}{V_A}\right) \qquad (2.2)$$

Where,
CRF_{adj} = Adjusted CRF considering traffic volume growth,
N_A, N_B = Number of accidents in after and before periods, respectively,
V_A, V_B = Traffic Volumes in after and before periods, respectively.

Continuing with the previous example, the calculated CRF can be adjusted to discount the effects of changes in traffic volume between the before and after period. Suppose the total intersection volume before and after the improvement is 19000 and 21000 vehicles per year respectively. Therefore, adjusted CRF can be computed as:

$$ARF_{adj} = 1 - \left(\frac{30}{40}\right)\left(\frac{19000}{21000}\right) = 1 - (0.75)(0.9) = 0.32 = 32\%$$

Sometimes, a simple before and after study tends to estimate inaccurate CRF because of the reasons stated above. It has been found that of the four factors mentioned above, regression to the mean effect is often the most significant one in a before and after study, while the other factors are not likely to affect the results of the analysis in a significant manner (11). Current literature appears to indicate that a before and after study has a tendency to overestimate the safety benefits derived from particular improvement.

2.1.1.1.2 The Before and After Study with Control Site Method

This method compares the percent change in the MOE at the project site (treatment site) with the percent change in the MOE at similar sites (control sites) without the improvement for the same before and after time periods. A comparison group or control site should have similar characteristics in terms traffic volume, geometrics, traffic control and general driver behavior to those of the treatment site. An assumption is made that the treatment site, in absence of the improvement, exhibits similar accident experience as the control site. Any difference between the accident experience at the project and control sites is attributable to the improvement. This is likely to produce more reliable and accurate estimates of CRF than a simple before and after study, mainly because of its ability to address maturation and external causal problems discussed earlier. On the other hand, identification of control sites or comparison groups can be very challenging. Additionally, collecting data for the comparable group can also be a formidable task. Figure 2.3 shows the schematic of a before and after study with comparison group. In figure 2.3, the number of accidents at the control site has increased after the improvement has been implemented at the project site. It is assumed here that the same increase would have been occurred at the project site, without the improvement project. Hence, the CRF computed will be higher than that computed by using a before and after method. The exact opposite would have been true if the number of accidents declined at the control site after the project was implemented at the project site.

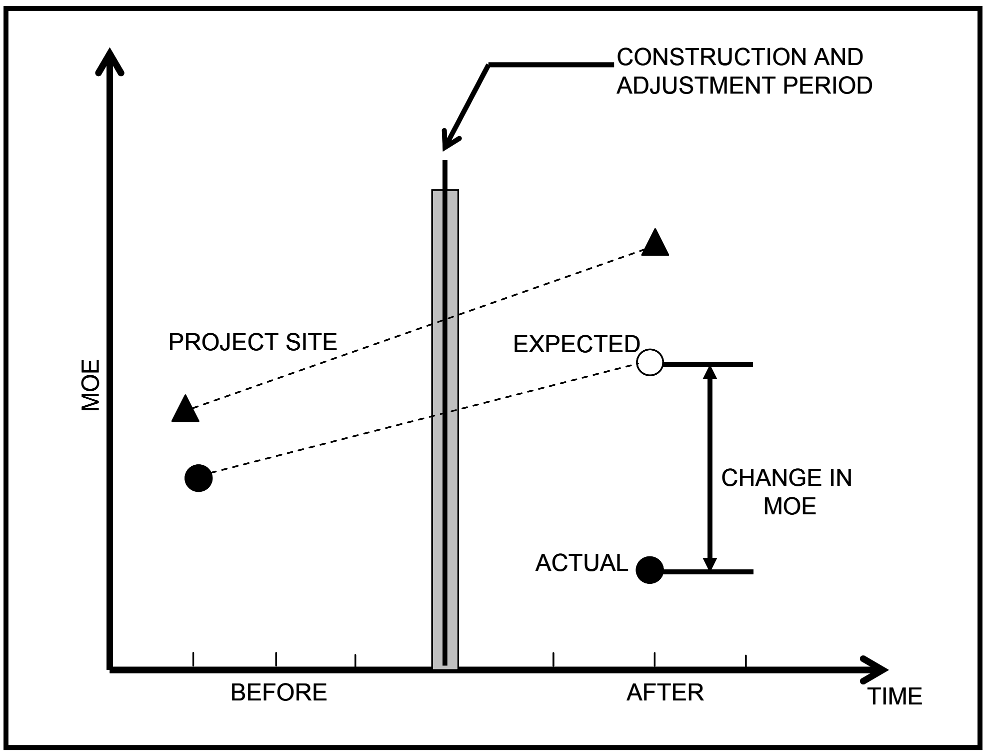


Fig. 2.3 Experimental Design a Before and After Study with Control Site Method
(Source Ref: 23)

For example, assume the average annual accident frequencies at the control sites before and after the implementation of the safety improvement project are 28 and 20 respectively, and those at the project site are 15 and 12, respectively. Therefore, the expected increase in the accidents at the control sites can be computed as:

$$\left[1-\left(\frac{20}{28}\right)\right]\times 100 = 28.57\%$$

It is further assumed that an increase of 28.57% of crashes will occur at the project site too. Hence, the expected accidents at project site without treatment = $1.2857 \times 15 = 19.28$ accidents/year.

Therefore, percent reduction in accidents at project site = $\left[1 - \frac{12}{19.28}\right] \times 100 = 37.76\%$

When the plotted values of the "before" MOEs at the control sites indicate an increasing or decreasing trend over time, the expected value of the MOE should be based on an extension of the trend into the period following project implementation as shown in figure 2.4. Depending upon the availability of data points, regression techniques may be used to develop these trend lines.

2.1.1.1.3 The Before, During and After Study Method

This is similar to the Before-After Study with the modification that measurements are taken at three points in time. This plan is applicable for temporary projects such as pavement reconstruction, lane closure, etc., which are to be discontinued or eliminated after a period of time. The objective of this analysis is to determine if there is a significant change in the MOE during project period, and if the original MOE is restored after the project is completed (observed typically in work zone projects, and selective Law Enforcement projects).

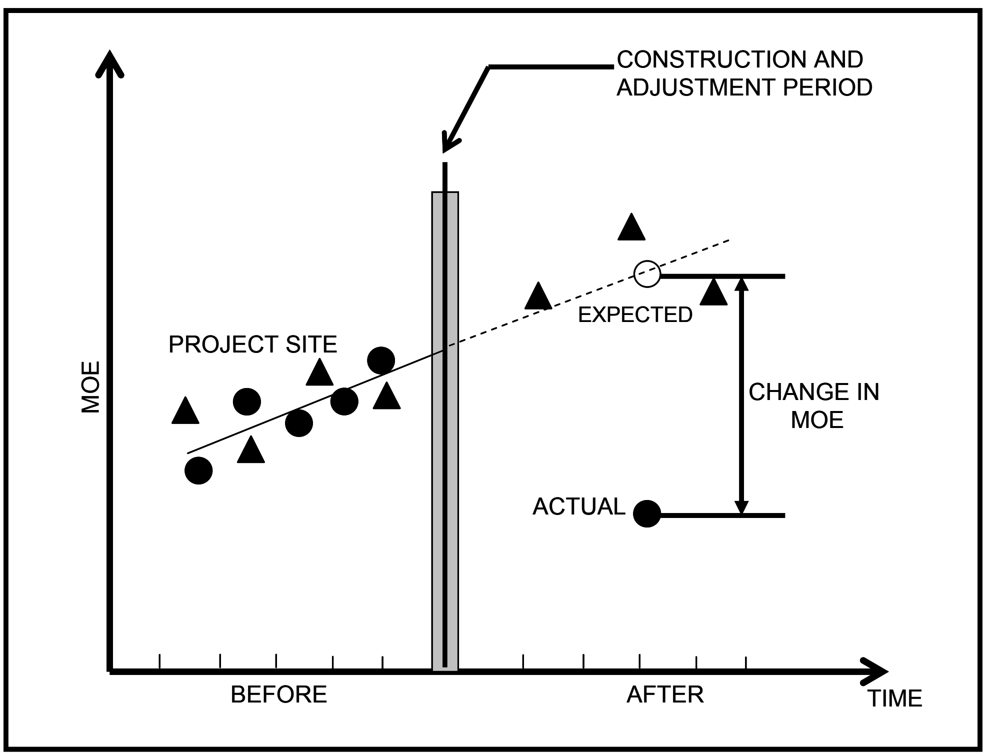


Fig. 2.4 Experimental Design of a Before and After Study with Control Sites with Trend Analysis
(Source Ref: 23)

For example, assume the accident frequencies at a typical construction zone site during the 'Before (B)' 'During (D)' and 'After (A)' period are 20, 30, and 18 respectively. We can compute that:

The % change in the B-D Period = $\frac{20-30}{30} = -33.33\%$

The % change in the D-A Period = $\frac{30-18}{30} = 40\%$

The % change in the B-A Period = $\frac{20-18}{20} = 10\%$

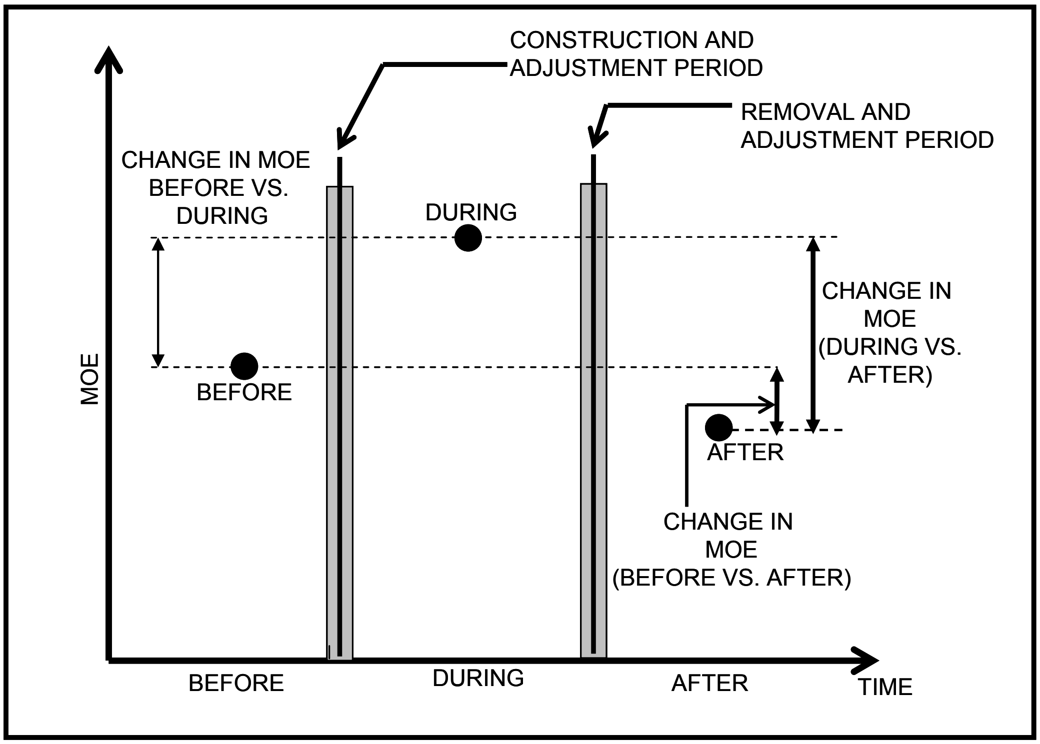


Fig. 2.5 Experimental Design of a Before-During-After Method *(Source Ref: 23)*

2.1.2.1.4 The Comparative Parallel Study Method

This method is similar to Before-After Study with Control Sites with the exception that MOEs are not required prior to project implementation. This method is utilized where the accident data before the implementation of improvement is not available. This method compares control sites' accident data with that of the project site after the project implementation. Any difference in MOEs, between the project and control sites is attributed to the improvements.

For example, assume that average annual accident frequencies of a group of control sites and the project site are 25 and 20 respectively. Then percent reduction in accidents can be computed as:

% Reduction = $1-\left[\frac{20}{25}\right] = 1-0.8 = 0.2 = 20\%$

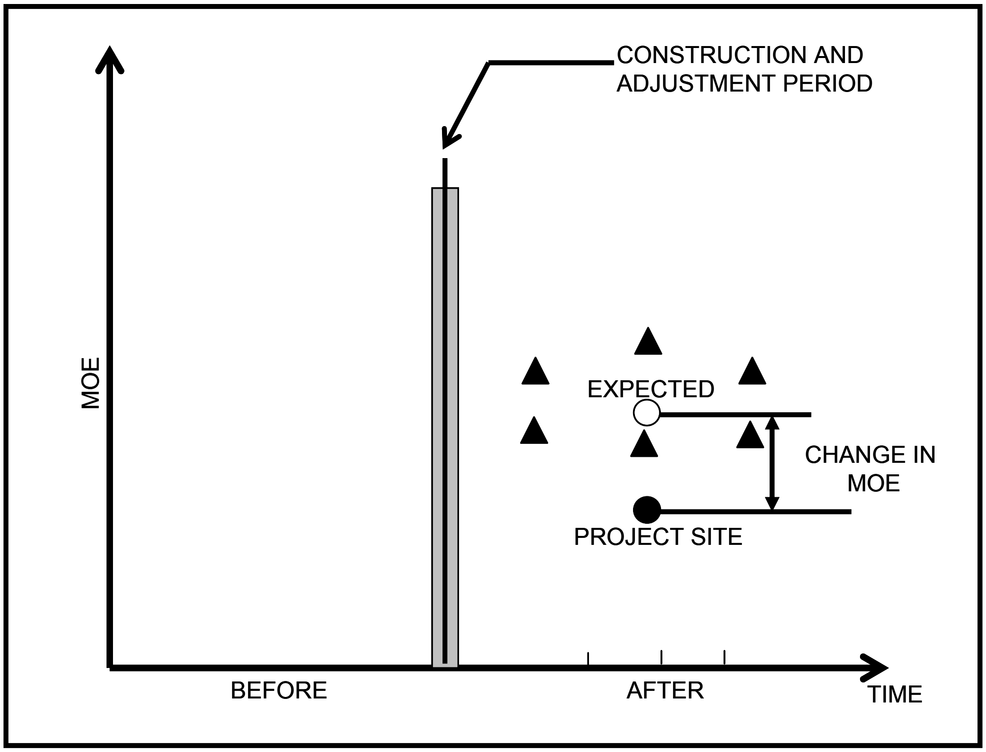


Fig. 2.6 Experimental Design of a Comparative Parallel Study Method *(Source Ref: 23)*

2.1.1.1.5 The Before and After Study with Empirical Bayes (EB) Method

The main goal of using Empirical Bayes (EB) method is to mitigate the effect of regression to the mean, which is found to be the most serious problem encountered in first two methods. This method predicts the expected number of accidents during the 'after' period if the improvement had not been implemented. EB method uses accident history of the project site as well as that of reference sites that depict similar traffic volume and geometrical characteristics. (The terms reference site and control site are used interchangeably in the literature). Hauer et al. have given general expression as below (7):

Expected number of accidents at project site = (Weight x Accidents expected at reference sites) + [(1 – Weight) x Actual accidents at project site]

Where, weight is between 0 and 1.

If E(k) is the expected number of accidents at the reference sites, K is the actual number of accidents at the project sites and α is the weight factor, then E(k/K) is the estimate of expected number of accidents at project site.

$$E(k/K) = \alpha E(k) + (1-\alpha)K \qquad (2.3)$$

A number of regression models have been developed and reported in the literature to determine the empirical formula of E(k). General expression for most of these models is of the following form:

$$E(k) = \beta_0 \times X_1^{\beta_1} \times X_2^{\beta_2} \ldots \qquad (2.4)$$

Where, β_0 is a constant, $\beta_1, \beta_2...$ are the parameters associated with the independent variable such as traffic flow, land width, number of lanes, percentage of grade, etc., and X_1, X_2… are the independent variables.

Some researchers contend that EB method is superior to the simple before and after method, because it considers the effect of regression to the mean. However, this method is difficult to implement and requires accurate data on accidents and other independent variables. At this time, there is not a consensus among researchers about the overall superiority of the EB method compared to others.

2.1.1.2 Cross-Sectional Method

The cross-sectional method is mostly used in sensitivity analysis and evaluation of alternative highway improvements. Unlike the before and after method, this method does not take into consideration the effects of parameters that are not included in the model. It consists of a two-step approach, the first being the selection of a proper regression model for estimating the relationship between highway/traffic characteristics and accident occurrence. The second step is to determine CRFs for the improvements by computing the difference in predicted accidents between the before and after conditions and dividing that value by the predicted accidents in the before conditions (12). The advantage of this approach is that data readily available from state DOTs can be directly utilized. However, this method is known to underestimate the effectiveness of safety improvements and thus tends to give a more conservative estimate of the effect of the improvement, than the before and after study.

2.1.2 State-of-the-art Literature Review

Gan et al., of Lehman Center for Transportation Research, Florida International University, performed a comprehensive review of CRFs or CRFs developed and used by various states in the USA. Letters of request were sent to all state DOTs to provide information on CRFs and benefit-cost analysis. Thirty-four states indicated that they used some type of CRFs in their safety improvement programs (13). Among these 34 states, 19 indicated that they had developed their own CRFs. Of the remaining 15 states that had not developed their own CRFs, five adopted CRFs from the other states while the rest used CRFs from published literature or a combination of literature and CRFs from other states. The CRF reports from Kentucky, Florida, New York, and FHWA were adopted by the other states the most often. Table 2.1 shows summary of sources for development of CRFs by various states.

Table 2.1: Sources for development of CRF *(Source: Ref. 12)*

Source to develop CRFs	**States**
Developed their own CRFs or part of CRFs	Alaska, Arizona, California, Florida, Idaho, Indiana, Iowa, Kentucky, Michigan, Minnesota, Missouri, Montana, New York, Ohio, Oklahoma, Oregon, Texas, Vermont, Virginia
Use CRFs from literature and other States	Alabama, Colorado, Connecticut, Indiana, Kentucky, Louisiana, Michigan, Montana, Nebraska, North Carolina, Pennsylvania, South Carolina, South Dakota, Virginia
Adopted CRFs completely from other states	Delaware, Maine, Maryland, Nevada, West Virginia
Do not use CRFs	Arkansas, Hawaii, Massachusetts, Mississippi, North Dakota, Utah, Wisconsin, Wyoming

Gan et al had also summarized methods of development of CRFs by various state DOTs. They found before-after method and cross sectional method were the only two methods used, with the former method being most commonly used. Table 2.2 shows CRF development methods adopted by the states.

Table 2.2: Methods used by various States for Development of CRFs *(Source: Ref. 12)*

Method Used	**States**
Before and After Study	Alaska, Arizona, California, Florida, Idaho, Indiana, Iowa, Kentucky, Minnesota, Montana, New York, Ohio, Oklahoma, Texas, Vermont
Cross Sectional Method	Missouri, Oregon

The Transportation Research Center of University of Kentucky has been involved in the development of CRFs since 1980s. Agent et al. completed two studies on “Development of Accident Reduction Factors” in 1985 and 1996, in which comprehensive tables of accident reduction factors were developed for various countermeasures based on literature review and survey from 43 states (6). According to 1996 report, 37 states used accident reduction factors in their safety improvement projects, out of which 19 states developed their own CRFs and other 18 states used those of other states (6). Those states that have developed their own factors from either before-after study or cross sectional study are Arizona, California, Delaware, Iowa, Indiana, Kansas, New York, Tennessee and Texas. Other states including Alabama, Florida, Idaho, Illinois, Kentucky, Michigan, Minnesota, Mississippi, Missouri, Nevada, Vermont and Wisconsin used combination of reduction factors recommended in the Kentucky Report or in the literature and those from past safety improvement projects in their states. By contrast, states such as: Arkansas, Colorado, Connecticut, Georgia, Maryland, Montana, New Jersey, Utah, Virginia, Washington and West Virginia completely relied on the literature and other states CRFs. The 1996 Kentucky Report also suggested following formula to reflect effects of more than one improvement on CRF.

$$CRF = 1 - [(1 - AR_1)(1 - AR_2)(1 - AR_3)] \quad (2.5)$$

Where,

CRF = Combined accident reduction factor

AR_1 *to* AR_3 = Individual accident reduction factors.

The Institute of Transportation Engineers (ITE) developed a report called "Intersection Safety Toolbox" in association with FHWA, in which a range of percentage reductions (Potential Effectiveness), for different crash patterns are assigned to various types of improvements at intersections (signalized and unsignalized) (14). These percentage reductions were compiled from various documents such as a study by Agent et al. (Kentucky Transportation Center), Southeast Michigan Council of Governments (SEMCOG), Traffic Safety Toolbox of ITE, NCHRP Report 500, NCHRP Report 17-18(3), Texas DOT, etc.

The Michigan Department of Transportation (MDOT) developed safety improvement projects and respective CRFs from literature and various evaluation studies within Michigan (15). MDOT has also developed AFRs by accident patterns based upon improvements that resulted from particular types of countermeasures. However, these reduction factors are based on evaluation studies conducted more than 20 years back, and need to be updated. SEMCOG has published a synthesis of accident reduction factors in Traffic Safety Manual based on a review of factors developed by the Kentucky Transportation Center, MDOT and TX DOT in 1997 (16).

NYDOT has developed reduction factors by estimating accident reduction benefits from safety improvement projects in 2001 (17). Separate CRFs were developed for locations with AADT less than 5000 vehicles per lane (two lane highways) and for locations with AADT greater than 5000 vehicles per lane (multilane highways). Voss from the Kansas DOT conducted a before (three year) and after (three year) study for various safety improvement projects and evaluated the projects in terms of total number of accidents, severity of the accident, accident pattern, accident rate, benefit cost ratio and net annual return to ascertain CRFs for traffic signal related improvements (18).

The North Carolina Highway Safety Research Center developed and updated a comprehensive list of accident reduction factors for a specific type of countermeasures for signalized and unsignalized intersections, mid-block sections, and railroad grade crossings in 2001 (19). These factors were compiled from different resources including the Kentucky Research Program 1985, Highway Safety Improvement programs of different states, FHWA office of Highway Safety, and others. South Dakota Research Center updated their accident reduction factors in 2004, which are being utilized by South Dakota DOT for various safety improvement projects (20). Detailed literature review on CRF's carried out by FHWA, NYDOT, CALTRANS, University of Kentucky, Missouri Valley Section of the Institute of Transportation Engineers (MOVITE), and others, was performed. The researchers used accident data from Roadway Safety Improvements (RSI) projects from 1994 and 2000 to calculate CRFs.

Another recent study is a compilation of reduction factors in a report titled "Countermeasure Handbook", developed by Dixon et al. at Georgia Institute of Technology in 1997 (21). Several other reports on accident prediction models and safety performance functions were developed by various researchers for two-lane rural highways, with the objective of establishing CRFs. Since the focus of this study is on urban arterials, those factors would not be applicable here. There are also several ongoing projects to determine effectiveness of safety project in terms of percentage reduction in accidents. An example of such project is NCHRP 17-25 "Crash Reduction Factors for Traffic Engineering and ITS Improvements".

2.1.3 Development of CRFs for Multiple Improvements

When several improvements are intended to be implemented at a specific site, separate CRFs to reflect each individual improvement are to be applied in economic evaluation. These multiple CRFs cannot be simply added together because the effects are not additive. Rather, each successive CRF must be applied on the remainder value. Therefore, CRF of each improvement should be considered in succession to determine composite CRF that reflects the combined effect of all improvements. Different states DOTs have adopted different expressions to take into account the effect of multiple countermeasures.

Michigan, Kentucky and Arizona use following expression for considering more than one countermeasures, which was originally being developed by Kentucky Research Center, and has been utilized by other states (12).

$$CRF_t = 1 - [(1 - AR_1)(1 - AR_2)(1 - AR_3)] \qquad (2.5)$$

Where,

CRF_t = Total accident reduction factor

AR_1 to AR_3 = Individual accident reduction factors

A different formula with following expression is used by California, Delaware and Idaho (12):

$$ARF_t = \frac{\sum_{i=1}^{n} A_i \times ARF_i}{A_t} \qquad (2.6)$$

Where,

ARF_t = Total CRF,

A_i = Accidents before improvement i,

ARF_i = CRF for improvement i,

A_t = Total number of accidents before improvement,

n = Number of improvements.

Alabama uses following formula (12):

$$ARF_t = \sum_{i=1}^{n} \frac{1}{i} \times ARF_t(\%) \qquad (2.7)$$

Where,

ARF_t = Total CRF,

ARF_i (%) = CRF for used in decreasing order for improvement i,

n = Number of improvements.

The following formula is the most widely used and very similar to Kentucky expression:

$$CRF_t = CRF_1 + (1 - CRF_1) CRF_2 + (1 - CRF_1)(1 - CRF_2) CRF_3 + \ldots \qquad (2.8)$$

CRF_t = Total CRF,

CRF_1 to CRF_3 = CRF for individual countermeasures.

For example,

Three improvements are intended for a signalized intersection:

Signal Modification – 20% reduction expected in accident frequency

Lighting Improvement – 15% reduction expected in accident frequency

Radii Improvement – 10% reduction expected in accident frequency

Average number of accidents per year = 66

Among 66 accidents, 27 accidents are attributable to problems related to signals, 16 to improper lighting, 23 to problems with radii and 6 to others.

Using formula developed by the State of Kentucky, (equation 2.5)

$CRF_t = 1 – [(1 – AR_1) (1 – AR_2) (1 – AR_3)]$
$CRF_t = 1 – [(1 – 0.2) (1 – 0.15) (1 – 0.1)]$
$CRF_t = 0.388 = 38.8\%$

Using formula developed by the State of California, Delaware and Idaho,

$$ARF_t = \frac{\sum_{i=1}^{n} A_i \times ARF_i}{A_t} = \frac{27 \times 0.2 + 16 \times 0.15 + 23 \times 0.1}{66} = 0.153 = 15.3\%$$

Using expressing developed by state of Alabama,

$$ARF_t = \sum_{i=1}^{n} \frac{1}{i} \times ARF_t(\%) = \frac{0.2}{1} + \frac{0.15}{2} + \frac{0.1}{3} = 0.308 = 30.8\%$$

Following is the computation of CRF by the formula which is being most widely used.(equatin 2.8)
$CRF_t = CRF_1 + (1 – CRF_1) CRF_2 + (1 – CRF_1) (1 – CRF_2) CRF_3 + \ldots$
$CRF_t = 0.2 + (1 – 0.2) 0.15 + (1 – 0.2) (1 – 0.15) 0.1$
$CRF_t = 0.388 = 38.8\%$

Note that equation (2.5) and (2.8) yield the same results, while the other two produced different results. Further, equations (2.5) and (2.8) do not require information on the number of accidents, while the other two require information on the number of accidents or the number of improvements.

2.1.4 Summary

CRF/CMF are used in safety improvement projects to predict expected reductions in the number of accidents (all, injury, PDO) resulting from particular engineering countermeasures. Before and after study methods and cross-sectional method are used to develop CRFs, the former method being most widely used. The literature review clearly shows that many states and agencies have a common source of information in developing CRFs. Some states evaluate their safety improvement projects to estimate reduction in accidents, while others utilize such factors developed by other states or agencies. However, a limited number of state DOTs have considered the effect of more than one type of improvement on accident reduction factor at a given location.

Based upon the review of literature presented above, a comprehensive list of the type of countermeasures and respective reduction factors in percentage has been prepared. A separate document prepared as a part of this study summarizes CRFs from various sources.

2.2. Identifying High Accident Locations

The objective of reviewing literature is to document various methods used in identifying high accident locations and to provide a framework that will enable the analyst to choose the best method(s) applicable in a project, considering factors such as: reliability of results, availability of data, etc. Identifying high accident locations is one of the most vital steps in any safety improvement program. The method(s) used should be accurate to yield a high degree of confidence in the reported results. It is not a simple process and the topic has been a subject of ongoing research for many years. Some researchers also call this process “Determining Candidate Locations”, “Identifying High Hazard Locations”, “Screening Sites with Promise”, etc. However, they all denote the same meaning, that is identification of those locations, at which numbers of accidents or accident rate or severities are significantly higher than those at other similar locations (in characteristics like volume, geometry, land use, road classification, etc.). Further, once these locations are identified, these become candidates for appropriate engineering countermeasures, with the object of reducing the future accident potentials in the most cost-effective manner.

There are two basic techniques for identifying high accident locations. These are the conventional or classical techniques utilizing accident frequency and/or rates, accident severity and/or combination thereof. The second technique is called Empirical Bayesian (EB) method, combining accident frequency with various exposures such as volume, roadway segment length, roadway geometry, roadway classification, etc. A comprehensive literature review, which covers both the techniques, is presented below.

2.2.1 Conventional Techniques

A total of eight methods have been described in "Highway Safety Improvement Program (HSIP)", Users Manual by Federal Highway Administration (FHWA), 1981 (23, 49). A brief description of these methods is presented below:

1. Spot Map Method – It involves developing a map showing clusters of accident frequency and sometimes severities on each spot on the roadway network, and locations having highest number of clusters are recognized as high accident locations.
2. Frequency Method – The method is based upon accident frequency data to identify and rank locations in descending order. Locations having accident frequency greater than critical frequency, a threshold value often determined based upon the distribution of the accident frequency, is considered high accident locations. Many agencies use this method to select an initial group of high accident locations for further analysis (11).

$$f_{avg} = \frac{\sum f_i}{n} \qquad (2.9)$$

Where,
f_{avg} = Average accident frequency for referenced population
f_i = Accident frequency for location i
n = Number of sites in the study area
Critical accident frequency can be determined by using following expression:

$$f_{cr} = f_{avg} + S_f \qquad (2.10)$$

f_{cr} = Critical accident frequency,
S_f = Standard deviation of accident frequency of all locations of referenced population
Frequencies at subject locations are compared to critical frequency and if it exceeds the critical value then the location may be classified as a high accident location.

3. Accident Rate Method – It combines accident frequency and exposure factor to calculate number of accidents per million vehicles entering for spot locations or number of accidents per million vehicle miles of travel for segments.

$$R_{sp} = \frac{A \times 1{,}000{,}000}{365 \times T \times V} \qquad (2.11)$$

And

$$R_{se} = \frac{A \times 1{,}000{,}000}{365 \times T \times V \times L} \quad (2.12)$$

Where,
R_{sp} = Accident Rate at a spot (accidents per million vehicles)
R_{se} = Accident Rate at a segment (accident per million vehicle miles of travel)
A = Accident frequency for the study period
T = Period of Study (Years)
V = Average Annual Daily Traffic (AADT) during the study period
L = Length of segment (Miles)

If the accident rate exceeds a minimum established threshold, then the location is identified as high accident location. This method provides better results than the accident frequency method because it identifies those locations having higher number of accidents based upon accident frequency as well as exposure.

4. Frequency Rate Method – It is based on a simultaneous analysis of accident frequency and rate, plotted on each axis of two directional matrixes. Such a typical matrix is shown in figure 7. The upper right corner (area of the matrix with highest values on both variables) indicates most hazardous location and decreasing level of hazardous locations are indicated by moving further downward and to the left (lowest value).

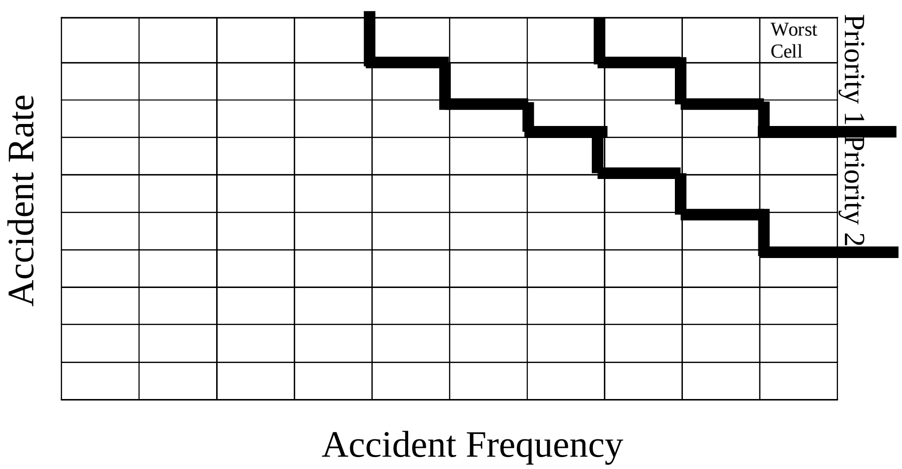


Fig. 2.7 Frequency Rate Method for Identifying High Accident Locations (*Source Ref: 23*)

5. Rate Quality Control Method – It utilizes a statistical test and compares accident rate of a subject location with critical rate of entire population of sites within the category. Critical rate is an average rate of locations having similar characteristics as that of subject location.

$$R_c = R_a + K \times \left(\frac{R_a}{M}\right)^{0.5} + \frac{1}{2M} \quad (2.13)$$

Where,
R_c = Critical rate for spot or section
R_a = Average accident rate for all spots of similar characteristics or on similar road types
M = Millions of vehicles passing over a spot or millions of vehicles miles of travel on a section

K = A probability factor determined for the desired level of significance

6. Accident Severity Method (EPDO Method) – Considers accident severity levels (fatal, injury, property damage only, etc.) and their weighting factors to calculate some form of severity index or severity number to identify and rank high accident locations.

   One of such methods is Equivalent Property Damage Only (EPDO) method.
   $$EPDO = W_1 (F+A) + W_2 (B+C) + PDO \qquad (2.14)$$
   Where,
   F = Number of fatal (one or more deaths) accidents
   A = Number of A-Type injury (in-capacitating) accidents
   B = Number of B- Type injury (visible injury) accidents
   C = Number of C- Type injury (probable injury) accidents
   PDO = Number of PDO accidents
   $W1$, $W2$ = Weighting factors given to severity levels
   HSIP used value of W_1 and W_2 to be 8.5 and 3.5, respectively.
   Another method very similar to the EPDO method is the Relative Severity Index (RSI) method in which dollar value of an accident is assigned to respective accident severity.

7. Hazard Index Method – Employs a formula to develop a rating index for each suspect site based on factors such as accident frequency, rate and severity, sight distance, volume to capacity ratio, traffic conflicts, erratic maneuvers, driver expectancy, information system deficiencies, etc.

8. Hazardous Roadway Features Inventory – Identifies sites with a potential for high accident frequency and/or severity by comparing existing roadway features to safety and design standards.

2.2.2 Literature on Conventional Techniques

A document entitled "Traffic Safety Manual" published by SEMCOG has illustrated six methods with appropriate examples for identifying high crash locations (16). Five of them are very similar to the methods described in HSIP, FHWA, 1981. Those are Spot Map Method, Accident Frequency Method, Accident Rate Method, Frequency Rate Method, and Accident Severity Methods. The sixth method is Crash Probability Index (CPI) Method, which combines accident frequency and accident rate with a simplified severity method. Locations having their values exceeding a threshold value are assigned penalty points. High accident locations are identified from summing up the penalty points and arranging the intersections in descending order. The SEMCOG manual recommends determining rankings from more than one method for accurate identification of high accident locations (16).

A study conducted by Souleyrette et al., in 2001, determined top 100 high crash locations for five potential study topics (horizontal curve, fixed object crashes, rural four-way expressway intersections, head-on crashes, urban four-lane undivided corridors) within the State of Iowa. Each of the three ranks by Frequency Method, Accident Rate Method and Accident Loss ($) Method were added together giving equal weight to each method and a final ranking was performed with the lowest cumulative ranking receiving the highest ranking of one (24).

Methods presented by Pawlovich for the state of Iowa were identical to those described in HSIP and SEMCOG (25). Another FHWA publication "Signalized Intersections – Informational Guide" has described similar methods as those given in HSIP and SEMCOG (26). Two additional methods, Safety Performance Functions and Empirical Bayes, are also described. Safety Performance Function is an empirical formula depicting the relationship between accident frequency and traffic volume and other similar characteristics at the study locations. Empirical Bayes Method also utilizes Safety Performance Functions in calculating the expected number of accidents per year for locations having similar characteristics as those of the study location. However, these two are relatively new methods in the area of traffic safety and are currently under development.

Agent et al of Kentucky Transportation Center developed a Statewide Crash Buildup Program, in year 2003, as a part of Hazard Elimination Program (HEP) to identify sites with a high frequency of crashes (27). Actual crash rates for each spot and section were calculated and Critical Rate Factors (CRFs) were determined by dividing actual crash rate by the critical rate. The Crash Buildup Program was used which directly produces a value of CRF as an output based on specified input data.

2.2.3 Emerging Techniques

"New Approaches to Highway Safety Analysis" – a report published by FHWA, suggested the use of Safety Performance Functions (SPF) to calculate Potential for Safety Improvement (PSI) index for network screening (28). According to this document, conventional or classical techniques for network screening may not necessarily produce correct ranking of locations, because these methods are biased towards high volume sites and do not consider the effect of regression to mean. As explained earlier, SPF is the empirical formula representing a relationship between accident frequency and various exposure factors. Generally, it is derived separately for each highway classifications (urban, rural, arterial, local, intersection, mid-block, etc.), control type (signalized, two-way stop control, four-way stop control, no control, etc.) and accident severity (injury and PDO). Bayesian Technology is employed for the development of SPFs. The report suggested following formula for computation of PSI index.

$$PSI_{index} = rc_{pdo} \times PSI_{pdo} + rc_{inj} \times PSI_{inj} + rc_{fat} \times PSI_{fat} \qquad (2.15)$$

Where,

rc_{pdo}, rc_{inj}, rc_{fat} = Relative cost for PDO, injury and fatal crashes, respectively.

After calculating PSI_{index} by the above formula, locations are ranked in descending order of their index values and locations with higher PSI_{index} value are considered candidates for improvement. Literature also demonstrated ranking differences by crash frequency, crash rate and PSI methods.

Two papers by Hingle et al proposed the use of Empirical Bayes (EB) Technique for identifying hazardous locations. In the paper "Bayesian Identification of Hazardous locations", the authors developed empirical methods for identifying hazardous locations and concluded that these methods have added advantage over classical methods (29). In another research paper "A Comparison of Techniques for the Identification of Hazardous Locations", classical and Bayesian techniques are applied on the same datasets and the authors concluded that Bayesian and Critical Rate methods perform better than other classical methods (30). Four datasets of signalized intersections from the State of Arizona were used along with four methods. The four methods used are: accident rate associated with confidence interval, critical rate method and two Bayesian methods (one using mean accident rate for a particular dataset and second using mean accident rate of other similar locations).

Another 1999 study "Empirical Bayes Procedure for Ranking Sites with Safety Investigation by Potential for Safety Improvement" by Persaud et al contended that conventional techniques utilizing accident counts and/or rates are not fully capable of identifying sites with potential for safety improvement because of not considering regression-to-mean (31). 28,000 highway segments and 197 four-legged signalized intersections in the Province of Ontario, Canada were selected for the experiment. Accident and volume data for the period 1888-1990 were used for model calibration and data of 1991-1993 were used for validation of methods. Four methods – accident count, accident rate, EB to estimate expected annual number of accidents and positive difference between EB estimate and appropriate regression estimate – were evaluated for above data. The authors concluded the methods based EB techniques were better suited for identifying safety needs.

Studies by Hauer et al. "Estimating Safety by the Empirical Bayes method: A Tutorial" and "Screening the Road Network for Sites with Promise", in 2001, suggested the use of Empirical Bayes Technology because of its ability to address the regression-to-means effect (7, 32). However, a recent study by Datta et al, in 2000, shows that low cost treatments at three intersections in Detroit reduced total accidents by 44%, 48% and 57% (33). Those intersections were selected for treatment based on crash frequency and/or crash rates.

By reviewing the above literature, it was found that Empirical Bayesian technique is gaining recognition among researchers and further research on this topic is currently underway at different institutions. One of the most crucial steps in employing this method is the development and calibration accident prediction models based on accident history and various measures of exposure, and obtain Safety Performance Function (SPF). As this project is on the development of safety toolbox for urban signalized intersections, literature review on safety performance functions was performed focusing only on urban area. However, only a small number of research papers were identified.

The primary objective of a paper by Lord and Persaud was to demonstrate the application of Generalized Estimating Equations (GEE) model, with and without trend effects, and to compare GEE model with Generalized Linear Model (GLM) (34). Data of 868 signalized intersections from Toronto for the years 1990 to 1995 were used to calibrate the model. Five models comprising both GEE, GLM techniques, incorporating with and without trend, were calibrated, and coefficients and standard errors were estimated for each of above model. The structure of the model is of the following form:

$$E(K) = \alpha \times F_1^{B_1} \times F_2^{B_2} \times e^{(B_3 F_3)} \qquad (2.16)$$

Where,
E(K) = the expected number of accidents per unit of time (also known as a safety performance function),
α, B_1, B_2 = coefficients
F_1, F_2 = total entering AADT on major and minor approaches, respectively.

$$Var(K) = \frac{K^2}{Y} \qquad (2.17)$$

Where, *Y* = standard error (over dispersion parameter) and *Var(K)* = variance in *E(K)*

Another paper published by Lord and Persaud "Calibration and Transferability of Accident Prediction Models for Urban Intersections" suggested the transmission of models from one place to another, and from one time period to another(31) Experiments conducted for such transferability of models were of the following form:

$$E(K) = \alpha \times F_1^{B_1} \times F_2^{B_2} \times e^{B_3 F_2}$$
$$E(K) = \alpha \times F_1^{B_1} \times F_2^{B_2} \times e^{B_4 F_1} \qquad (2.18)$$
$$E(K) = \alpha \times F_1^{B_1} \times F_2^{B_2}$$

The authors concluded that in most cases, the California and British Columbia models calibrated for Toronto data performed quite well as compared to other published models. However, the question of transferability of models in space or time is a topic where opinions vary among researchers. Thorough recalibrations of these models to reflect local conditions are considered an essential step by most researchers, before these models are transferred from one place to another.

Lastly, the topic of identifying hazardous locations has been a subject of research interest outside North American. For example, Gharaybeh conducted a study in Greater Amman and concluded that identifying high accident location by frequency method alone may result in inappropriate findings and suggested combining two or more methods for better and accurate results (36). He analyzed safety on 37 locations by Accident Frequency Method, Accident Rate Method, Accident Possibility Method and Accident Seriousness Method and gave ranking by each method. Then, four ranks of each location used to produce the Danger Index (DI), and the DI values were used to identify hazardous locations.

The detailed literature review presented above clearly reveals that many researchers have investigated different methods, and the selection of a particular method for a given study should be based on a range of factors including, availability of crash data, traffic & operational conditions, and the availability of control sites.

2.3 Economic Analysis Techniques

The purpose of “pre-project” evaluation of highway safety projects is to ensure that the project selected for implementation from a set of mutually exclusive alternatives is the one with the highest benefits. Indeed, in a broader sense, the purpose is to make the most efficient allocation of public resources in aiding social-decision making. This type of evaluation is often termed *ex-ante* analysis, conducted to identify the specific project where resources should be allocated. This is to be contrasted from *ex-post* analysis, conducted upon completion of the project to assess the degree to which the project actually “delivered” the expected services. The value of *ex-post* analysis is broader, designed to contribute to “learning” by the agencies concerned about the ultimate “worthwhileness” of such projects. The focus of this study is an *ex-ante* analysis for highway safety projects.

Any *ex-ante* evaluation is based on the premise that, in order for an alternative to be viable, the benefits to whomsoever they may accrue must exceed the estimated costs. In reality, there can be a number of alternative for which benefits may exceed cost. The question is “How to identify the alternatives with the highest benefit?”

Within the conceptual framework of incorporating all costs and benefits during the project evaluation, a number of analytic tools have been developed, each with a specific set of characteristics (8, 23):

- Cost Effectiveness (C/E) Technique
- Benefit Cost (B/C) Ratio Technique
- Internal Rate of Return (IRR) Technique, and
- Pay Off Period (PP) Technique
- Net Present Worth (NPW) Technique

The five techniques identified are associated with specific Measures of Effectiveness (MOEs) designed to reflect the degree to which a single project or a set of mutually exclusive projects are expected to meet their economic goals. The C/E technique essentially identifies the project with the least cost per unit benefit, while the B/C ratio technique is directed toward designating the project with the highest benefit per unit cost, both at a specified interest rate. One of the advantages of the C/E techniques is that (unlike in other techniques) the attachment of a dollar value to an accident saved is not necessary. The disadvantage is that a project identified as the most cost effective (i.e. the least cost project to prevent an accident) may not necessarily be a cost efficient project, relative to its ability to pay off for the investment. The IRR technique attempts to identify the project that provides the highest return to the investor within a specified project life. The TOR technique on the other hand, helps to identify the project that provides a specified return to the investor in the fastest possible time frame. Lastly, the NPW technique identifies the project with the highest positive Net Present Worth, being defined as difference between the Present Worth of Benefits and the Present Worth of Cost. These are discussed in more details below. The five MOEs are the C/E Index, B/C ratio, IRR, TOR, and NPW for the five techniques respectively.

2.3.1 The Five Analytic Techniques

A brief theoretical foundation of the five techniques is presented below. The following symbols are used in the discussion.

(A/F) = Sinking Fund Factor
(A/P) = Capital Recovery Factor
(B/C) = Benefit Cost Ratio
C = Unit $ Value of Each Accident Prevented
(C/E) = Cost Effectiveness Index
EUAB = Equivalent Uniform Annual Benefit ($/year)
EUAC = Equivalent Uniform Annual Cost ($/year)
I = Initial Cost ($)
i = Interest rate used (%, annual)
IRR = Internal Rate of Return (%, annual)
K = Annual Operating and Maintenance Cost ($)
MARR = Minimum Attractive Rate (%, annual)
N = Number of Accidents Prevented Annually
NPW = Net Present Worth = *PWOB – PWOC* ($)
n = Project life (years)
n_1 = Pay off period (PP)(years)
(P/A) = Present Worth Factor (Uniform Series)
(P/F) = Present Worth Factor (Single Payment)
(PP) = Pay off Period (years)
PWOB = Present Worth of Benefit ($)
PWOC = Present Worth of Cost ($)

S = Salvage Value ($)

2.3.1.1 Cost Effectiveness (C/E) Technique

The principle of Cost Effectiveness (C/E) techniques is based upon the premise that the alternative that costs the least to derive one unit of benefit is considered to be most cost effective. For a typical highway safety project, this should be the alternative that costs the least to prevent a highway accident (of a specific type). The algorithm is as follows:

$(C/E) = EUAC/N$ ____ (2.19)
$EUAC = I(A/P) + K - S(A/F)$ ($/year) ______________________________ (2.20)
N = Number of Accidents Prevented Annually
(C/E) = Cost Effective Index (Dollars spent to prevent each accident)

The (C/E) technique only provides comparative MOEs of the alternatives being tested and can be used to rank alternatives in order of their desirability. It cannot be used to determine if the benefits of any alternative "outweigh" its costs. Thus, a project designated as the most cost effective, may not necessarily be cost efficient. The advantage of this technique is that it is not necessary to attach a dollar value to the benefits, a task often considered the most difficult one in evaluating public projects, such as highway safety projects.

2.3.1.2 Benefit Cost (B/C) Technique

The (B/C) ratio is one of the more common techniques used in project evaluation, primarily because of its ease of interpretation. (B/C) ratio is simply a measure of the number of units of benefits that the project is expected to provide per unit cost. The algorithm used is:

(B/C) = Benefit/Cost = $EUAB/EUAC$ __________________________________ (2.21)
Where,
EUAC can be computed as shown in equation 2.21. The computation of EUAB can be problematic, particularly in public projects, a detailed discussion of which is beyond the scope of this report. For highway safety projects, EUAB can be computed as:

$EUAB = N \times C$ ____ (2.22)
Where,
N = Number of Accidents (of a particular type) Prevented Annually
C = Unit $ Value of Each Accident Prevented, so that

$(B/C) = (N \times C)/EUAC$ ____ (2.23)

2.3.1.3 Internal Rate of Return (IRR) Technique

The IRR technique is used quite frequently, despite difficulties in computation. Unlike the previous two cases, where an interest rate is assumed at the outset, the IRR technique requires the computation of the interest (or the yield) that the project is expected to return to the investor. The algorithm is based upon the premise that the IRR is the interest rate at which the Net Present Worth (NPW) of the project equals zero, and can be written as:

Set $NPW = 0$, i.e.

$PWOB = PWOC$, i.e.
$N \times C \times (P/A) = I + K(P/A) - S(P/F)$, ____(2.24)

A theoretical solution of equation 2.24 to derive the appropriate interest can be computationally complex. An empirical solution may be attained by using a trial and error process, by systematically altering the interest rate until a convergence is found. All projects yielding an IRR, exceeding an initially specified Minimum Attractive Rate of Return (MARR) become viable. The term MARR is used to designate a threshold value of yield, below which the corresponding project becomes unattractive from an investment point of view. The determination of MARR is generally a policy matter by the top management of the organization, designed to ensure that all fiscal decisions based on the same primary criterion, thereby ensuring the best use of available funds. Factors used in the setting the value of MARR are varied, and may include the following:

- Availability of funds
- Risks involved in competing investment opportunities
- The current cost of borrowing capital, as reflected by factors such as: "prime rate", short and long terms notes and bonds issued by the governments, etc.
- Opportunity cost of money, costs incurred by other sectors of the govt. for projects that are deprived of funding because of lack of sufficient fund.

2.3.1.4 Pay Off Period (PP) Technique

The (PP) technique is used when "the time taken by the project to pay for itself" is the desired answer. The algorithm used is the same as the one used in the IRR technique (equation 2.24). However, the solution strategy is different. In this case, an interest rate must be assumed (usually the MARR or higher), and the value of n_1, (Pay off Period) is sought by trial and error, until equation 2.24 is satisfied.

If $n_1 > n$ Reject
If $n_1 \leq n$ Accept

The rationale is if a project pays for itself earlier than the period the project is expected to last, it essentially provides "free" service to the investor for the difference between the two periods. If on the other hand, it takes longer to pay for itself, the additional period is a "liability" to the investor.

2.3.1.5 Net Present Worth (NPW) Techniques

The NPW of this project is defined as:

$NPW = PWOB - PWOC$
$= [N \times C \times (P/A)] - [I + K(P/A) - S(P/F)]$ ___________________________ (2.25)

The project with the highest NPW is generally considered the best project. It is worth pointing out here, that the Benefit-cost technique discussed earlier, is designed to analyze the ratio of PWOB and PWOC. The project that maximizes the (B/C) ratio may not necessarily maximize NPW. Thus, two different solutions may be reached these two methods. There is a general consensus among practitioners and researchers that the (B/C) technique is preferred.

The selection of any one of the above five techniques for alternative evaluation/selection purposes depends upon a number of factors including the validity of assumptions, availability of data, and most importantly, the intended use of the results (37). While each of the five techniques has certain basic characteristics and limitations, under compatible assumptions, the selection of the optimum project is not likely to be affected by the choice of analytic technique (37, 38).

2.3.2 Other Methods Developed by State DOTs

Our literature review also indicates that benefit-cost ratio is one of the most widely used analysis methods used among the states in the US. Many states have developed their own methodology for economic evaluation of safety improvement projects that are derived from the fundamental concepts presented above. For example, the State of Texas (2002) refers B/C ratio as a Safety Improvement Index (SII) and it is calculated as follows (13):

$$S = \frac{R\left(C_f \times F + C_i \times I + C_p \times P\right)}{Y} - M$$

$$Q = \left(\frac{A_a - A_b}{A_b \times L}\right)S \qquad (2.26)$$

$$B = \frac{S + \frac{1}{2}Q}{1.08} + \sum_{i=2}^{L}\left[\frac{\left(S + \frac{1}{2}Q\right) + (i-1)Q}{1.08^i}\right] \qquad (2.27)$$

$$SII = \frac{B}{C} \qquad (2.28)$$

Where,
S = Annual savings in accident costs,
R = Percentage reduction factor,
F = Number of fatal and/or incapacitating injury accidents,
C_f = Cost of a fatal and/or incapacitating injury accident,
I = Number of non-incapacitating and/or possible injury accidents,
C_i = Cost of a non-incapacitating and/or possible injury accident,
P = Number of property-damage-only accidents,
C_p = Cost of a property-damage-only accident,
Y = Number of years of crash data,
M = Change in annual maintenance costs for the proposed project relative to the existing situation,
Q = Annual change in accident cost savings,
A_a = Projected average annual ADT at the end of the project service life,
A_b = Average annual ADT during the year before the project is implemented,
L = Project service life,
B = Present worth of project benefits over its service life, and
C = Initial cost of the project.

Similarly, the state of Virginia (2002) uses the following expression to calculate B/C ratio for its Hazard Elimination Safety Programs (13):

$$\frac{B}{C} = \frac{\sum\left[\left(\left(F \times ARF_f\right) + \left(I \times ARF_i\right)\right) \times Q_{dol} + \left(PDO \times ARF_p \times Q_p\right)\right] \times GR}{\left(PEC + RWC + CC\right) \times K} \qquad (2.29)$$

Where,
F = Number of related fatal accidents per year,
CRF_f = Percent reduction in fatal accidents,
I = Number of related injury accidents per year,
CRF_i = Percent reduction in injury accidents,
Q_{dol} = Weighted average cost of fatal and injury accidents at all similar locations,
PDO = Number of related property-damage-only accidents per year,
Q_p = Annual average cost of property-damage-only accidents,
CRF_p = Percent reduction in property-damage-only accidents,
GR = Projected district annual traffic growth rate,
PEC = Estimated preliminary engineering costs,
RWC = Estimated right-of-way and utilities costs,
CC = Estimated construction cost, and
K = Capital recovery factor.

Some states combine fatal and injury accidents simply because fatality figures are relatively small. The State of Montana combined reduction in fatal and injury accidents into a single parameter 'Q', which is defined as follows:

$$Q = \frac{C_f\,(F + A) + C_i\,(B + PDO)}{F + A + B} \qquad (2.30)$$

Where,
C_f = Cost of fatal accident,
F = Number of fatalities,
A = Number of incapacitated injuries,
C_i = Cost of injury accident,
B = Number of non-incapacitating injuries,
PDO = Number of PDO accidents.

Further, State of Montana suggested following formula to compute B/C ratio (12):

$$\frac{B}{C} = \frac{\left[\frac{ADT_a}{ADT_b}\right] \times \left[\left(Q \times A_{fi} \times P_{fi}\right) + \left(C_{pd} \times A_{pd} \times P_{pd}\right)\right]}{\left(C \times K\right) + M} \qquad (2.31)$$

Where,
Q = Average cost per fatal and injury combined,
ADT_a = Projected average daily traffic after improvement,
= 1.03L + 1 where L = number of years for the life of the project,
ADT_b = Average daily traffic before improvement
= 1.03-S + 1 where S = number of years of the crash records used in the analysis,
A_{fi} = Average number of annual fatalities or injuries combined,
P_{fi} = Expected percent reduction in fatalities or injuries,
A_{pd} = Average annual property-damage-only accidents,
C_{pd} = Cost per property-damage-only accidents,
P_{pd} = Expected percent reduction in property-damage-only accidents,
C = Capital costs,
K = Capital recovery factor (interest rate), and

M = Change in annual maintenance or operations costs.

The state of Indiana developed a similar methodology for economic evaluation in 1994:

$$ARB = N \times ARF \times APF \times A_C \times PWF$$

Where,
ARB = Accident reduction benefits,
N = Number of accidents,
CRF = Accident reduction factor of a particular improvement per year,
APF = Accident projection factor,
A_C = Accident cost,
PWF = Present worth factor.
B/C ratio is computed as:

$$\frac{B}{C} = \frac{K \times ARB}{K\left[Ic + (Mac \times SPW) - (T \times PWF)\right]} \quad (2.32)$$

Where,
K = Capital recovery factor for the last year of the improvement's service life,
ARB = Summation of yearly benefits,
I_c = Initial cost,
M_{ac} = Annual maintenance cost,
SPW = Present worth factor (equal payment series),
PWF = Present worth factor (single payment), and
T = Terminal value.

The state of Kentucky (1974) used present worth of cost and benefits to assess the economic feasibility of safety improvement projects. Further, the state applied Dynamic Programming (DP) method to optimize safety benefits within the constraint of a given budget.

Although, B/C ratio is the most widely used method for economic analysis, some states used other methods too. The state of Arizona (1991) used Incremental B/C ratio method to examine whether extra increments of cost, on a particular project, are justified. The state of Vermont (1991) adopted the Cost-effectiveness method along with traditional B/C ratio method to prioritize its independent safety improvement projects. The state of Ohio (2002) used the Rate of Return method to select improvement projects. The states of Missouri and South Carolina used the Net Benefit method to rank mutually exclusive projects. Hence, different formulas and methodologies have been developed and used by various states to assess economic viability of selected countermeasures. The state of Michigan uses the Time of Return or Payoffs period method to assess the economic feasibility of safety improvement projects. However, in all cases, the fundamental concepts are the same, as presented in the earlier part of this report.

2.4 Incremental Analysis

The concept of marginal (incremental) benefits and marginal costs are often used to analyze mutually exclusive projects. Competition for dollars for other independent projects may not necessarily be a factor in the decision-making process. Projects are to be treated strictly as an investment opportunity, and be directed to fetch the highest return to the tax-payer. Further, no alternative should be disqualified just because it is "too expensive". Indeed if a project is deemed "too expensive" at the outset, it should not be considered as part of the mutually exclusive set.

The procedure for incorporating an investment perspective the decision making process is often termed as the "Defender-Challenger" technique (13). A pairwise comparison of alternatives is made and alternatives with higher investment costs are required to justify their selection through marginal cost analysis. Alternatives that cannot be justified are eliminated, and the pairwise comparison is continued until the most expensive alternative is analyzed. Select the alternative, subject to

B/C Ratio Technique

$(B/C)_{absolute} \geq 1.00$, and $(B/C)_{marginal} \geq 1.00$

IRR Technique

$IRR_{absolute} \geq MARR$, and $IRR_{marginal} \geq MARR$

TOR Technique

$(n_1)_{absolute} \leq n$ $(n_1)_{marginal} \leq n$

NPV Technique

$(NPV)_{absolute} \geq 0$ and $(NPV)_{marginal} \geq 0$

3. STUDY AREA

3.1 Introduction

Traffic accidents claim the lives of more than 40,000 people in the country every year. Michigan ranks eleventh in roadway fatalities in the US, with more than 1200 fatalities per year. The state trunk line in southeast Michigan is characterized by high congestion and by a large number of crashes: The Southeast Michigan region includes seven counties, namely Livingston, Macomb, Monroe, Oakland, St. Clair, Washtenaw, and Wayne (Figure 3.1), and covers approximately 50% of the state's population. In this chapter accident experiences of the state and southeast Michigan are discussed. Generally intersections and mid-blocks on the state trunk lines are the locations where most accidents occur. As a part of the study a number of intersections in the southeast Michigan were selected for further analysis. The process of selecting these sites is described in this chapter.

3.2 Accident Experience in Michigan

According to the publication of Traffic Safety Facts 2004, the state of Michigan covers 122,000 miles of highway and 101.8 billions vehicle miles of travel (39). There were 373,028 crashes, which include fatalities, injuries and property damages in 2004, that represents a 11.4% decrease from 1995. Figure 3.2 shows the total number of crashes from 1995 – 2004. Figure 3.3 shows traffic related fatalities or deaths in the state during the same period. Figures 3.4 and 3.5 show trends in fatalities and injuries for the last decade. Figure 3.2 through 3.4 generally indicate that crashes in the state have been declining over the years, thanks to concerted efforts undertaken by MDOT in cooperation with local and regional agencies. Despite this decline, the economic loss in the state resulting from highways crashes is estimated to be more than 9.5 billions annually.

3.2.1 Analysis of Accident Locations by Roadway Function Class

Arterials and collectors are the roadway classes responsible for a large number of fatal crashes. Figure 3.6 shows fatal crashes by roadway classification for 2004. It reveals that highway facilities with better design features such as interstate, freeways and expressways experienced a lower number of fatal crashes compared to other roadways.

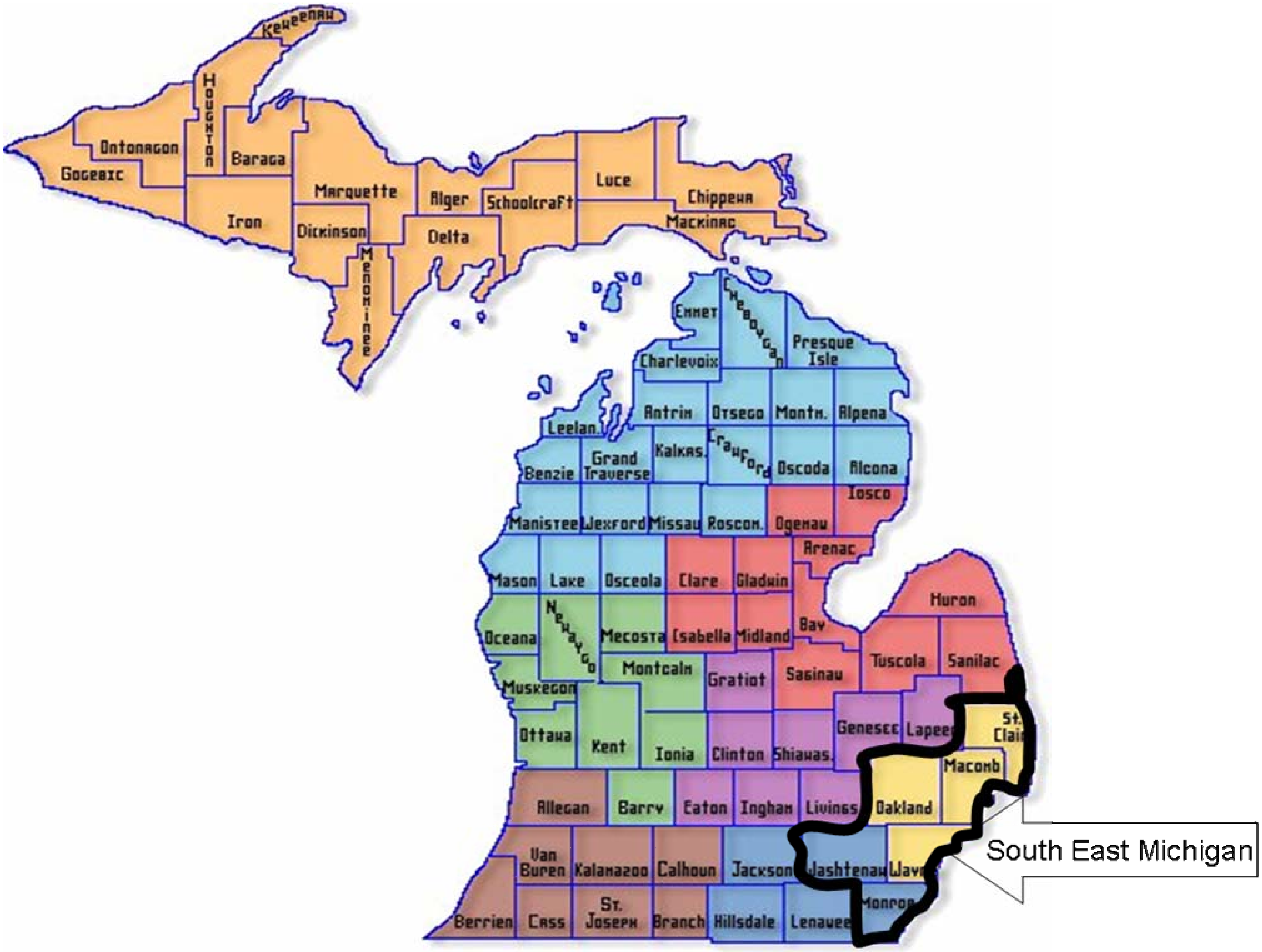


Figure 3.1 Seven counties in South East Michigan

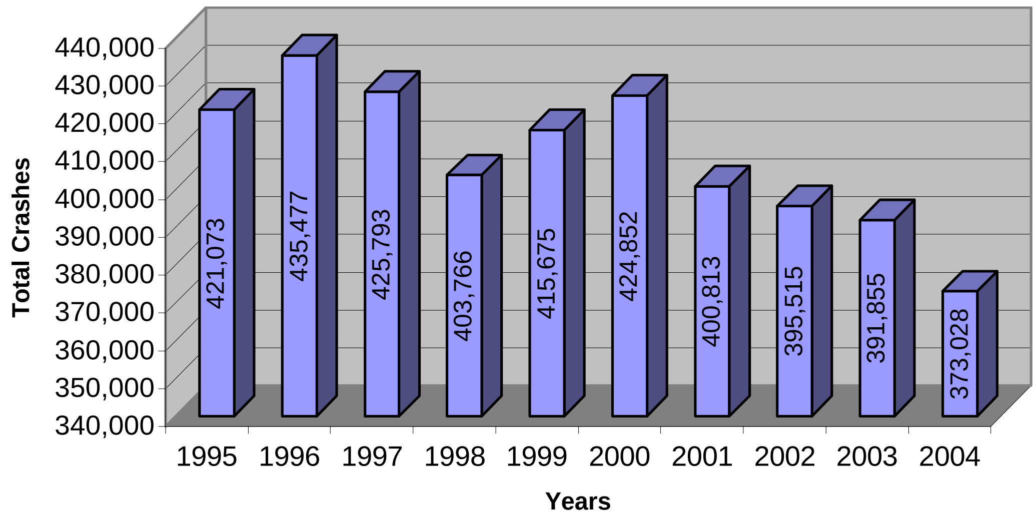


Figure 3.2 Total Crashes from 1995 – 2004 *(Source: Ref. 39)*

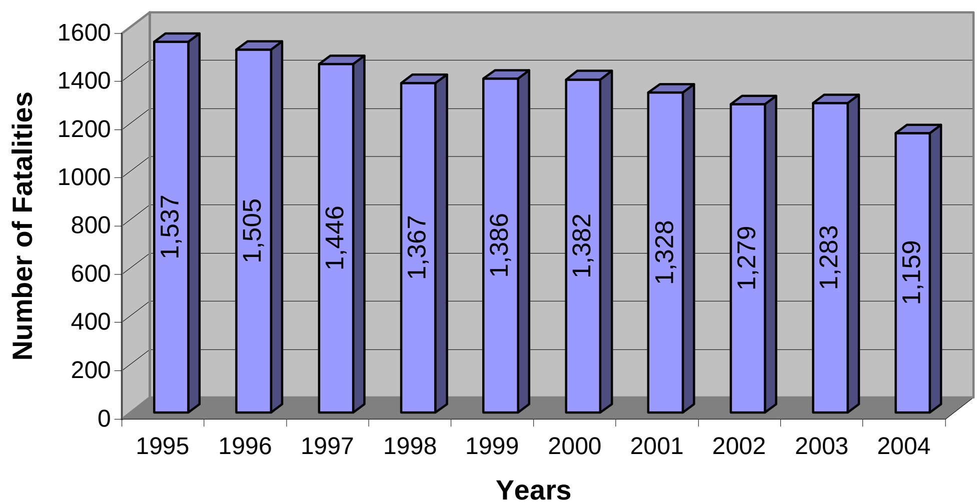


Figure 3.3 Number of Fatalities, 1995 – 2004 *(Source: Ref. 39)*

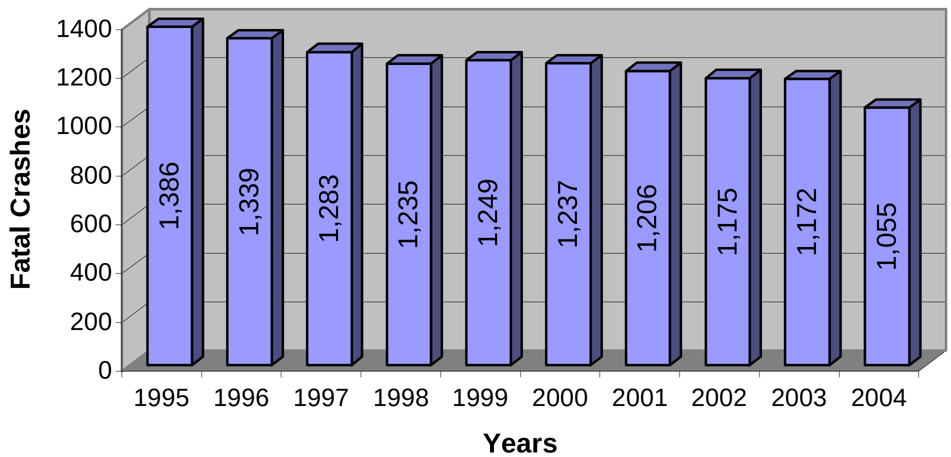


Figure 3.4: Number of Fatal Crashes 1995 – 2004 *(Source: Ref. 39)*

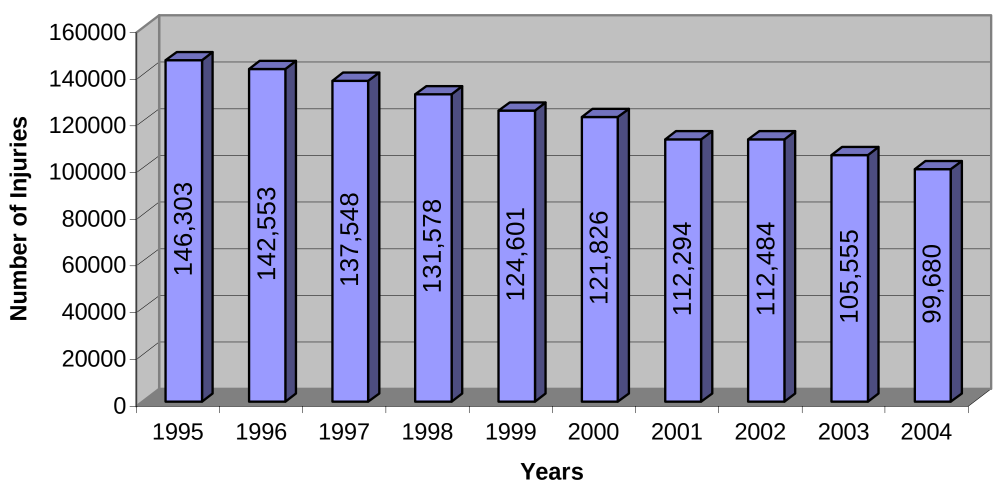


Figure 3.5: Number of Injuries, 1995 – 2004 *(Source: Ref. 39)*

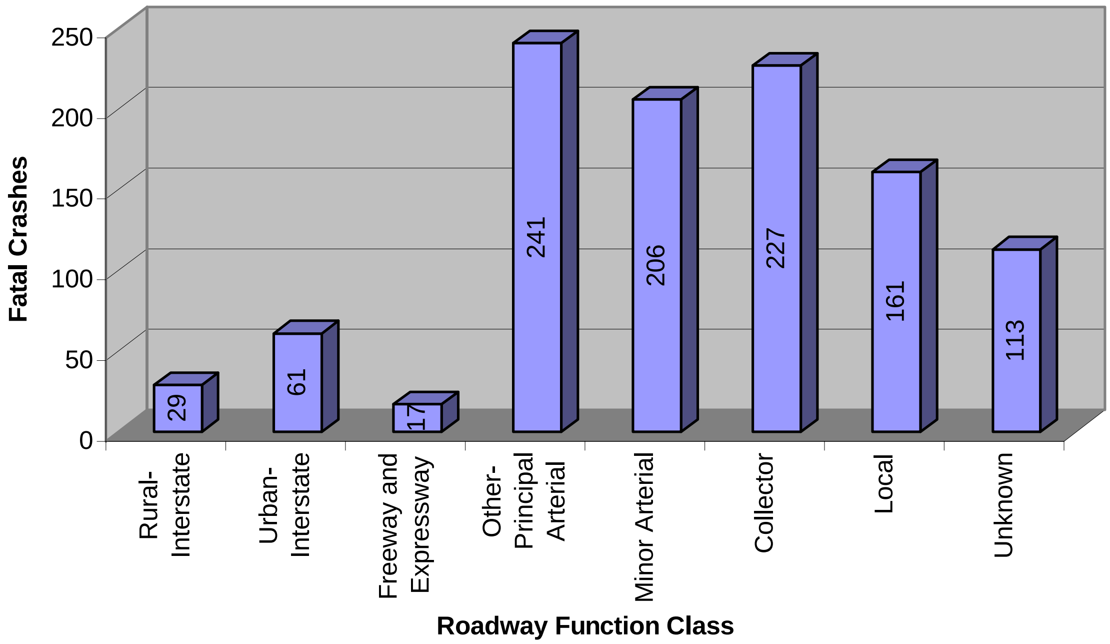


Figure 3.6 Fatal Crashes according to roadway function class: 2004 *(Source: Ref. 39)*

3.2.2 Analysis of Accident Locations by Traffic Control Type

Traffic crashes occur at various roadway locations. However, it is important to determine the predominant roadway locations that typically experience a large number crashes at urban arterials. Figure 3.7 shows fatal crashes by traffic control types for the entire state of Michigan. The highest percentage of fatal crashes occurs at stops signs followed by intersections. More than 45% of total crashes occur at intersections. Figure 3.8 demonstrates the distribution of total crashes according to different traffic control types. Clearly, intersections both signalized and stop sign controlled, are prime candidates for accident mitigation.

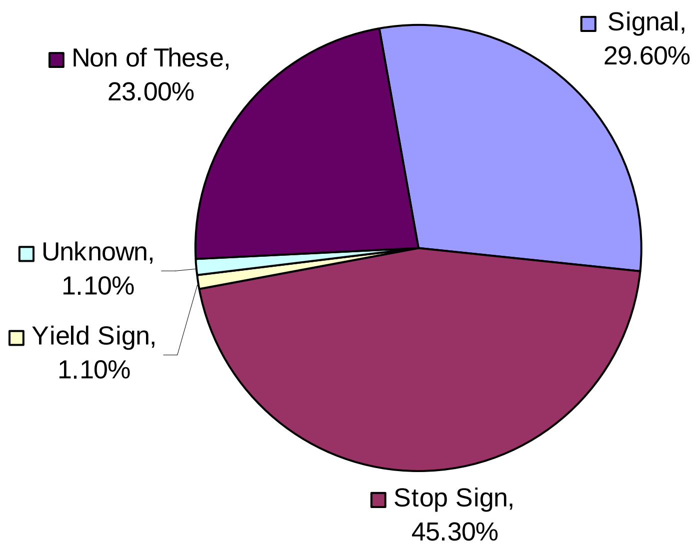


Figure 3.7: Fatal Crashes by Traffic Control Type in Michigan, 2004 *(Source: Ref. 39)*

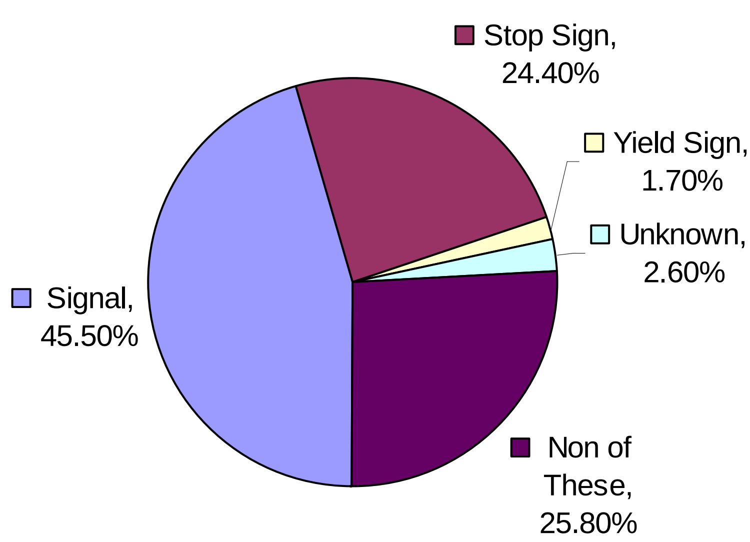


Figure 3.8: All Crashes by Traffic Control Type in Michigan, 2004 *(Source: Ref. 39)*

3.3 South East Michigan

The total number of crashes in the South East Michigan for the year 2004 is more than 150,000. As explained earlier, the highest number of accidents occurred at the intersections. The

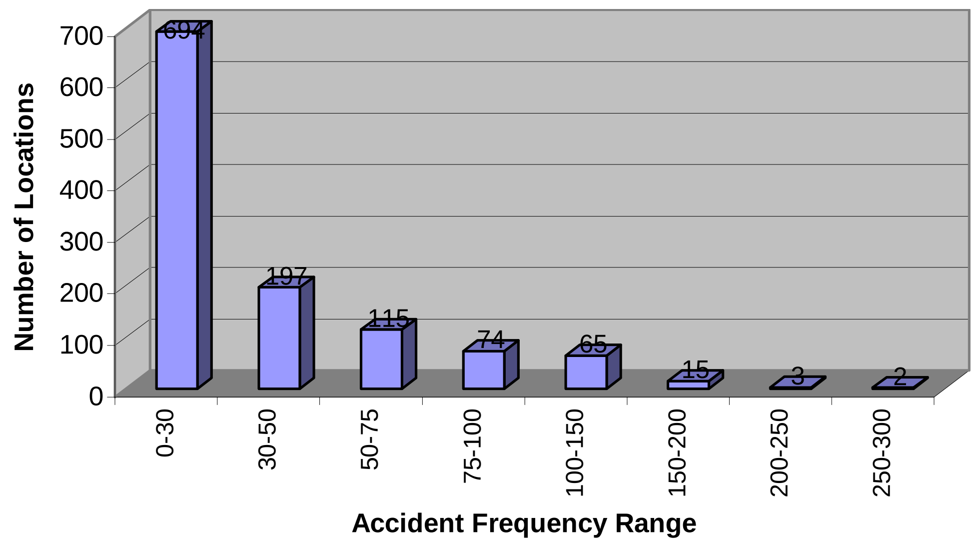


Figure 3.9: Locations of different accident frequency range

region has more than 25,000 intersections on the state trunk lines. Accident data for intersections was obtained from Michigan Department of Transportation (MDOT) for last three years, 2002 to 2004. Database was compiled based on a threshold value of 10 accidents for three years (or 3.33 accidents per year). The MDOT database identified 1167 such intersections with more than 10 accidents during the three-year period with information on the total number of crashes, injury crashes, number of crashes for different patterns (angle, rear end, etc.), severity rate etc. Numbers of intersections falling under different accident frequency ranges are plotted in Fig 3.9. Time and budget constraints prevented the project team from considering all 1,147 intersections from further analysis. Hence it was decided to review those intersections having average accident frequency more than 30 accidents for 3 years (or 10 accidents per year). It was found that 704 intersections had an accident frequency of less than or 30 accidents/3 years. Therefore, it was decided to consider the remaining **463** intersections with a frequency more than 30 accidents for the 3 year period (10 accidents/year) for further analysis.

Accident severity is another factor that deserves consideration while choosing the locations for study. Severity data for these locations were also collected and ranges of accident severity rate and number of locations falling under different severity range is presented in Fig 3.10 for a total of 1167 intersections.

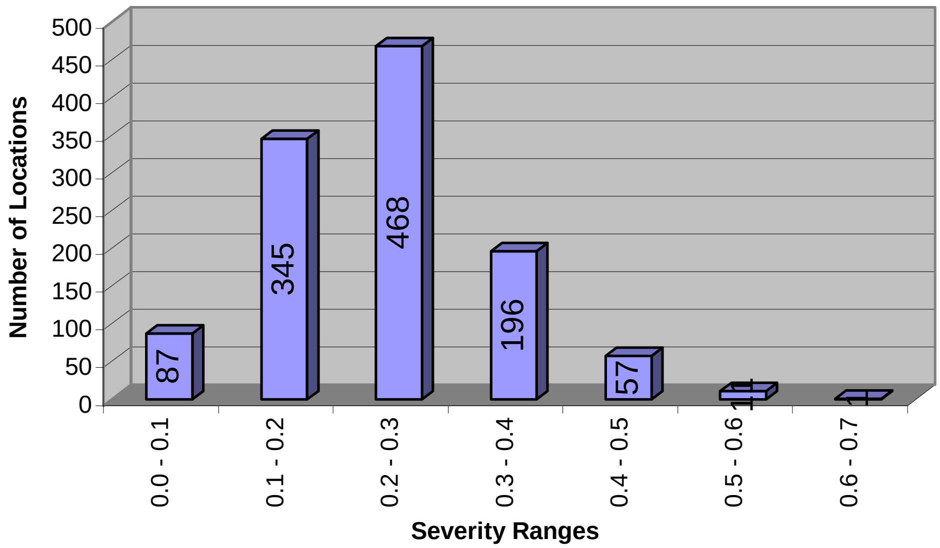


Figure 3.10: Locations of different severity range

Severity rate is computed as the ratio of injury accidents and all accidents at a particular location. It was found that most of the intersections have severity range 0.1-0.4. Severity can be defined as the ratio of total accidents to the injury accidents. Mathematically,

Severity = Injury Accidents / Total Accidents

The 463 intersections thus selected are arranged in the form of a matrix in Table 3.1. Table 3.1 indicates that the intersections with high frequency have low severity, and those with high severity have low frequency.

Table 3.1: Classification of Intersections by both accident frequency and severity

FREQ	SEVERITY								
	(B1) 0.45-0.50	(B2) 0.40-0.45	(B3) 0.35 - 0.40	(B4) 0.30-0.35	(B5) 0.25-0.30	(B6) 0.20-0.25	(B7) 0.15-0.20	(B8) < 0.15	SUM
(A1) 250-300							1		1
(A2) 200-250						1	2		3
(A3) 150-200				3		8	5	1	17
(A4) 100-150				5	14	24	16	5	64
(A5) 100 -75		2		8	25	24	12	6	77
(A6) 50 - 75		1	9	14	32	33	13	13	115
(A7) < 50	3	2	11	17	57	35	35	26	186
SUM	3	5	20	47	128	125	84	51	463

Both frequency and severity should be considered in the safety analysis process since these are typically associated with safety hazard. In the next chapter a detailed procedure followed in the identification of hazardous locations is presented. Briefly, a hazardous location can be defined as any section or spot that exhibits an abnormally high accident potential. The higher potential for accidents is usually expressed in terms of any accident measure such as accident frequency, rate, severity or a combination thereof. Different methods of determination of hazardous locations are presented in the literature review (Section 2.2). The methodology adopted for this study is specially tailored toward the study needs, with due consideration given to the availability of data. Locations needing immediate action were determined by giving equal importance to the accident frequency and severity. This procedure resulted in a total of 463 intersections in the study area with the following parameters:

Accident Frequency (3-year Period)	Accident Severity (3-year period)
Mean = 69.73	Mean = 0.2367
Standard Deviation = 38.16	Standard Deviation = 0.0705

After a thorough literature review of traffic safety procedures followed by different organization and research groups, a methodology was developed for this study to identify a select group of intersections from the list of 463 for further detailed level of analysis. This is explained in the next chapter.

4. RESEARCH METHODOLOGY

4.1 Introduction

Highway accidents have long been recognized as a major cause of death in the USA and considerable resources have been spent on strategies to prevent accidents and to reduce accident severities. As indicated earlier, intersections and mid blocks of urban arterials typically represent locations experiencing high accidents in the Detroit Metropolitan Area. An analysis of three year accident records indicated that 463 such intersections experience on average, a minimum of 10 accidents per year with the maximum of approximately 100. A systematic procedure was followed to determine the most hazardous locations from these 463 sites, which need immediate attention. The analysis resulted 36 such intersections that are considered prime candidates for improvements. Of the 36 sites identified, a total of 20 sites were selected for analysis in two categories as reported in Chapter 5.

Accident reports (UD-10) of 36 intersections from 2002-2004 were reviewed. All fatalities, injuries and systematic samples of Property Damage Only (PDO) crashes were plotted in a collision diagram. From the collision diagram, predominant crash patterns for individual locations were identified. Countermeasures for prevention of these predominant crashes were developed for these 36 locations. Crash Reduction Factors (CRF) or Crash Modification factors (CMF) for these countermeasures were determined from locations with similar geometric and traffic characteristics, and combined accident reduction factors were computed for locations needing more than one countermeasure. CRF values thus compiled were used to estimate the savings in accidents resulting from the implementation of the countermeasure. Next, costs (initial, operating, maintenance, etc.) associated for these improvements were determined. Road users cost and benefits associated with these improvements were determined where necessary as per AASHTO standards. After quantification of costs and benefits associated with a particular location, the economic justification of the improvement was determined.

4.2 Identification of the Most Hazardous Locations

There is a general consensus among safety experts that accident frequency should definitely be a measure of high hazard, and hence should be one of the variables used in identifying hazardous locations. The advantages and disadvantages of using accident rates are also well documented in the literature. Briefly, rates discount the effect of varying exposure levels, and using rates is a means of “normalizing” the frequency data. Hence many experts are proponents of using rate-frequency method as a two dimensional matrix. Others have recommended the use of Rate-Frequency-Severity method in a three dimensional context, based upon the premise that the addition of severity as a third dimension world incorporate the much needed concept of “degree” as contrasted from “magnitude” (depicted by frequency and rates) in the analysis. There is also a general consensus among experts that using a two factor method (i.e. rate-frequency) is more desirable than a one factor method (i.e. frequency) because a two factor method incorporates greater “breadth” to the analysis . A three factor method, if feasible, could incorporate additional “depth” to the analysis.

In practice however, there may be potential difficulties with the application of “Rate-Frequency” and “Rate-Frequency-Severity” methods. In the former case, the incidence of high rates and high frequency at specific sites may be a rare event, often resulting in independent (as opposed to simultaneous) identification of sites based upon rates and frequencies separately. Secondly, rates are derived from frequencies, and in the event, the candidate sites carry similar traffic volumes, the final selection is a consequence of frequency alone. In the latter case, the use of three dimensional approach requires the availability of a variety of data, that is often beyond the reach of many agencies. The above constraints are not to be construed as a criticism against the two methods; rather they represent practical difficulties that often preclude their deployment .

Considering the non-availability of exposure data, the methodology used in this study is a combination of frequency and severity. Let

$$f_{cr} = f_{av} + K \times S_f$$

where

f_{cr} = *Critical accident frequency for locations within jurisdiction under study*

f_{av} = *Average accident frequency for locations within jurisdiction under study*

K = *Level of confidence*

S_f = *Standard deviation of accidents for locations within jurisdiction under study*

and

$$S_{cr} = S_{av} + K \times S_s$$

S_{cr} = *Critical accident severity for locations within jurisdiction under study*

S_{av} = *Average accident severity for locations within jurisdiction under study*

K = *Level of confidence*

S_s = *Standard deviation of severity for locations within jurisdiction under study*

The proposed method is based upon joint consideration of critical frequency (f_{cr}) and critical severity (S_{cr}), with frequency as the primary variable. The logic of including frequency and severity is to incorporate the concept “magnitude” and “degree” in the analytic framework, particularly when the availability of exposure data posed a serious problem. The methodology used in this study consists of following steps

1. Identify initial candidate sites based upon an initially selected threshold frequency.
2. Identify a set of candidate sites based upon a revised threshold frequency
3. Cross-classify the candidate sites in a two dimensional frequency-severity matrix
4. Develop final threshold values or critical values of the two variables from the frequency-severity distribution
5. Use the critical values to identify a set of manageable project sites.

The 463 intersections (Section 3.3, Chapter-3) thus selected, based upon accident frequency as the primary factor are arranged in the form of a two dimensional matrix in Table 4.1. Table 4.1 indicates that the intersections with high frequency have low severity, and those with high severity have low frequency. On the other hand, intersections with lower accident frequency are likely to have lower severity. Further, the following means and standard deviations were derived, that indicated, that the frequency distribution has a much higher degree of variation than the severity distribution.

Table 4.1 Classification of Intersections by both Accident Frequency and Severity

	SEVERITY								
FREQ	(B8) < 0.15	(B7) 0.15-0.20	(B6) 0.20-0.25	(B5) 0.25-0.30	(B4) 0.30-0.35	(B3) 0.35 -0.40	(B2) 0.40-0.45	(B1) 0.45-0.50	SUM
(A1) 84-100		1							1
(A2) 67-84		2	1					Increasing hazard	3
(A3) 50-66	1	5	8		3	40 Locations (Frequency Based)			17
(A4-1) 44-50	2	4	8	3	2				19
(A4-2) 34-44	3	12	16	11	3			28 Locations (Severity Based)	45
(A5) 25-35	6	12	24	25	8		2		77
(A6) 17 - 25	13	13	33	32	14	9	1		115
(A7) 17-10	26	35	35	57	17	11	2	3	186
SUM	51	84	125	128	47	20	5	3	**463**

Accident Frequency(n= 463)
Mean = 23.04
Standard Deviation = 12.76
Coefficient of Variation = 55%

Accident Severity (n= 463)
Mean = 0.2367
Standard Deviation = 0.0705
Coefficient of Variation = 30%

One of the common approaches of determining hazardous locations is to identify those sites where accident experience is significantly higher than the average for the jurisdiction under examination (40). One way to accomplish this is to select those locations with accident rates in the highest 5% of the selected distribution. (40). Next, a process was developed to narrow down the number of intersections to a manageable size and to identify the most hazardous ones among the 463 intersections that may be considered prime candidates for improvements. This was accomplished by developing critical frequencies (f_{cr}) and critical severity (S_{cr}) and identifying a smaller subset of the matrix of 463 intersections presented in Table 4.1.

4.2.1 Critical Accident Frequency

Knowing the mean and standard deviation of the accident frequency as 23.04 and 12.76, respectively, the top five-percentile value, assuming a normal distribution, can be estimated as 44, signifying, that 5% of the 463 sites (i.e. 23 intersections) are likely to have an accident frequency of more than 44 accidents per year. It was found that there are actually 40 sites (or intersections) that experienced more than 44 accidents per year. This simply indicates that the distribution of accidents is not likely to be normal. The assumption of normality is not considered critical for the analysis presented. It simply was used as a means to initiate the process of identifying most hazardous locations.

4.2.2 Critical Accident Severity

Similarly, the mean and standard deviation of the accident severity were calculated as 0.2367 and 0.0705, respectively. The top five-percentile value was estimated, assuming a normal distribution, to be 0.3257. Locations that experienced severity of 0.3527 or higher are identified as the most hazardous sites within the study area. While theoretically the number of such sites are expected to be 23 (5% of 463), it was found that in actuality there were 27 such sites. The corresponding section of the larger matrix are identified as shaded areas in Table 4.1, for a total of 68 independently identified (as oppsed to simultaneously identified). Note that there is no overlap between the two shaded areas , showing that the joint probability of a site having high frequency and high severity is very small. The next generation as "how to narrow down the 68 intersections to a more manageable size?" This was accomplished by setting priorities as follows.

The 40 locations having frequency exceeding 44 were arranged in a two dimensional matrix as shown in Tables 4.2, with each cell displaying the number of intersections within particular range of frequency and severity. Similarly, the 27 locations with severities exceeding 0.3527 were arranged in a similar two dimensional matrix as shown in Table 3. Next, the 40 intersections with frequencies exceeding 44 accidents per year, and 27 intersections with severities exceeding 0.35 were prioritized as follows:

P (1) = Locations of highest priority
P (2) = Locations of medium priority
P (3) = Locations of modest priority

Note that within each subset higher priorities were assigned to those cells that are high on both counts (frequency and severity). This prioritization scheme resulted in the following distribution:

Priority Locations Based on Accident Frequency

40 locations from Table 4.2 are thus prioritized as follows:
$P(1)_{frequency} = 8$
$P(2)_{frequency} = 20$
$P(3)_{frequency} = 12$
Table 4.3, shows that locations having high severity tend to have low accident frequency. The 27 locations are further prioritized as follows:

Priority Locations Based on Accident Severity

$P(1)_{severity} = 3$
$P(2)_{severity} = 5$
$P(3)_{severity} = 19$

Table 4.2 Prioritization of 40 Intersections in a Two-Dimensional Matrix (Critical Frequency)

FREQUENCY	SEVERITY							SUM
	(B8)	(B7)	(B6)	(B5)	(B4)	(B3)	(B2)	
	<0.15	0.15-0.20	0.20-0.25	0.25-0.30	0.30-0.35	0.35-0.40	0.40-0.45	
(A1) 84-100	0	1 (P2)	0	0	0	0	0	1
(A2) 67-84	0	2 (P2)	1 (P2)	0	0	0	0	3
(A3) 50--66	1(P3)	5 (P3)	8 (P2)	0	3 (P1)	0	0	17
(A4-1) 44-50	2(P3)	4 (P3)	8 (P2)	3 (P1)	2 (P1)	0	0	19
SUM	3	12	17	3	5	0	0	**40**

Table 4.3 Prioritization of 27 intersections in a Two-dimensional Matrix (Critical Severity)

FREQUENCY		SEVERITY			SUM
		B3	B2	B1	
		0.353-0.40	0.40-0.45	0.45-0.50	
A 4-2	**34-44**	0	0	0	0
A5	**25-34**	0	2 (P2)	0	2
A6	**17-25**	8 (P3)	1 (P2)	0	9
A7	**10-17**	11(P3)	2 (P2)	3 (P1)	16
SUM		19	5	3	**27**

4.2.3 Combined Criteria

There is no standard procedure for selection of hazardous locations based upon both frequency and severity. Hence, those sites meeting P (1) and P (2) classifications by frequency and severity were selected as the most hazardous sites. This resulted in the following

P (1) $_{\text{frequency}}$ + P (2) $_{\text{frequency}}$ = 20 + 8 = 28

P (1) $_{\text{severity}}$ + P (2) $_{\text{severity}}$ = 3 + 5 = 8

Total highly hazardous locations = 28 + 8 = 36

These 36 hazardous locations are presented in Table 4.4. Details of these intersections are shown in Table 4.5 with cross streets, name of the trunkline, accident frequency, fatality and severity. These 36 intersections are considered prime candidates for improvements

Table 4. 4 Selected Intersections Based on both Frequency and Severity

FREQ	SEVERITY							
	(B8) < 0.15	(B7) 0.15-0.20	(B6) 0.20-0.25	(B5) 0.25-0.30	(B4) 0.30-0.35	(B3) 0.35 - 0.40	(B2) 0.40-0.45	(B1) 0.45-0.50
(A1) 84-100		1						
(A2) 67-84		2	1			Frequency Based (28 Intersections)		
(A3) 50--67			8		3			
(A4-1) 44-50			8	3	2		Severity Based (8 Intersections)	
(A4-2) 34-44								
(A5) 25 - 34							2	
(A6) 17-25							1	
(A7) 10-17							2	3

TABLE 4.5 Selected 36 Intersections

SL NO	TRKNAME	XRDNAME	TOT†	INJ†	FAT†	SEV‡	Selection Cell
1*	M59 HALL RD	SCHOENHERR RD	292	57	1	0.199	(P2)*
2*	M59 HALL RD	HAYES RD	202	41	0	0.203	(P2)*
3*	M3 GRATIOT	PROMENADE ST	221	43	0	0.195	(P2)*
4*	M59 HIGHLAND	AIRPORT RD	213	41	0	0.192	(P2)*
5*	M97	METRO PKWY	184	60	0	0.326	(P1)*
6*	M3 GRATIOT	MASONIC DR	159	54	0	0.34	(P1)*
7*	US24	TEN MILE RD	150	49	0	0.327	(P1)*
8*	M59 HALL RD	GARFIELD RD	176	39	0	0.222	(P2)*
9*	M59 HIGHLAND	CRESCENT LAKE RD	172	39	0	0.227	(P2)*
10*	M8 DAVISON	W DAVIS/N I75	166	39	0	0.235	(P2)*
11*	M153 FORD RD	WAYNE RD	166	41	0	0.247	(P2)*
12*	US24	GODDARD RD	159	38	0	0.239	(P2)*
13*	US24	VAN BORN RD	159	33	0	0.208	(P2)*
14*	US24	FRANKLIN RD	154	38	0	0.247	(P2)*
15*	M39 SOUTHFLD	DIX TOLEDO HWY	151	36	0	0.238	(P2)*
16*	M97	15 MILE RD	138	43	0	0.312	(P1)*
17*	M153 FORD RD	N MERCURY DR	133	39	1	0.301	(P1)*
18*	US24	FRANKLN,CIVIC CNTR	145	38	0	0.262	(P1)*
19*	M53 VAN DYKE	7 MILE RD	137	36	1	0.27	(P1)*
20*	M102 8 MILE	DEQUINDRE AVE	136	38	0	0.279	(P1)*
21*	US24	I96 SERVICE DRIVES	147	31	0	0.211	(P2)*
22*	M59 HIGHLAND	WILLIAMS LAKE RD	140	30	0	0.214	(P2)*
23**	M1 WOODWARD	S WOODWARD AVE	140	30	0	0.214	(P2)*
24*	M150	HAMLIN RD	140	32	0	0.229	(P2)*
25*	M153 FORD RD	INKSTER RD	139	34	0	0.245	(P2)*
26*	M24	HARMON ST	138	32	0	0.232	(P2)*
27*	M3 GRATIOT	12 MILE RD	137	33	0	0.241	(P2)*
28*	US24	MAPLE RD	134	27	0	0.201	(P2)*
29**	US12 MICH	JOHN DALY RD	40	17	1	0.45	(P2)**
30**	M29 23 MILE	SEATON RD	34	15	1	0.471	(P1)**
31**	M97 HOOVER	GREINER AVE	32	15	0	0.469	(P1)**
32**	M59 HIGHLAND	WHITTIER ST	32	14	0	0.438	(P1)**
33**	M59 HIGHLAND	TEGGERDINE RD	76	32	0	0.421	(P2)**
34**	M153 FORD RD	ARTESIAN,AUTO CLUB	38	15	1	0.421	(P2)**
35**	M3 GRATIOT	MARTIN ST	95	39	0	0.411	(P2)**
36**	US24	KING RD	62	25	0	0.403	(P2)**

Note:
*: Sites selected based on accident frequency
**: Sites selected based on accident severity
P (1)*: Intersection selected based on frequency criteria with Priority P (1)
P (2)*: Intersection selected based on frequency criteria with Priority P (2)
P(1)**: Intersection selected based on severity criteria with Priority P(1)
P(2)**: Intersection selected based on severity criteria with Priority P(2)
†: Represents number of crashes in respective category for a three year period, i.e. 2002-2004
‡: Ratio of injury crashes to total crashes

4.3 Geometric, Traffic Volume and Signal Timing Information

Accidents can occur primarily due to three factors and / or some combination of thereof: driver, vehicle and roadway. Improper roadway design and control strategies are the main concerns from a transportation safety point of view. Hence, an analysis of the current geometric, traffic and signal timing data for intersections is considered essential for safety evaluation. Operating level of service (LOS) of the intersections can be determined using the Highway Capacity Software (48), presented in the Highway Capacity Manual (49).

Geometric data of the intersections were collected from field surveys and plotted in the form of condition diagram. The condition diagram provides a complete presentation of the physical layout of the study location. Physical features include location geometry, description of control devices such as signs, signals, markings, lightings etc and all roadway features such as location of driveways, road side objects and land uses. Condition diagrams may provide insights to design deficiencies and to other geometric features that might contribute to the occurrence of accidents. Key features to look for are lane configurations, intersection alignment, driveways accessibility, posted speed and warning signs etc.

Traffic volume data for a few selected intersections were collected from South East Michigan Council of Governments (SEMCOG) and Michigan Department of Transportation (MDOT). Growth rate for each intersection from the past trends were determined for each intersection and it was found that traffic volume in almost all locations were increasing by 4% annually. Traffic volume for the base year and future years were determined by applying this growth rate.

Signal timing permits were obtained from MDOT. The 36 sites identified include intersections with fixed time, semi actuated, actuated controlled signals and stop signs. Signal timing data is an important feature of safety analysis, since yellow time and clearance intervals affect accident occurrence. Further, changes in signal timing may result in reduced accidents and improvement of level of service with little capital cost.

4.4 Study of Accident Reports (UD-10)

Accident reports were obtained from the Transportation Management System (TMS) from MDOT. Nearly 4000 accidents occurred in the selected 36 intersections over the three-year period (2001-2004). As it is beyond the scope of this research to review all accident reports, those containing all injury and fatality accidents during three-year period were reviewed. Further, accident reports containing all PDO accidents for the year 2004 and one eighth of those for the year 2002 and 2003 were also examined. The probable causes of accidents were noted as the first step towards the design of countermeasures.

4.5 Preparation of Condition and Collision Diagrams

A collision diagram provides information on the location and type of accidents for a given time frame. Each accident is plotted on the geometric diagram of the corresponding intersection. A collision diagram provides a visual representation of the types of accidents, their exact locations, and helps to determine the predominant accident patterns. Further, it assists in determination of probable causes and countermeasure design. A sample collision diagram for one of the 36 intersections, is shown in Figure 4.1. A summary of the collision diagram analysis of the 36 intersections is shown in Table 4.5.

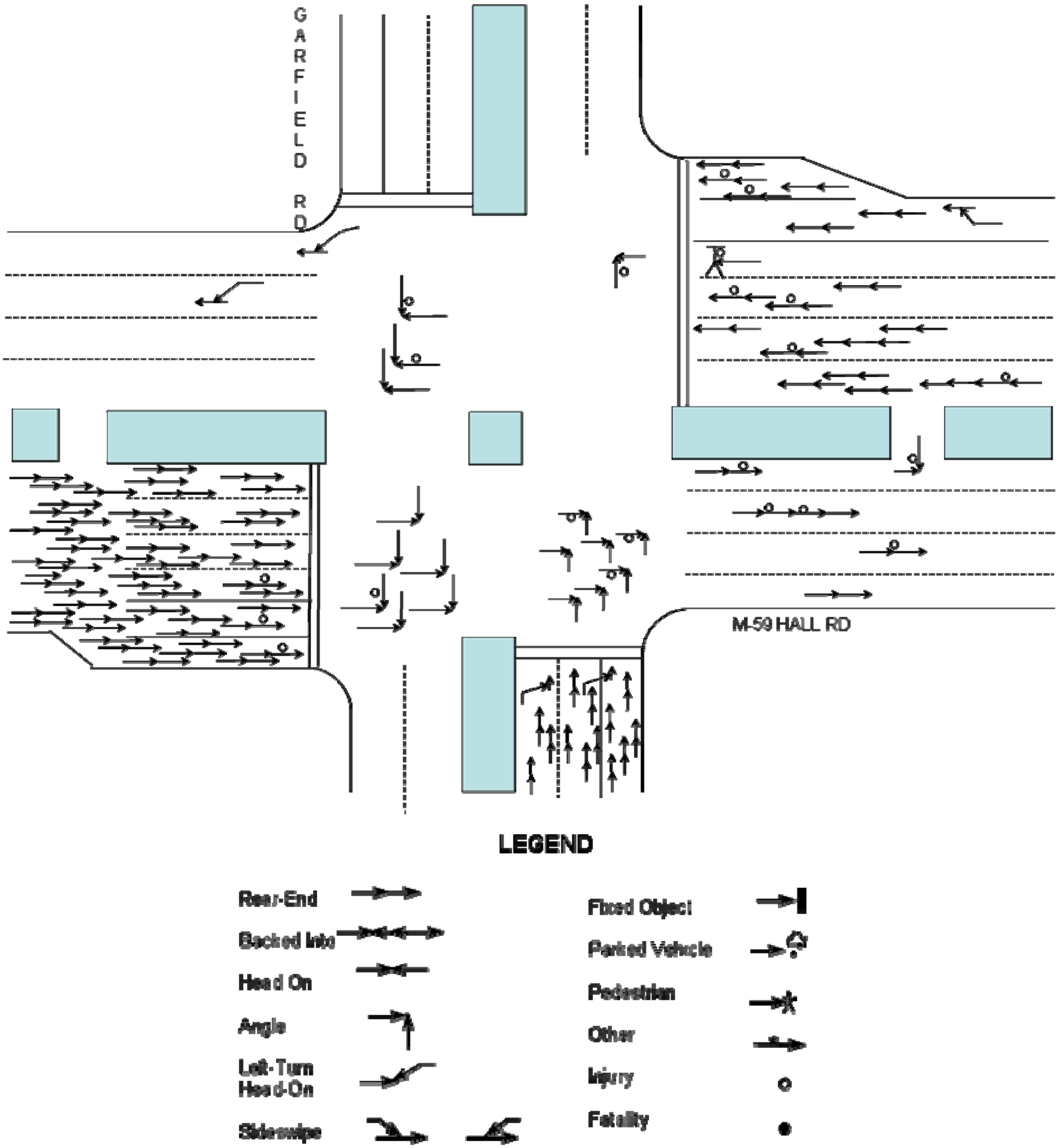


Figure 4.1: A sample collision diagram, Location- M-59 Hall Road and Goddard Road

4.6 Predominant Crash Patterns

Predominant crash patterns are those, which comprise very high percentage of total crashes, and can be identified from collision diagrams. Some of the predominant crashes identified for the intersections analyzed are:

1. Rear End Crashes
2. Angle Crashes
3. Left Turn Head on Crashes
4. Sideswipe – Same Direction Crashes
5. Driveway related Crashes

Three major predominant patterns responsible for high crashes are listed in table 4.6.

4.7 Identifying Probable Causes and Countermeasures

Once predominant crash patterns and geometric/operational features were determined, the next and most important step is to identify probable causes and design countermeasures. Countermeasures were selected based upon information available in the literature (Table 4.6). Next, CRFs for these countermeasures were compiled and used to estimate the safety benefits. Operational benefits, if any, are estimated from AASHTO Red Book and other sources (41). Relevant cost data of improvements, maintenance and operations of the countermeasures were obtained from either MDOT or other sources. This data is then used to conduct the economic analysis.

Table 4.6: Summary of Collision Diagram Analysis

SL	TRKNAME	XRDNAME	Predominant Crash Pattern			
			First	Second	Third	Comments
1	M59 HALL RD	SCHOENHERR RD	Rear End	Angle	Side Swipe	A,C,D
2	M59 HALL RD	HAYES RD	Rear End	Angle	Side Swipe	A,D
3	M3 GRATIOT	PROMENADE ST	HD-LT	Rear End	Side Swipe	B,C
4	M59 HIGHLAND	AIRPORT RD	Rear End	Angle	HD-LT	B,C,D
5	M97*	METRO PKWY	Angle	Rear End	Side Swipe	B,C
6	M3 GRATIOT	MASONIC DR	Rear End	Angle		C,D
7	US24	TEN MILE RD	Rear End	Angle	Side Swipe	D,E
8	M59 HALL RD	GCRFIELD RD	Rear End	Angle	Side Swipe	C,D
9	M59 HIGHLAND	CRESCENT LAKE RD	Rear End	HD-LT	Side Swipe	C,D
10	M8 DAVISON *	W DAVIS/N I75				
11	M153 FORD RD	WAYNE RD	HD-LT	Rear End	Side Swipe	C,D
12	US24	GODDARD RD	Rear End	Angle		C,D
13	US24	VAN BORN RD	Rear End	Side Swipe	Angle	C
14	US24*	FRANKLIN RD				
15	M39 SOUTHFLD	DIX TOLEDO HWY	Rear End	Angle	Side Swipe	D
16	M97	15 MILE RD	Driveway Related	Rear End	HD-LT	B,C,D
17	M153 FORD RD	N MERCURY DR	Rear End	Angle	Side Swipe	D,E
18	US24	FRANKLN,CIVIC CNTR	Rear End	Angle	Side Swipe	D,E
19	M53 VAN DYKE	7 MILE RD	HD-LT	Angle	Rear End	B,C,F
20	M102 8 MILE	DEQUINDRE AVE	Angle	Rear End	Side Swipe	A,C
21	US24*	I96 SERVICE DRIVES				
22	M59 HIGHLAND	WILLIAMS LAKE RD	Rear End	HD-LT	Angle	A,C
23	M1 WOODWARD*	S WOODWARD AVE				
24	M150	HAMLIN RD	Rear End	Driveway Related	Angle	B,D
25	M153 FORD RD	INKSTER RD	Rear End	HD-LT	Angle	C,D
26	M24	HARMON ST	Rear End	Angle		A,D
27	M3 GRATIOT	12 MILE RD	Angle	Rear End	Side Swipe	C,D
28	US24	MAPLE RD	Rear End	Angle	Side Swipe	C,D
29	US12 MICH	JOHN DALY RD	Rear End	Angle		C
30	M29 23 MILE	SEATON RD	HD-LT	Rear End	Angle	C
31	M97 HOOVER	GREINER AVE	HD-LT			C
32	M59 HIGHLAND	WHITTIER ST	HD-LT	Driveway Related	Angle	B,C
33	M59 HIGHLAND	TEGGERDINE RD	HD-LT	Angle	Rear End	C
34	M153 FORD RD	ARTESIAN,AUTO CLUB	Rear End	Angle		B,G
35	M3 GRATIOT	MARTIN ST	HD-LT	Angle		C,D
36	US24	KING RD	HD-LT	Angle		C

Comments Explanation for Table 4.6:

A: Heavy Traffic
B: Driveway Related Problems
C: Signal Time
D: Number of Lanes
E: All Red Period
F: Wet Surface or Snowy Pavement
G: Location of Michigan Left
*: Data Accessing Problem or Mismatch

4.8 Economic Evaluation of Countermeasures

Economic analysis is a critical component of a comprehensive project or program evaluation methodology that considers all key impacts of highway investments. It allows highway agencies to identify, quantify, and value the economic benefits and costs of highway projects and programs over a multiyear timeframe. With this information, highway agencies are better able to target scarce resources to their best uses in terms of maximizing benefits to the public and to account for their decisions. Recognizing importance of economic evaluation, following comprehensive methodology, presented in the form of flow chart, was adopted. The five economic analysis techniques, B/C Ratio, IRR, C/E, NPV and TOR have discussed in detail in Chapter 2.

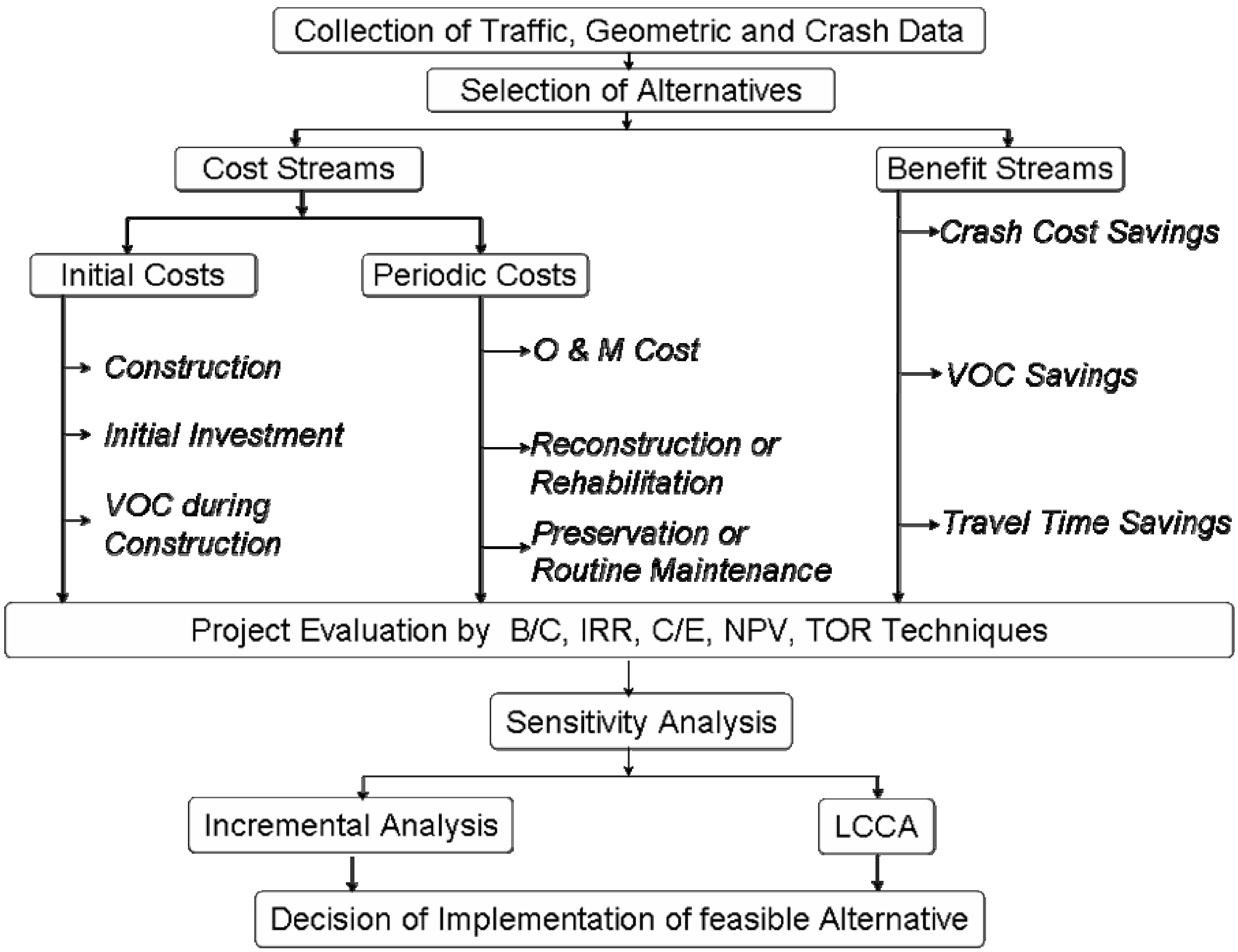


Figure 4.2 Economic Analysis Procedure

While the five techniques described above are likely to lead to the same solution, there are state to state variations in the use of a specific technique, that is determined by factors such as availability of data, the intended use of the results, and to the some extent, the prevailing practice in the state. In Michigan, the prevailing practice has been the use of the Pay Off Period or Time of Return technique, and the project that pays off for its investment earlier than the project life, essentially qualifies for further consideration.

The selection of the best project from a group of mutually exclusive alternatives that all meet the pay-off period criterion, is not however, a straight forward process. Further, when a specific budget for the program is specified, project selection from a large number of independent sites, each of which may have a number of mutually exclusive alternatives, can be a really challenging task for the agency. Since a budget is not specified in this study, the incremental cost analysis technique was used in this study in selecting the best alternatives from mutually exclusive set. Detailed case studies are presented in the next chapter.

4.8.1 Cost Stream

The life cycle of any transportation facility (including design, construction, operation, maintenance, and salvage) is associated with various types of costs and benefits incurred to agency, facility user and facility non-users. Fig 4.3 shows typical structure of cost components in highway improvements projects.

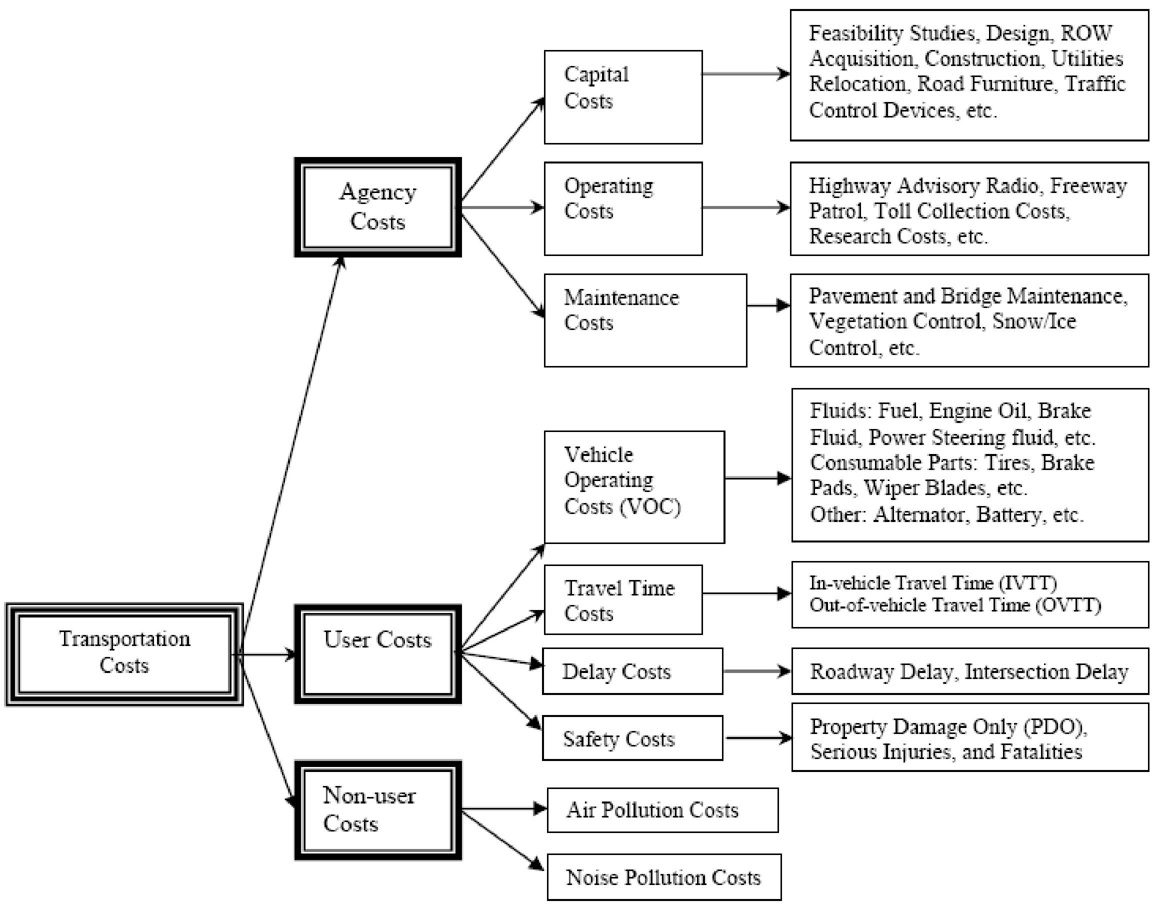


Figure 4.3: Flow Chart of Various Cost Components *(Source: Ref. 42)*

4.8.1.1 Agency Costs (Capital, Maintenance and Operation Costs)

Agency costs refer to the costs that are borne by the owner or operator of the transportation facility. Agency costs are typically placed into five major categories: advance planning, preliminary engineering, final design, right-of-way acquisition and preparation, construction, maintenance, and operations. In some cases, disposal of physical components of the transportation facility at the end of its service life involves some costs that are referred to as salvage costs. Fig 4.4 demonstrates various agency costs involved in highway construction project.

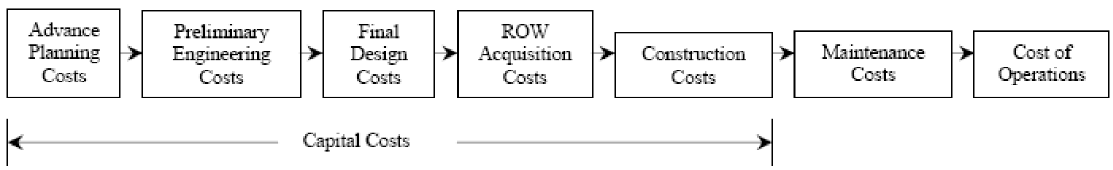


Figure 4.4: Agency Costs *(Source: Ref. 42)*

Various agency costs of improvements were reviewed from many websites and some cost figures were assumed where necessary.

4.8.1.2 Road user cost due to delay during construction

It may be necessary to close some part of the road during construction period. It results in reduction in speed of traffic and increased travel time to road users. It is essential to consider this road user cost while carrying out economic analysis of improvement involving construction. Some improvement alternative may involve some form of construction/reconstruction activities such as adding a lane, repaving the surface, etc. This would cause some delay to road users and value of this delay was estimated. The following data is needed in estimating road user delay during construction.

- Average travel speed before construction,
- Average travel speed during construction,
- Length of roadway affected by construction,
- Duration of construction/reconstruction activity.

Expression for calculating delay cost to road users due to construction is given below (41):

$$RUC_{const} = ADT \times \left(TT_{during} - TT_{before}\right) \times VOT \times D \qquad (4.1)$$

Where,
RUC_{const} = Road User Cost due to construction activity in \$,
ADT = Average Daily Traffic of an intersection,
TT_{before} = Travel Time before improvement in hr/veh,
TT_{during} = Travel Time during construction activity in hr/veh,
VOT = Value of travel time in \$/hr,
D = Duration of construction activity in days.

4.8.2 Benefit Stream

Benefits can be tangible and intangible. Tangible benefits include reductions in crash cost, travel time, delay, and vehicle operating cost. Reductions in cost due to noise and environmental pollution may be considered as intangible benefits, and are quite difficult to estimate.

4.8.2.1 Savings due to Expected Reduction in Crashes

Countermeasures are implemented with the expectation of reducing the number and severity of crashes, which would pay off their expenses in the near future. Hence, appropriate crash reduction factors were applied to each improvement to estimate the expected number of crashes after the improvement. Analyses were performed at a level of aggregation compatible with the CRF used. For example, if CRF is available for injury crashes or rear end crashes, then savings due to reduction in such crashes were computed. Dollar value of injury and PDO crashes, from NSC 2003, was assigned to respective severity of crashes to quantify savings due to crash reduction. For simplicity, it was assumed that crashes increase linearly with increase in ADT. Therefore, the following formula was used to forecast the expected number of crashes without improvement for each year of the service life for an improvement (50):

$$E_F = B_{PF} \times \left(\frac{ADT_{After}}{ADT_{before}} \right) \times \left(\frac{T_A}{T_B} \right) \qquad (4.2)$$

Where,
E_F = Expected Frequency-related MOE at the project site if no improvement had been made,
B_{PF} = Before Period Frequency,
T_A = Length of time in after period = 1 year,
T_B =Length of time in before period = 3 years.
However, crashes may not change linearly with ADT and it is advisable to develop such empirical formula (in other words, accident prediction models) based on crash history of locations having similar operating, geometric, traffic features to those of study site.

Literature review on CRFs described in Chapter 2 showed some variations in these estimates between different sources. The minimum of these CRF values was considered in the case studies, to keep the benefit assessment at a conservative level. The procedure used by the States of Kentucky and Michigan (equation 4.2) was used to compute CRF for multiple countermeasures.

4.8.2.2 Statistical Significances

It is essential to test whether the reduction in crashes is statistically significant. Therefore, a Poisson test was performed for statistical significance of reduction in number crashes (figure 4.5). A 90% Level of Confidence was taken as the criteria for selection of effective reduction in crashes.

The National Safety Council makes estimates of the average costs of fatal and nonfatal unintentional injuries to assess their impact on the nation's economy. The costs are a measure of the dollars spent and income not received due to accidents, injuries, and fatalities. Average economic cost per death, injury, and PDO crash is given below:
Death = $1,130,000
Nonfatal disabling injury = $49,700
PDO = $7,400

4.8.2.3 Savings due to Reduction in Travel Time

Travel time costs refer to the cost of the time spent by users for the duration of time they spend in the use of the transportation facility. Estimation of value of travel time is the most crucial step in order to calculate accurate travel time savings. The value of travel time for this study ($8.00/person-hr) is based on the literature (43).

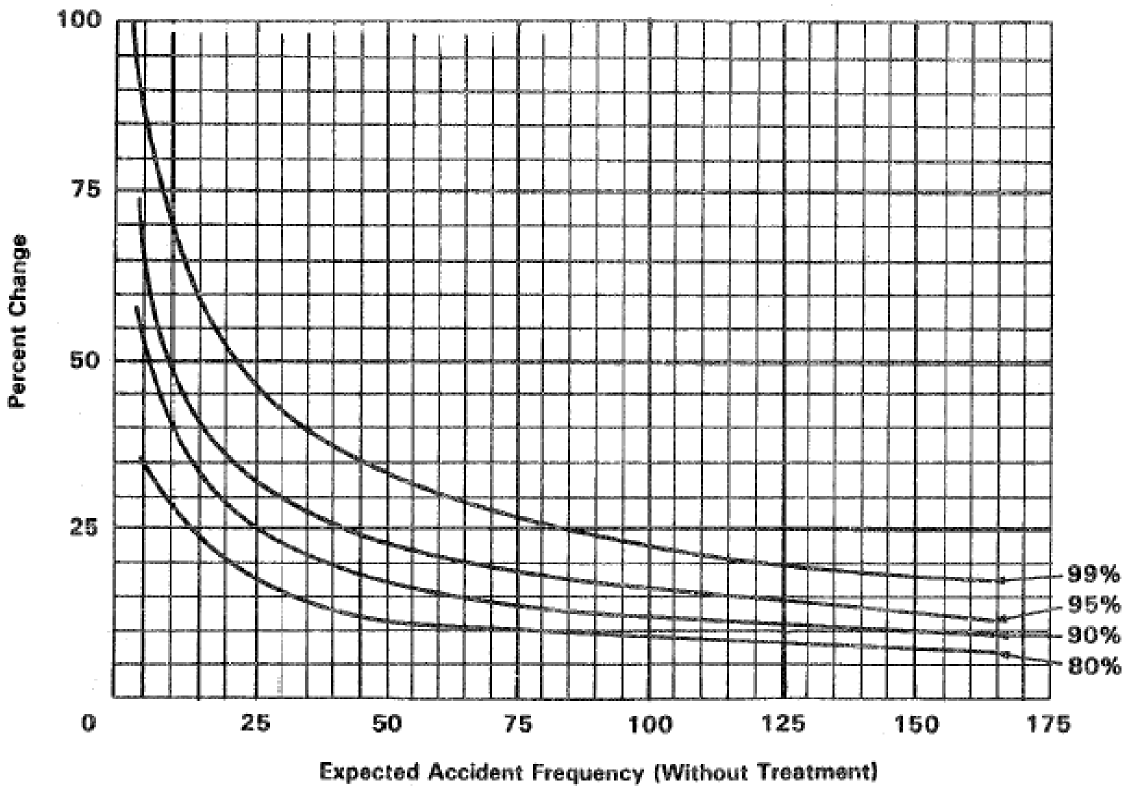


Figure 4.5: Poisson Curves (*Source: Ref 23*)

The Highway Capacity Software (HCS-2000) was used to estimate approach and intersection delay (sec/veh). General expression to determine travel time cost is as follows (42):

TTC = ADT x Delay x Number of hours x days x LF x VOT ___________________________ (4.3)

Where,
TTC = travel time cost in $/year
ADT = intersection or approach volume in veh/hr
Delay = hours of delay per vehicle
LF = load factor = 1.2 (in this case)
VOT = value of time in $/hr = $8.0 (in this case).

Travel time costs were calculated for "before" and "after" periods. Any saving in travel time cost is to be considered as positive benefits, and vice-versa.

4.8.2.4 Savings due to Reduction in Fuel Consumption

Fuel cost constitutes a major portion of vehicle operating costs. For a given vehicle type, the most significant factor that affects the level of fuel costs is the speed of the vehicle. Results from HCS were utilized in the computation of savings in fuel consumption. A methodology, similar to that of computation of savings in travel time, was adopted for calculating savings in fuel consumption, using the following formula :

$$CFC = ADT \text{ x } Delay \text{ x } Number\ of\ hours \text{ x } days \text{ x } C_D \text{ x } C_F \qquad (4.4)$$

Where,
CFC = cost of fuel consumption in $/year
ADT = intersection or approach volume in veh/hr
Delay = hours of delay per vehicle
C_D = cost of delay in gallon/hr of delay = 0.5 gallon (assumed)
C_F = cost of fuel in $/gallon = $2.25 (assumed)

4.8.3 Sensitivity Analysis

Typically, the analyst is faced with a number of uncertainties when evaluating a highway investment. These uncertainties can sometimes be measured by estimating the probability of an event and its impact (46). Eeconomic analysis produces an numerical assessment, the magnitude of which depends upon engineering judgment in selecting factors and estimating the future. To gain some understanding of how certain factors affect the solution, a good practice is to conduct the economic analysis by using low, medium, and high values of the critical factors, and in different combinations. This exercise, often termed as sensitivity analysis, allows the analyst to examine the relative importance of these factors in the overall economic analysis.

Here, three such criteria, such as increasing cost by 10%; decreasing benefits by 10%; and combination of both, were used to analyze sensitivity to changing scenarios. The main reason to examine such criteria is due to fact that both costs and benefits could change due to many factors such as change in vest charge, incidental cost, lawsuit settlement costs, deviation from forecasted volume data, change in expected savings in crashes, travel time and fuel consumption, etc.

5. CASE STUDIES

5.1 Introduction

A total of 36 hazardous intersections were identified in Chapter 4 that may be considered as prime candidates for safety improvements. In this chapter, a total of 20 case studies, each representing one of those 36 intersections are presented in two groups. In Group A, a total of five comprehensive case studies analyzed by each of the four economic analysis techniques are presented. Further, these case studies include the consideration of both safety and operational benefits associated with the implementation of the specific projects. Typically, safety benefits include savings in crashes, while operational benefits include savings in road user costs, in delay, etc. In Group B, the remainder 15 intersections are analyzed using the Time of Return (TOR) technique, which has been used by MDOT in the past. Also, these 15 case studies are based upon the consideration of safety benefits only, conducted with the premise that safety benefits should be the only factors used to justify a safety project. These twenty intersections are identified in Table 5.1.

5.2 Group-A Results

In all the case studies presented in this chapter a set of common assumptions were made as outlined below,

Interest rate i = 6% / Year
Project Life = 10 Years
Traffic Growth = 4%
Period of Construction = 1 Year
Vehicle Occupancy = 1.2 Passenger / Car
Value of Travel Time = $8 / Hr
Fatality = $1,130,000
Nonfatal Disabling Injury = $49,700
Property Damage Crash (including nondisabling injuries) = $7,400

The format used for the five case studies includes a brief discussion about the site, data collection, analysis of UD-10 reports, an assessment of current level of service, improved level of service by the use of HCS (44), aaSIDRA (48) and presentation of the results. Results are presented in Tabular format that include

- Identification of Probable Causes and Suggested Countermeasures
- Development of Alternatives and Identification of Crash Reduction Factors for Each Alternative
- Presentation of Crucial Data for Economic and Statistical Analysis
- A series of bar charts depicting various costs and benefit data over the life of the project.
- Summarized Results of Economic Analysis by four MOE's (B/C, IRR, NPV and TOR) for each alternative in three categories
    - Crash Savings as the only benefit
    - Crash and Vehicle Operating Cost (VOC) savings as the benefits
    - Crash, VOC and TT savings as the benefits
- A set of sensitivity analyses is presented to demonstrate that the results are sensitive (as they should be) to changes in cost and benefit data.

Table 5.1: Intersections Selected for Group A and Group B Analysis

SL No	CS	BMILE	TRKNAME	XRDNAME	TOT	INJ	FAT	SEV
1**	50022	2010	M59 HALL RD	SCHOENHERR RD	292	57	1	0.199
2**	50022	3020	M59 HALL RD	HAYES RD	202	41	0	0.203
3*	82072	5828	M3 GRATIOT	PROMENADE ST	221	43	0	0.195
4**	63041	14530	M59 HIGHLAND	AIRPORT RD	213	41	0	0.192
5*	50031	9490	M97	METRO PKWY	184	60	0	0.326
6*	50051	6310	M3 GRATIOT	MASONIC DR	159	54	0	0.34
7**	63031	2040	US24	TEN MILE RD	150	49	0	0.327
8**	50022	4020	M59 HALL RD	GCRFIELD RD	176	39	0	0.222
9*	63041	15540	M59 HIGHLAND	CRESCENT LAKE RD	172	39	0	0.227
10	82104	1030	M8 DAVISON	W DAVIS/N I75	166	39	0	0.235
11**	82081	8060	M153 FORD RD	WAYNE RD	166	41	0	0.247
12**	82052	6140	US24	GODDARD RD	159	38	0	0.239
13**	82052	9080	US24	VAN BORN RD	159	33	0	0.208
14	63052	5650	US24	FRANKLIN RD	154	38	0	0.247
15	82192	620	M39 SOUTHFLD	DIX TOLEDO HWY	151	36	0	0.238
16	50031	8300	M97	15 MILE RD	138	43	0	0.312
17	82081	17540	M153 FORD RD	N MERCURY DR	133	39	1	0.301
18	63031	2590	US24	FRANKLN,CIVIC CNTR	145	38	0	0.262
19**	82151	3890	M53 VAN DYKE	7 MILE RD	137	36	1	0.27
20	82143	2140	M102 8 MILE	DEQUINDRE AVE	136	38	0	0.279
21	82053	5680	US24	I96 SERVICE DRIVES	147	31	0	0.211
22**	63041	12690	M59 HIGHLAND	WILLIAMS LAKE RD	140	30	0	0.214
23	63051	0	M1 WOODWARD	S WOODWARD AVE	140	30	0	0.214
24	63132	1130	M150	HAMLIN RD	140	32	0	0.229
25**	82081	12028	M153 FORD RD	INKSTER RD	139	34	0	0.245
26	63112	1400	M24	HARMON ST	138	32	0	0.232
27**	50051	4590	M3 GRATIOT	12 MILE RD	137	33	0	0.241
28**	63031	7110	US24	MAPLE RD	134	27	0	0.201
29	82061	12980	US12 MICH	JOHN DALY RD	40	17	1	0.45
30	50072	2360	M29 23 MILE	SEATON RD	34	15	1	0.471
31	82171	1410	M97 HOOVER	GREINER AVE	32	15	0	0.469
32	63041	13900	M59 HIGHLAND	WHITTIER ST	32	14	0	0.438
33**	63041	9920	M59 HIGHLAND	TEGGERDINE RD	76	32	0	0.421
34	82081	16455	M153 FORD RD	ARTESIAN,AUTO CLUB	38	15	1	0.421
35**	50051	4020	M3 GRATIOT	MARTIN ST	95	39	0	0.411
36*	82052	1041	US24	KING RD	62	25	0	0.403

Note:

* Group A Study, ** Group B Study

The case studies presented in Group A include four economic analysis tools: B/C ratio, IRR, TOR, and NPV techniques. Additionally it is possible to include C/E technique if MDOT so desires. The available literature on this topic generally indicates that under compatible assumptions all of the techniques result in the same final solutions. The five case studies presented support this view point. For each alternative analyzed, three independent sets of analyses are presented; (1) only with safety benefits (2) safety benefits and road user benefits (3) safety benefits, road user benefits and travel time savings. The results are designed to assist the analyst in examining the benefit picture in an incremental manner.

For selecting the best alternative from a set of mutually exclusive alternatives, the marginal cost approach was used that essentially examines the effect of every additional dollar investment, and selects higher-cost alternative only if the marginal benefit exceeds the marginal cost. The implied assumption here is that there is no budgetary constraint. In reality, budget constraints are likely to prevail. Additional studies to select the optimum project from a set of mutually exclusive alternatives projects with a specific budget constraint are recommended.

5.2.1 Case Study 1

The study site is the intersection at M-3 Gratiot and Masonic Blvd, located in Macomb County with a total of 80,000 vehicles per day using this intersection. Gratiot is a ten-lane facility with 5 lanes in each direction. Masonic Blvd is a five lane facility with a centre left turning lane. Other operating features of the intersection are:

1. No left turn is allowed on the intersection with Michigan left turns on Gratiot.
2. Speed Limit is 45 mph and 30 mph for Gratiot and Masonic Blvd respectively
3. Signal operation is two phase
4. Large median on Gratiot and signals are placed on near and far ends

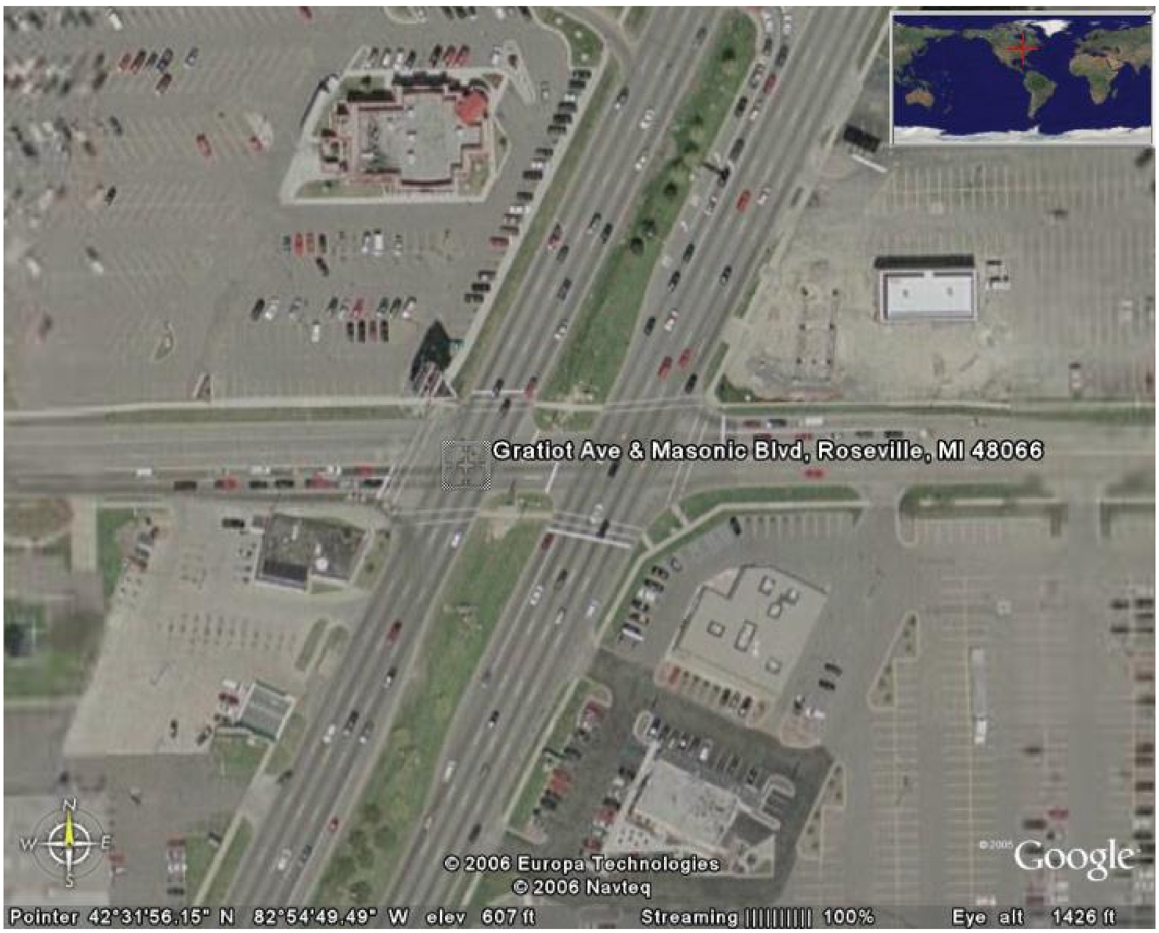


Fig 5.1: Map of Study Area

Fig 5.1 shows the location of intersection in South East Michigan. Fig 5.2 and 5.3 are the pictures of the intersection during the time of data collection. The signals at the intersection are box spanned and the intersection has many access points on its surroundings in the form of gasoline stations and retail outlets.

Fig 5.2: Photograph-1 of Study area

Fig 5.3: Photograph-2 of Study area

5.2.1.1Data Collection and Analysis

Data collection procedure involved plotting of condition diagram, traffic volume, collection of signal timing data, UD-10 screening for analyzing the predominant crash pattern.

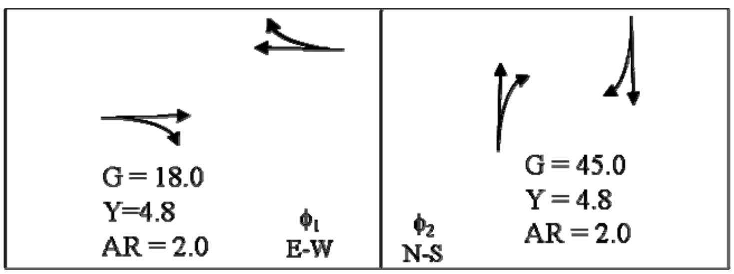
Traffic Volume

Traffic volume counts were made for 15-minute intervals for 4 times for all approaches. The collected traffic was converted to daily traffic from the off peak period by assuming two percent of traffic volume. The peak hourly data was computed from the estimated daily traffic volume (8%) shown below.

Signal Timing

Signal timing data were collected with a stopwatch and are shown below.

	NB		SB		EB		WB	
Peak Hr	TH	RT	TH	RT	TH	RT	TH	RT
Total	2180	980	2135	988	690	230	620	380



UD-10 Analysis

A total 159 crashes including 57 injury crashes were reported during last three years (2002-2004). Salient features from the collision diagram report (Figure 5.4) and actual UD-10 observations are;

a) Predominant crash patterns: Rear end on M-3 Gratiot and Angle crashes
b) Rear end crashes due to poor visibility of the signals and high v/c ratio
c) More angle crashes resulting from vehicles on M-3 Gratiot having to cover long distance to cross the intersection.

Existing Level of Service

Using traffic volume and signal timing data, the current Level of Service was determined as “D” using Highway Capacity Software. Each approach LOS is shown in Table 5.2.

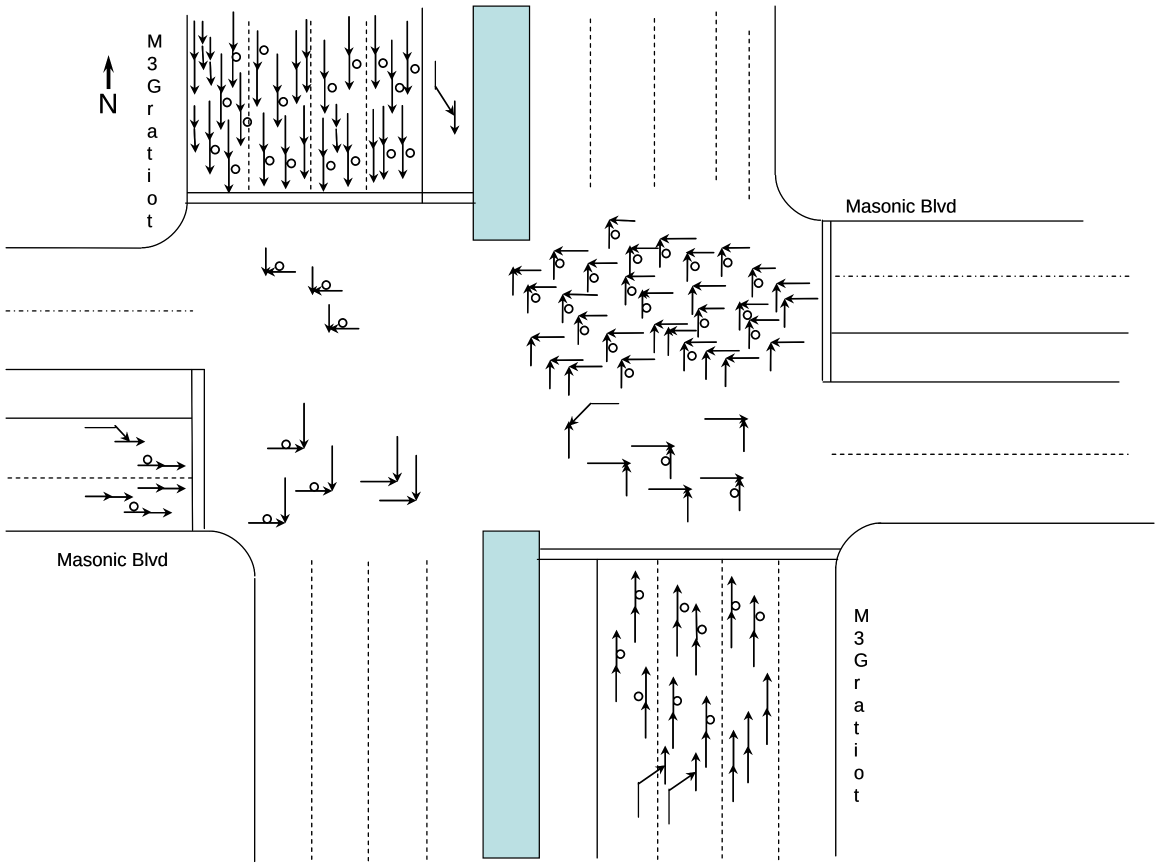


Fig 5.4: Collision Diagram of M-3 Gratiot and Masonic Blvd.

Table 5.2: Existing LOS of M-3 Gratiot and Masonic Blvd

Item	NB	SB	EB	WB
Delay (sec)	36.7	38.4	41.3	63.6
LOS	D	D	D	E
Intersection LOS	D			

A set of probable causes of the crashes based upon review of the UD-10 reports and its site visits, along with suggested countermeasures are presented in Table 5.3

Table 5.3: Probable Causes and Countermeasures.

Probable Causes	Suggested Countermeasures
1. Signal Timing Problem 2. Diagonal Span wire signals causes visibility problem 3. High Traffic Volume on Gratiot 4. Insufficient light at the intersection causes night time crashes 5. Placing of Near and Far Signals Causes Confusion on the minds of Drivers. 6. Pavement Markings	1.Signal Time Redesign 2. Install Mast Arm Separate Right Turn Lane for EW movement 3. Add Lane on M-3 Gratiot 4. Intersection Lighting 5.Proper Placement of Signal Heads 6.pavement markings

5.2.1.2 Proposed Improvements and Analysis

Three alternatives are proposed to address the safety hazards and presented in Table 5.4. Results of the analysis are presented in Table 5.5 to 5.12 and Figure 5.5 to 5.10.

Table 5.4: Proposed Alternatives for M-3 Gratiot and Masonic Blvd.

Improvement Alternatives	Type of Alternatives	CRF
Alternative -1	1. Pavement markings, resurfacing, with periodic operation and maintenance. 2. Change in signal time to improve the LOS and reduction of angle crashes.	CRF1= 25% CRF2=8 % Combined CRF =31%
Alternative – 2	1. Replacement of existing diagonal span wire signals with mast arms signals 2. Improvement of lighting up to 0.3 mile, on all approaches 3. Pavement markings, resurfacing with periodic operation and maintenance 4. Modification of signal time to improve the LOS and reduction of angle crashes	CRF1= 20% CRF2=30% CRF3=25% CRF4=8% Combined CRF =54%
Alternative -3	1. Widen lane on NB and SB of M-3 Gratiot 2. Replacement of existing diagonal span wire signals with mast arms signals 3. Pavement markings, resurfacing with periodic operation and maintenance 4. Modification of signal time to improve the LOS and reduction of angle crashes 5. Improvement of lighting up to 0.3 mile, on all approaches	CRF1= 20% CRF2=20% CRF3=25% CRF4=8% CRF5=30% Combined CRF = 70%

Table 5.5: Summary of Poisson test Results for Alternative-1 for the First Year

Inputs	Injury		PDO		Total
	Angle Crash	Rear End Crash	Angle Crash	Rear End Crash	
Crashes Before Improvement (2002- 2004)	30	36	33	72	171
After Period Crashes Without Improvement, 2007, (Annual)	10.45678375	12.54814	11.5025	25.0963	57
CRF for Combined Improvements	0.31	0.31	0.31	0.31	0.26
Estimated Reduction in number of crashes	3.24	1.88	3.56	3.76	14.82
Crashes After Improvements	7.215180788	10.66592	7.9367	21.3318	42.18
Significance	Yes @ 95% LOC	No @ 95% LOC	Yes @ 95% LOC	Yes @ 95% LOC	Yes @ 95% LOC
Savings in crash cost due to improvement(s) ($/year)	147493	85641	29239	30868	293242

Table 5.6: Summary of Poisson test Results for Alternative-2 for the First Year

Inputs	Injury		PDO		Total
	Angle Crash	Rear End Crash	Angle Crash	Rear End Crash	
Crashes Before Improvement (2002- 2004)	30	36	33	72	171
After Period Crashes Without Improvement, 2007, (Annual)	10.45678375	12.548141	11.50246	25.09628	57
CRF for Combined Improvements	0.54	0.54	0.54	0.54	0.53
Estimated Reduction in number of crashes	5.673118888	5.5512974	6.240431	11.10259	30.3012
Crashes After Improvements	4.783664862	6.9968431	5.262031	13.99369	26.6988
Significance	Yes @ 95% LOC	No @ 95% LOC	Yes @ 95% LOC	Yes @ 95% LOC	Yes @ 95% LOC
Savings in crash cost due to improvement(s) ($/year)	258126.9094	252584.03	51171.53	91041.28	652923.75

Table 5.7: Summary of Poisson test Results for Alternative-3 for the First Year

Inputs	Injury		PDO		Total
	Angle Crash	Rear End Crash	Angle Crash	Rear End Crash	
Crashes Before Improvement (,2002-2004)	30	36	33	72	171
After Period Crashes Without Improvement, 2007, (Annual)	10.45678375	12.548141	11.50246	25.09628	57
CRF for Combined Improvements	0.70	0.70	0.70	0.70	0.70
Estimated Reduction in number of crashes	7.319748625	9.7875496	8.051723	19.5751	39.9
Crashes After Improvements	3.137035125	2.7605909	3.450739	5.521182	17.1
Significance	Yes @ 95% LOC	Yes @ 95% LOC	Yes @ 95% LOC	Yes @ 95% LOC	Yes @ 95% LOC
Savings in crash cost due to improvement(s) ($/year)	333048.5624	445333.51	66024.13	160515.8	1004922

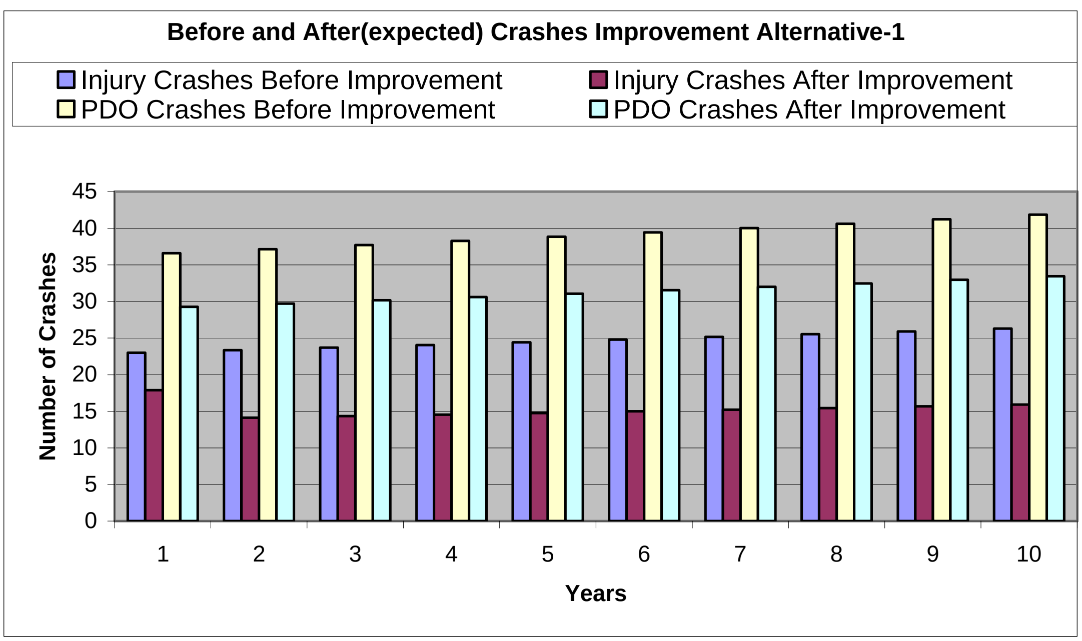


Figure 5.5: Comparison of Before and After Period Crashes due to Improvement Alternative-1

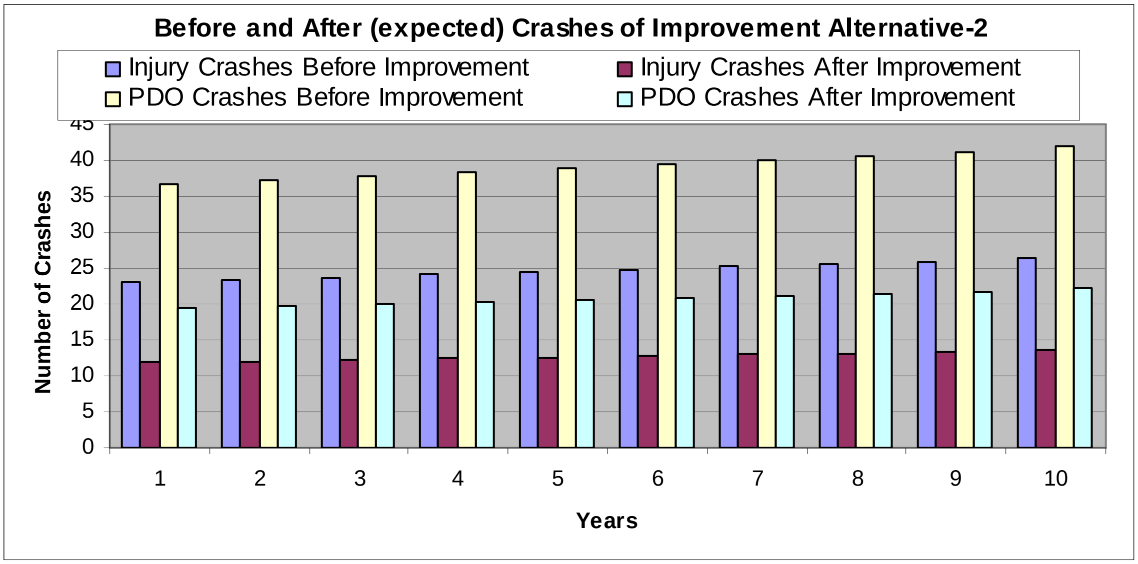


Figure 5.6: Comparison of Before and After Period Crashes due to Improvement Alternative-2

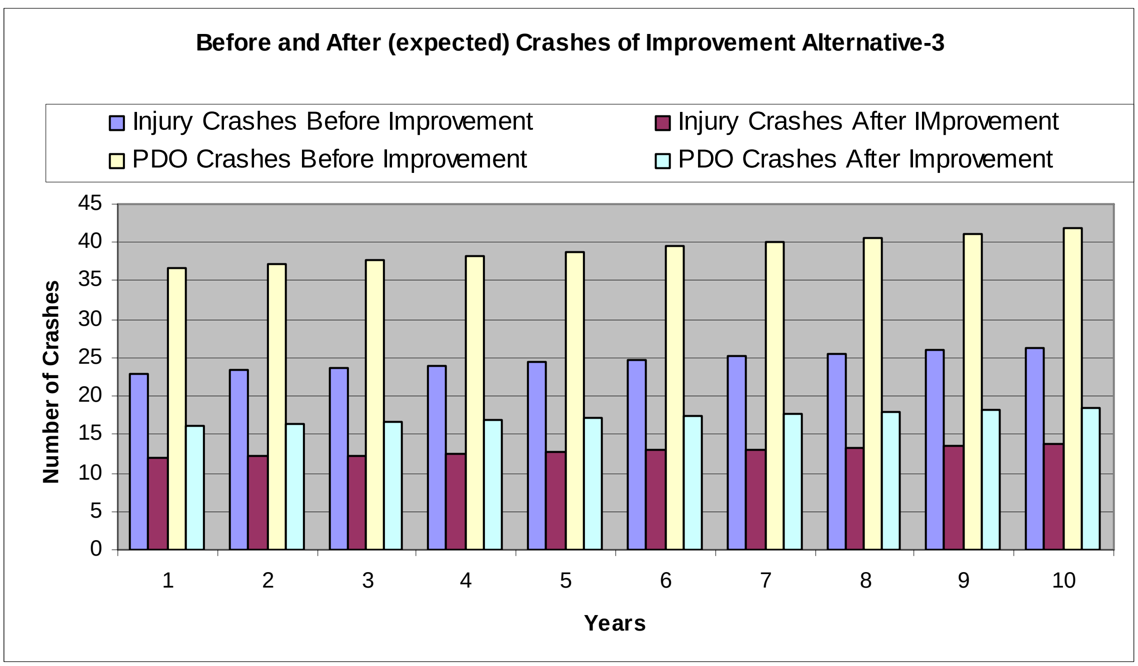


Figure 5.7: Comparison of Before and After Period Crashes due to Improvement Alternative-3

Table 5.8: Savings in Travel Time due to Improvement Alternative-1, 2 and 3 for the First Year

Direction of Travel	Peak Hour Traffic in veh/hr	Delay Before Improvement in sec/veh	Delay After Improvement in sec/veh	Change in Delay in hr/veh	Change in Vehicle Travel Time in veh-hrs	Change in Passenger Time in person-hrs	Dollars Amount Saved in $/year
NB	3160	36.7	17.2	0.005416667	8,901	10,681	**85,446**
SB	3123	38.4	17.1	0.005916667	9,608	11,530	**92,241**
EB	920	41.3	29.6	0.00325	1,555	1,866	**14,926**
WB	1000	61.6	35.4	0.007277778	3,784	4,541	**36,331**

Table 5.9: Savings in VOC due to Improvement Alternative-1, 2 and 3 for the First Year

Direction of Travel	Peak Hour Traffic in veh/hr	Delay Before Improvement in sec/veh	Delay After Improvement in sec/veh	Change in Delay in hr/veh	Cost of Delay in terms of Fuel gal/hr of delay	Savings in Fuel Consumption gallons	Cost of Fuel in $/gal	Dollar Saved in $/year
NB	3160	36.7	17.2	0.005416667	0.5	4450.333333	2.25	**10,013**
SB	3123	38.4	17.1	0.005916667	0.5	4804.215	2.25	**10,809**
EB	920	41.3	29.6	0.00325	0.5	777.4	2.25	**1,749**
WB	1000	61.6	35.4	0.007277778	0.5	1892.222222	2.25	**4,258**

Table 5.10: Cost Components for Alternatives

Cost Component	Alternative-1	Alternative-2	Alternative-3
Cost of Construction			$500,000
Cost of Excavation			$50,000
Signal Changing		$150,000	$150,000
VOC Cost Due to Delay			$49,196
Regular O&M Cost	$20,000	$20,000	$20,000
Periodic O&M Cost	$10,000	$10,000	$10,000
Lighting		$30,000	
Marking and Resurfacing	$200,000	$200,000	

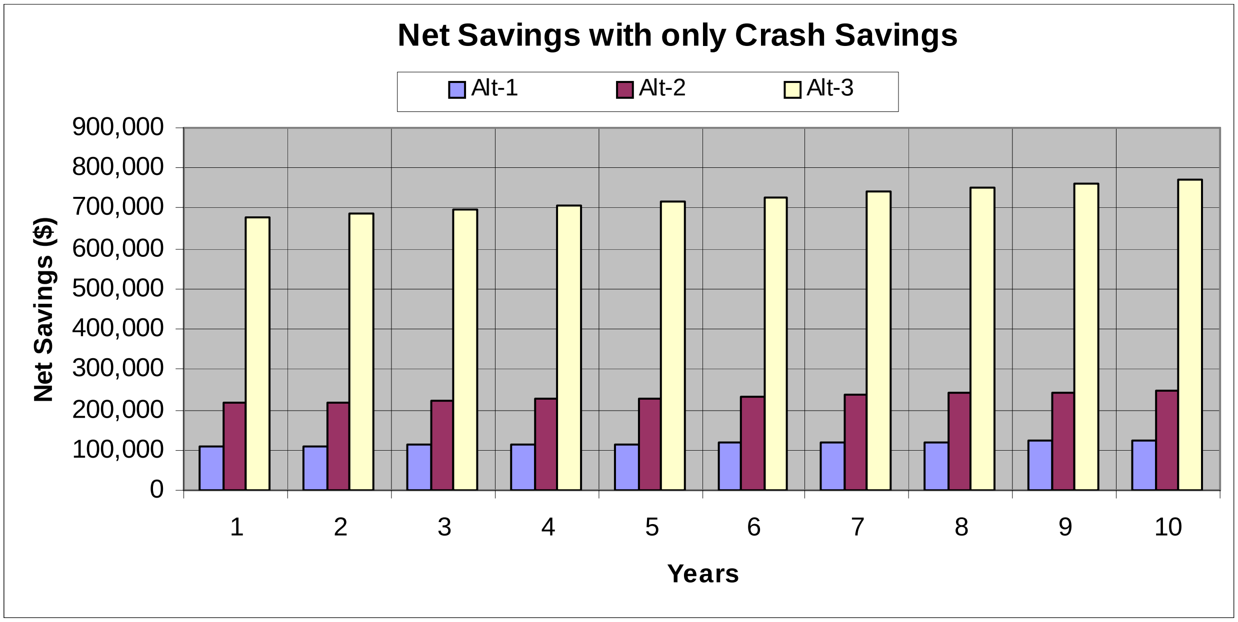


Figure 5.8: Net Savings in crash cost due to improvements for all alternatives

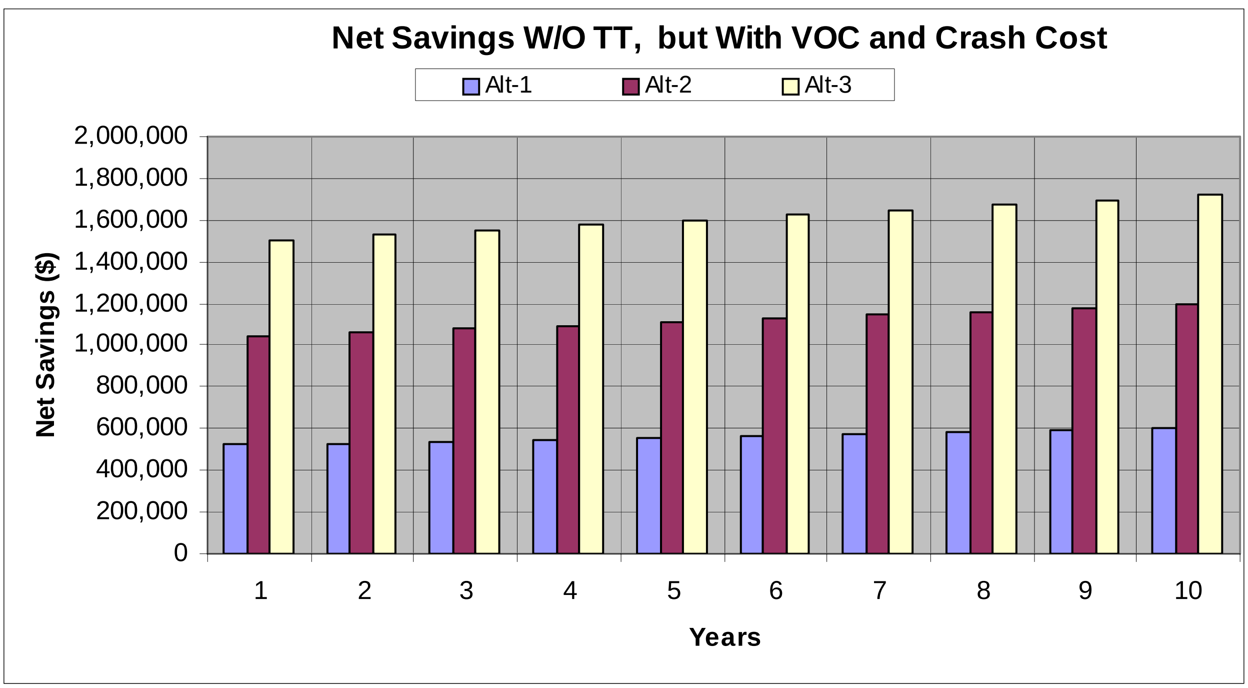


Figure 5.9: Net Savings in crash cost due to improvements for all alternatives

Table 5.13. Incremental Analysis is shown Table 5.14.

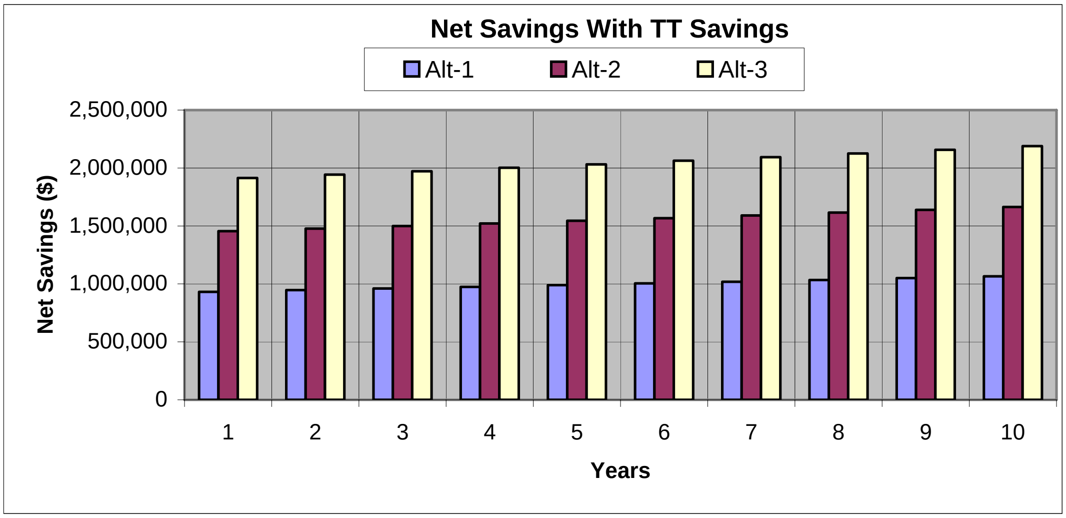


Figure 5.10: Net Savings in with travel time for all alternatives

Table 5.11: Summary of Economic and Sensitivity Analysis

Variation		Alternative -1			Alternative -2			Alternative -3		
		Only Crash Cost Savings	W/O TT Savings	W / TT Savings	Only Crash Cost Savings	W/O TT Savings	W / TT Savings	Only Crash Cost Savings	W/O TT Savings	W / TT Savings
B/C Ratio	Original Value	1.81	2.03	10.81	2.29	10.99	15.29	4.49	4.87	9.61
	Total Cost (10%)	1.65	1.85	9.83	2.08	9.15	12.72	4.08	4.43	8.74
	Total Benefit (-10%)	1.63	1.83	9.73	2.06	9.06	12.59	4.04	4.38	8.65
	Combination	1.48	1.66	8.85	1.87	8.23	11.45	3.67	3.98	7.86
IRR	Original Value	41.72%	50.18%	486.21%	45.77%	55.07%	237.21%	81.80%	89.29%	183.01%
	Total Cost (10%)	35.23%	43.09%	351.91%	40.04%	48.63%	214.07%	73.71%	80.54%	165.70%
	Total Benefit (-10%)	34.57%	42.38%	348.00%	39.46%	47.98%	211.76%	72.90%	79.66%	163.97%
	Combination	28.53%	35.85%	312.90%	34.19%	42.09%	191.00%	65.59%	71.76%	148.40%
NPV	Original Value	$41,709	$74,634	$3,015,061	$147,976	$351,119	$3,291,547	$1,503,394	$1,725,121	$4,499,110
	Total Cost (10%)	$4,259	$13,964	$2,954,392	$70,326	$273,469	$5,213,989	$1,390,914	$5,083,027	$10,051,869
	Total Benefit (-10%)	$4,090	$12,208	$2,468,381	$55,528	$180,912	$4,380,054	$1,240,574	$1,440,129	$3,936,718
	Combination	$3,570	$8,878	$2,407,712	$14,123	$103,261	$4,309,007	$1,128,094	$1,327,648	$3,824,238
TOR (Yrs)	Original Value	2-3	1-2	0-1	2-3	1-2	0-1	1-2	4-5	0-1
	Total Cost (10%)	4-5	2-3	0-1	3-4	1-2	0-1	1-2	4-5	0-1
	Total Benefit (-10%)	4-5	2-3	0-1	3-4	1-2	0-1	1-2	4-5	0-1
	Combination	5-6	3-4	1-2	4-5	2-3	1-2	2-3	4-5	0-1

Table 5.12: Incremental Analysis

Variation Type	Alternative Comparison	B/C Ratio	IRR	NPV	TOR (Years)	Decision in Favor of	Final Decision
Only Crash Savings	A-2 to A-1	5.37	99.86%	$317,261.29	1<n<2	A-2	A-3
	A-3 to A-2	12.7	135.78%	$1,463,372.18	0<n<1	A-3	
Crash and VOC Savings	A-2 to A-1	6.44	477.08%	$1,929,661.81	1<n<2	A-2	A-3
	A-3 to A-2	13.32	135.78%	$1,463,372.18	0<n<1	A-3	
Crash, VOC and TT Savings	A-2 to A-1	6.44	477.08%	$1,929,661.81	1<n<2	A-2	A-3
	A-3 to A-2	13.32	135.78%	$1,463,372.18	0<n<1	A-3	

5.2.1.3. Conclusion for Case Study-1

The MOE's are presented in Table 5.11 and 5.12. The results indicate that all the alternatives are highly cost effective. This is because the alternatives are small scale improvement where the benefits accrued are much higher than the investment. The sensitivity analysis shows that the MOE's are sensitive to changes in cost and benefit data. The Incremental analysis (Table 5.12) shows that A-3 is the best alternative and should be considered as the forerunner among the three.

5.2.2 Case Study -2

The Intersection of US24 (Telegraph Road) and King Road has been selected as the second study site. It is one of the heavily traveled stop sign controlled intersections in the Detroit Metro area. The aerial photograph is shown in Figure 5.11.

Figure 5.11: Location of the Intersection

It is a four-way stop sign controlled intersection since year 2004; it was previously equipped with just two-way stop sign. King Road has one lane in each direction and US24 has two lanes in each direction.

5.2.2.1Data Collection and Analysis

Data collection procedure involved plotting of condition diagram, traffic volume, collection of signal timing data, UD-10 screening for analyzing the predominant crash pattern.

Traffic Volume

Traffic volume counts were made for 15-minute intervals for 4 times for all approaches. The collected traffic was converted to daily traffic from the off peak period by assuming two percent of traffic volume. The peak hourly data was computed from the estimated daily traffic volume (8%) shown below.

Year	ADT					Peak Hour Volume			
	NB GR = 4%	SB GR = 4%	EB GR = 4%	WB GR = 4%	Total	NB	SB	EB	WB
2006	10487	10487	1068	5867	27909	1049	1049	107	587

Analysis of Crash Report Forms (UD-10)

A total 66 crashes including 26 injury crashes were reported during last three years (2002-2004). Therefore, this intersection ranks high when severity of crashes is taken into consideration. A collision diagram containing crashes for three years is shown in figure 5.12.

A review of the above diagram clearly shows that most crashes occurred within the intersection, or at their approach sections, with left turn head on and angle crashes being the predominant ones. Probable causes of the crashes are, higher traffic, absence of traffic signal, higher approach speeds and poor sight distance at intersection approaches. It was found that some crashes occurred at nights. Therefore, poor night visibility of stop signs at nights might be one of the causes of the accidents.

Existing Level of Service

Using traffic volume and signal timing data, the current Level of Service was determined as “F” using Highway Capacity Software. Each approach LOS is shown in Table 5.13.

Table 5.13: Existing LOS at US24 and King Road

	NB	SB	WB	EB
Approach Delay in sec/veh	145.73	157.3	131.8	15.12
LOS	F	F	F	F

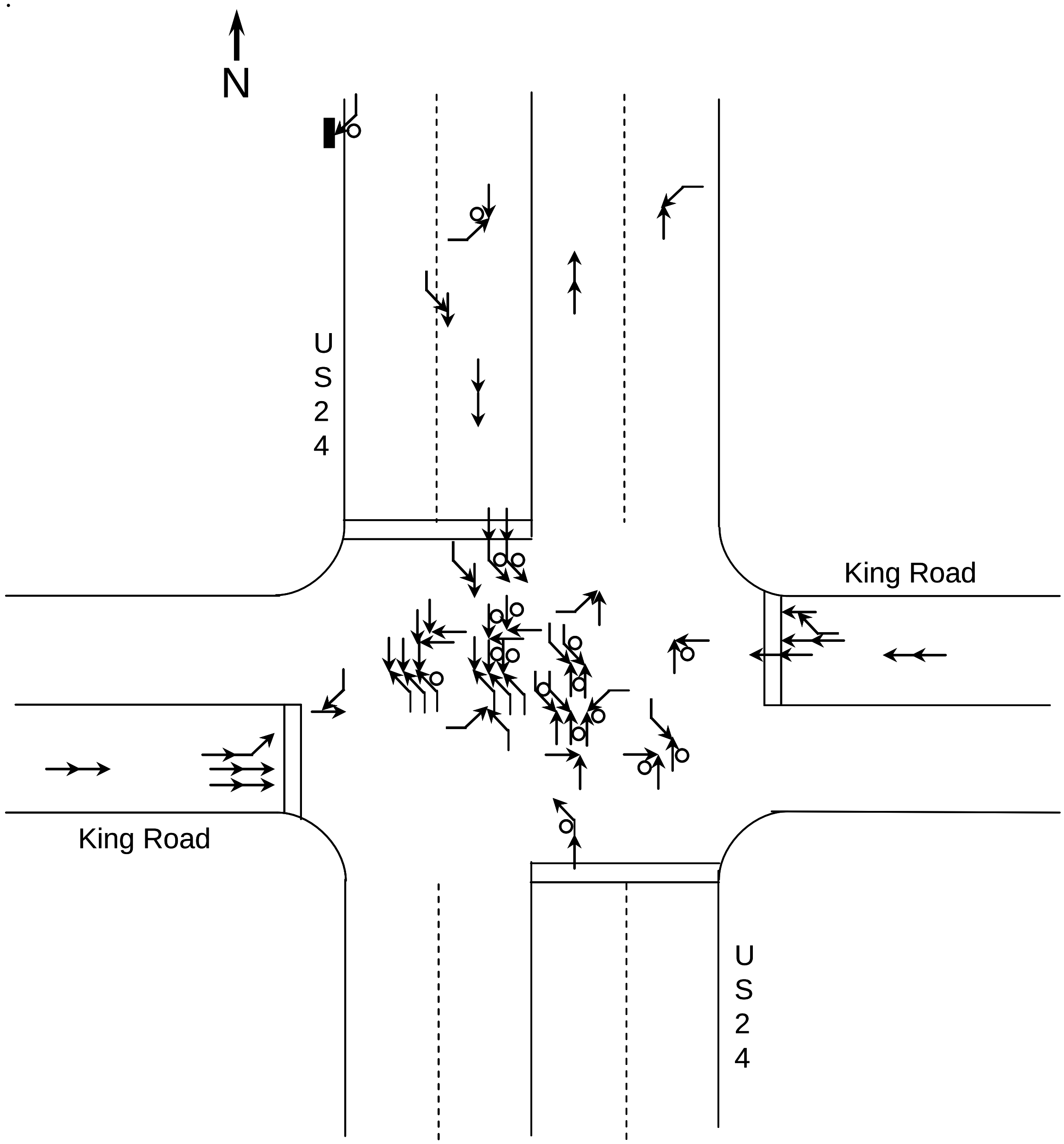


Figure 5.12: Collision Diagram of US24 and King Road

Probable Causes and Suggested Countermeasures

A set of probable causes of the crashes, based upon review of the UD-10 reports and site visits along with the suggested countermeasures are presented in Table 5.14

Table 5.14: Probable Causes and Proposed Countermeasures

Probable Causes	**Suggested Countermeasures**
1. No Advance Intersection Ahead Sign 2.Insufficient light at the intersection causes night time crashes 3. Heavy Traffic on Both Streets 4. Stop Sign Causes Confusion for the higher volume intersection 5. Pavement Markings	1.Install Advance Intersection Ahead Sign 2. Provide Sufficient Intersection Lighting 3. Add Lane on King Road to counter left turning vehicles 4. Convert Stop Sign Intersection to Signalized one 6.Provide Proper Pavement markings

5.2.2.2.Proposed Alternatives and Analysis

Three alternatives are proposed to address the safety hazards and presented in Table 5.31. Results of the analysis are presented in Table 5.15 to 5.25 and Figure 5.13 to 5.18.

Table 5.15: Proposed Alternatives

Improvement Alternatives	Type of Alternatives	CRF
Alternative -1	1. Install high retro reflectivity stop sings 2. Install advance intersection signs 3. Improve intersection lighting	CRF1= 10% CRF2 = 10 CRF2=30 % Combined CRF = 40.5%
Alternative – 2	1. Install box span wire traffic signal 2. Add asphalt left turn lane on US24 and restripe 3 lanes from 2 lanes on King Road with minor construction 3. Speed limit enforcement (reduce speed limit)	CRF1= 15% CRF2=20% CRF3=20% Combined CRF = 49%
Alternative -3	1. Install box span wire traffic signal 2. Add RCC left turn lane on US24 and re stripe 3 lanes from 2 lanes on King Road with minor construction 3. Improve intersection lighting	CRF1= 15% CRF2=25% CRF3=30% Combined CRF = 55%

Table 5.16: Savings in Crash Cost due to Improvement Alternative-I for the First Year

Inputs	Severity of Crash		
	Injury	PDO	Total
Crashes before improvements (2002-2004)	26	40	66
Expected after crashes without improvements (2007),(Annual)	9.4	14.4	23.8
CRF for combined improvements (%)	40.5	40.5	40.5
Estimated reduction in number of crashes	3.8	5.8	9.6
Expected crashes After improvement	5.6	8.6	14.2
Significance	No @ 95% LOC	Yes @ 95% LOC	Yes @ 95% LOC
Savings in cost due to improvement(s) ($/year)	**173,219**	**47,822**	**221,041**

Table 5.17: Savings in Crash Cost due to Improvement Alternative-II for the First Year

Inputs	Severity of Crash		
	Injury	PDO	Total
Crashes before improvement (2002-2004)	26	40	66
Expected after Crashes without improvement (2007),(Annual)	9.4	14.4	23.8
CRF for combined improvements (%)	49.0	49.0	49.0
Estimated reduction in number of crashes	4.6	7.1	11.7
Expected crashes after improvement	4.8	7.3	12.1
Significance	No @ 95% LOC	Yes @ 95% LOC	Yes @ 95% LOC
Savings in crash cost due to improvement(s) ($/year)	**209,573**	**57,859**	**267,432**

Table 5.18: Savings in Crash Cost due to Improvement Alternative-III for the First Year

Inputs	Severity of Crash		
	Injury	PDO	Total
Crashes before improvement (2002-2004)	26	40	66
Expected after crashes without improvement (2007),(Annual)	9.4	14.4	23.8
CRF for combined improvements	55.0	55.0	55.0
Estimated reduction in number of crashes	5.2	7.9	13.1
Expected crashes after improvement	4.2	6.5	10.7
Significance	Yes @ 95% LOC	Yes @ 95% LOC	Yes @ 95% LOC
Savings in crash cost due to improvement(s) ($/year)	**235,235**	**64,944**	**300,179**

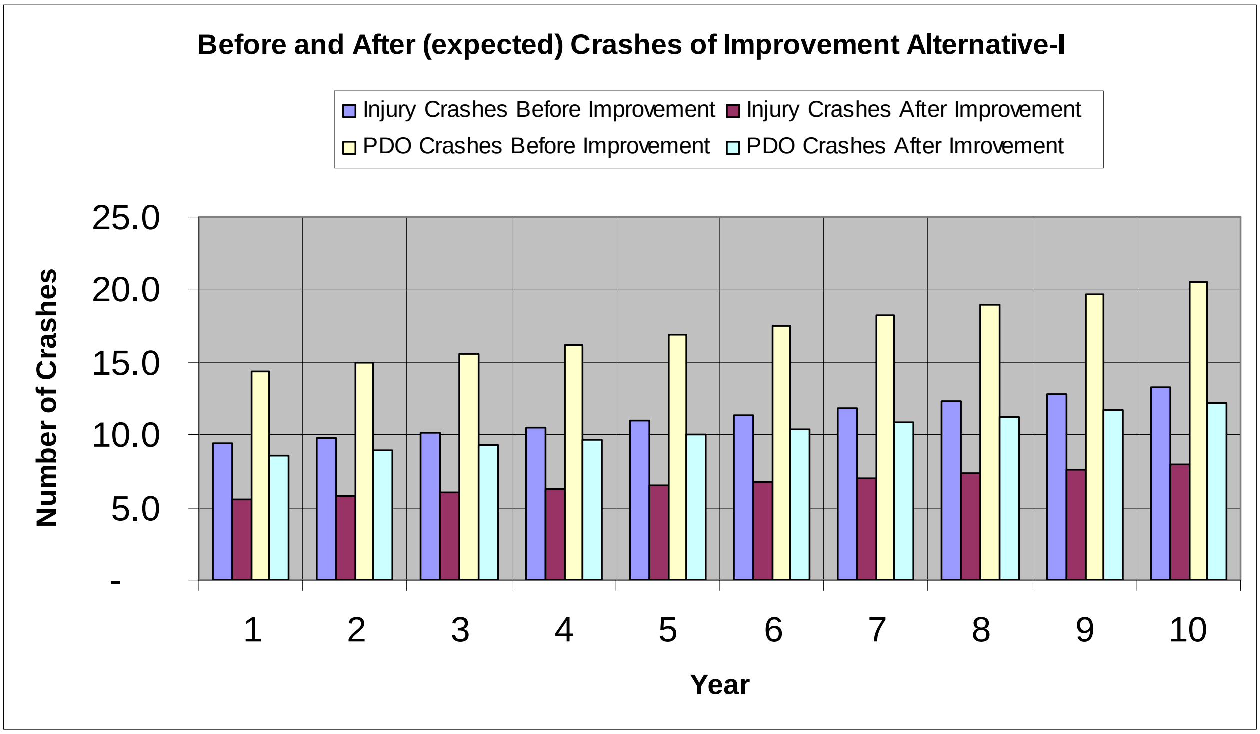


Figure 5.13: Comparison of Before and After Crashes due to Improvement Alternative-I

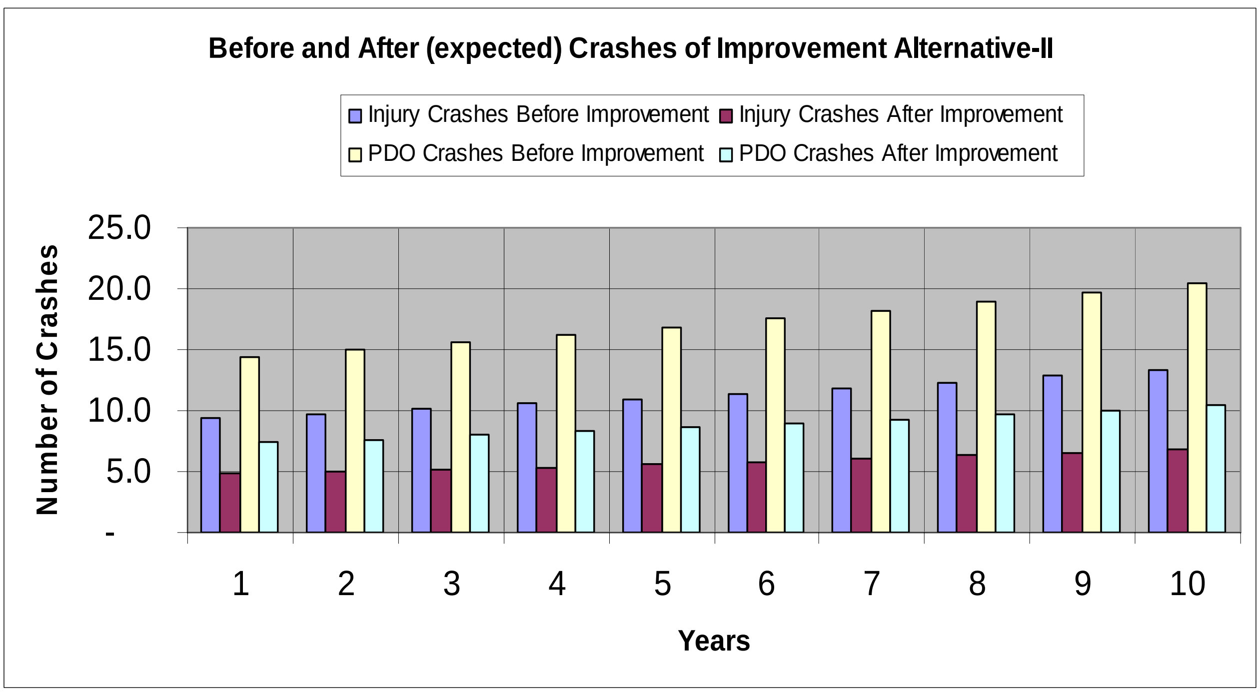


Figure 5.14: Comparison of Before and After Crashes due to Improvement Alternative-II

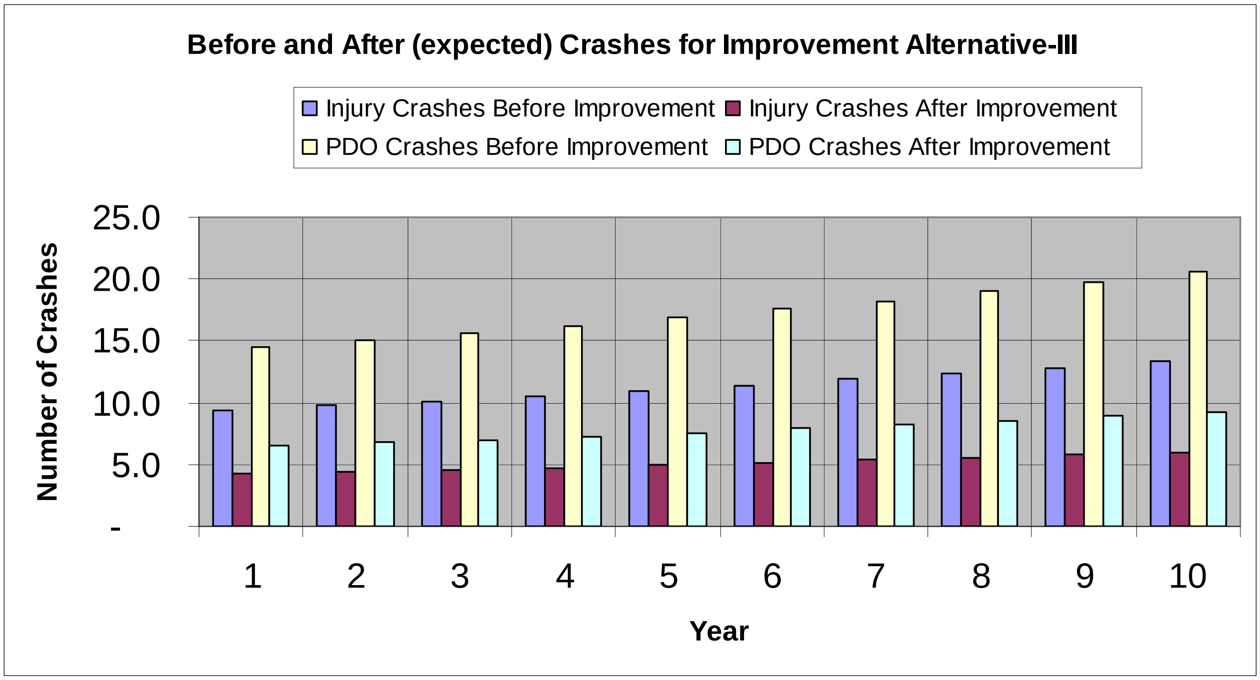


Figure 5.15: Comparison of Before and After Crashes due to Improvement Alternative-III

Table 5.19: Cost Components for all Alternatives

Cost Component	Alternative-1	Alternative-2	Alternative-3
Planning and Design Cost	$10,000	$25,000	$30,000
Retro-reflectivity STOP Sign Cost	$800		
Lighting Improvement Cost	$20,000		$20,000
Intersection Warning Sign Cost	$2,000		
ROW Acquisition		$600,000	$600,000
Construction Cost		$150,000	$200,000
Traffic Signal		$80,000	$80,000
Speed Limit Enforcement		$2,000	

Table 5.20: Savings in Travel Time due to Improvement Alternative-II and III for the First Year

Direction of Travel	Peak Hour Traffic in veh/hr	Delay Before Improvement in sec/veh	Delay After Improvement in sec/veh	Change in Delay in hr/veh	Change in Vehicle Travel Time in veh-hrs	Change in Passenger Time in person-hrs	Dollars Amount Saved in $/year
NB	1092	145.73	25	0.0335	19,043	22,852	**182,814**
SB	1092	157.3	21.5	0.0377	21,420	25,704	**205,634**
EB	111	16.01	18.9	-0.0008	-46	-56	**-445**
WB	611	131.81	34.1	0.0271	8,623	10,348	**82,785**

Table 5.21: Savings in VOC due to Improvement Alternative-II and III for the First Year

Direction of Travel	Peak Hour Traffic in veh/hr	Delay Before Improvement in sec/veh	Delay After Improvement in sec/veh	Change in Delay in hr/veh	Cost of Delay in terms of Fuel gal/hr of delay	Savings in Fuel Consumption gallons	Cost of Fuel in $/gal	Dollar Saved in $/year
NB	1092	145.73	25	0.0335	0.5	9522	2.25	**21,424**
SB	1092	157.3	21.5	0.0377	0.5	10710	2.25	**24,098**
EB	111	16.01	18.9	-0.0008	0.5	-23	2.25	**-52**
WB	611	131.81	34.1	0.0271	0.5	4312	2.25	**9701**

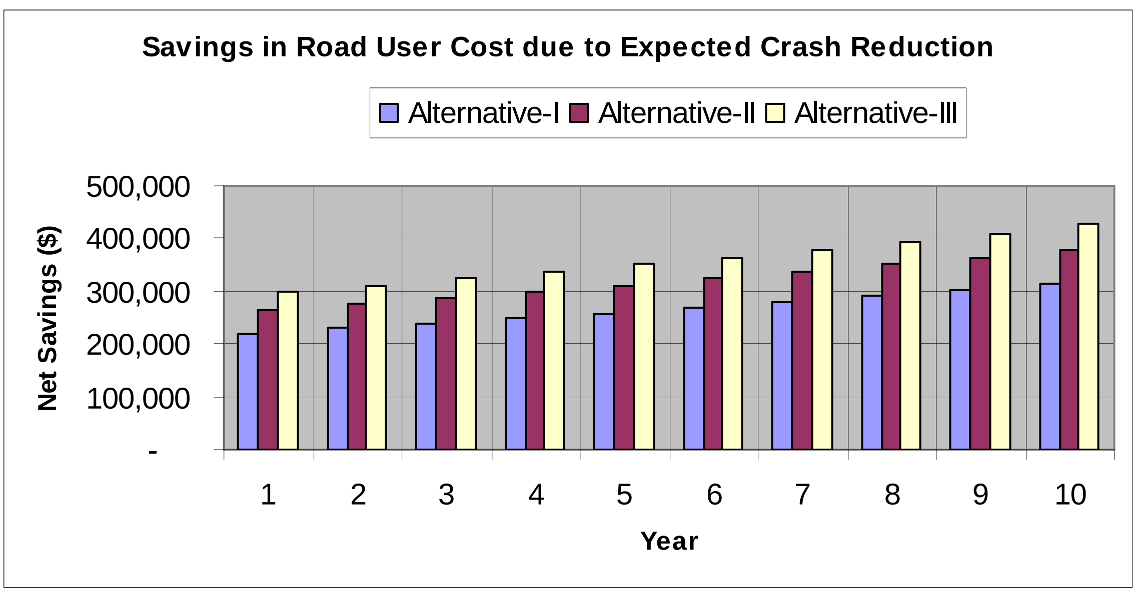


Figure 5.16: Savings in Road User Cost due to Crash Reduction for the Service Life

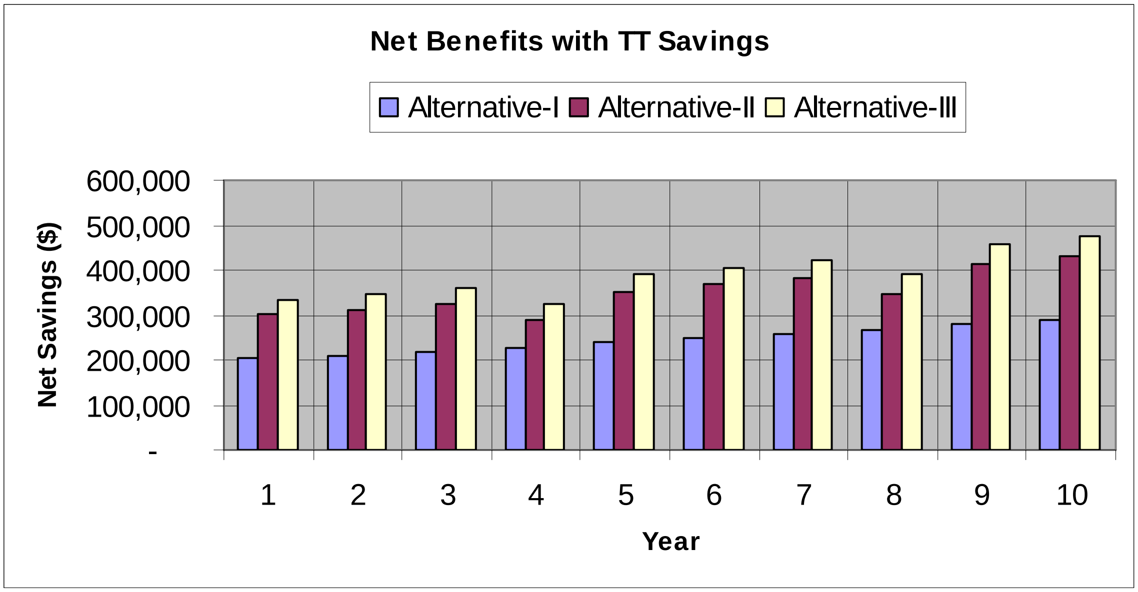


Figure 5.17: Net Benefits including TT Savings due to Improvements

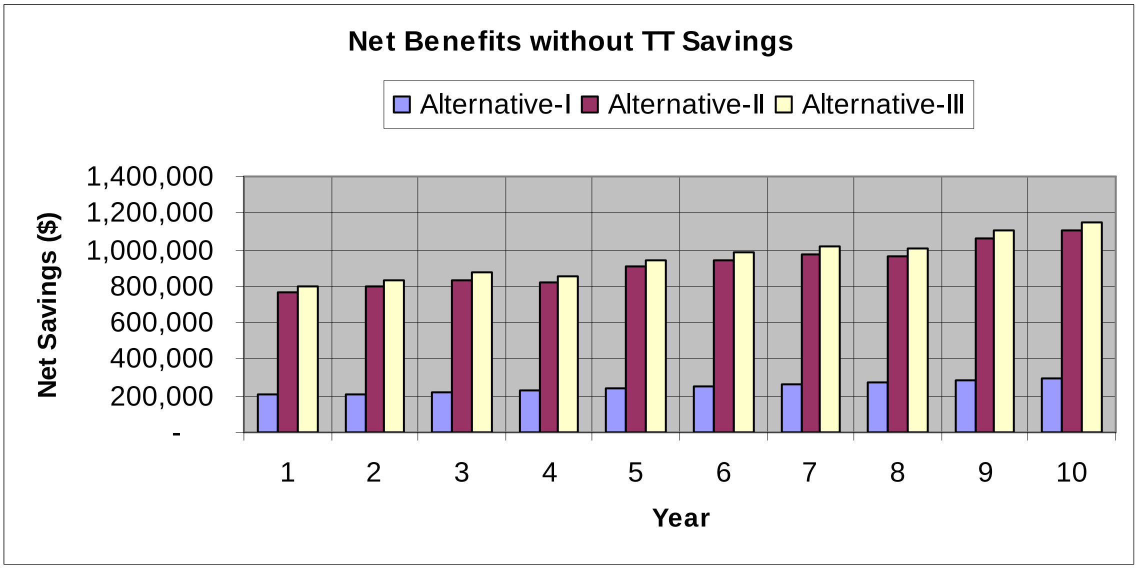


Figure 5.18: Net Benefits excluding TT Savings due to Improvements

Table 5.22: Summary of Economic and Sensitivity Analysis

Variation		Alternative -2			Alternative -3		
		Only Crash Cost Savings	Crash Cost and VOC Savings	Crash Cost, VOC and TT Savings	Only Crash Cost Savings	Crash Cost and VOC Savings	Crash Cost, VOC and TT Savings
B/C Ratio	Original Value	1.89	2.29	5.63	1.94	5.34	2.29
	Total Cost (10%)	1.72	2.08	5.12	1.83	2.17	5.04
	Total Benefit (-10%)	1.7	2.06	5.06	1.81	2.14	4.99
	Combination	1.55	1.87	4.6	1.65	1.95	4.54
IRR	Original Value	23.87%	30.62%	81.12%	25.77%	31.99%	79.20%
	Total Cost (10%)	20.74%	27.09%	73.71%	22.55%	28.39%	71.96%
	Total Benefit (-10%)	20.42%	26.73%	72.96%	22.22%	28.03%	71.24%
	Combination	17.47%	23.44%	66.24%	19.20%	24.68%	64.67%
NPV	Original Value	$1,010,848	$1,462,358	$5,315,244			
	Total Cost (10%)	$893,550	$1,345,060	$5,197,946	$1,088,453	$1,539,963	$5,392,849
	Total Benefit (-10%)	$792,465	$1,198,824	$4,666,422	$967,219	$1,373,578	$4,841,175
	Combination	$675,168	$1,081,527	$4,549,124	$843,330	$1,249,689	$4,717,286
TOR (Yrs)	Original Value	4-5	3-4	1-2	3-4	3-4	1-2
	Total Cost (10%)	5-6	1-2	2-3	3-4	1-2	3-4
	Total Benefit (-10%)	5-6	1-2	2-3	3-4	1-2	3-4
	Combination	5-6	1-2	3-4	4-5	1-2	4-5

Table 5.23 Incremental Analysis

Variation Type	Alternative Comparison	Inc. B/ Inc. C	IRR	NPV	TOR (Years)	Decision in Favor of	Final Decision
Only Crash Savings	A-2 to A-1	0.74	-12.35%	-($621,943.71)	n>10	A-1	A-3
	A-3 to A-1	1.18	7.00%	$1,463,372	0<n<1	A-3	
Crash and VOC Savings	A-2 to A-1	3.51	33.93%	$1,634,563.91	3<n<4	A-2	A-3
	A-3 to A-2	3.63	50.78%	$201,494.28	2<n<3	A-3	
Crash, VOC and TT Savings	A-2 to A-1	8.65	85.70%	$5,487,449.72	1<n<2	A-2	A-3
	A-3 to A-2	8.46	50.78%	$201,494.28	2<n<3	A-3	

5.2.2.3 Conclusion for Case Study-2

The MOE's are presented in Table 5.22 and 5.23. The results indicate that all the alternatives are highly cost effective. This is because the alternatives are small scale improvement where the benefits accrued are much highr than the investment. The sensitivity analysis shows that the MOE's are sensitive to changes in cost and benefit data. The Incremental analysis (Table 5.23) shows that A-3 is the best alternative and should be considered as the forerunner among the three.

5.2.3 Case Study 3

The third study site is the intersection at M-3 Gratiot and Conner Street, located in Macomb County with an ADT of more than 60,000 vehicles per day using this intersection. .Some of the operating features of the intersection are:

1. The north bound and south bound is 4 lanes with one exclusive lane for each left and right turn.
2. The east bound and west bound is 3 lanes with one exclusive lane left turn lane.
3. Speed Limit is 45 mph and 30 mph for Gratiot and Conner respectively

The aerial picture of the intersection is shown in Figure 5.19. Figure 5.20 and 5.21 show some of the pictures of the intersection during the time of data collection.

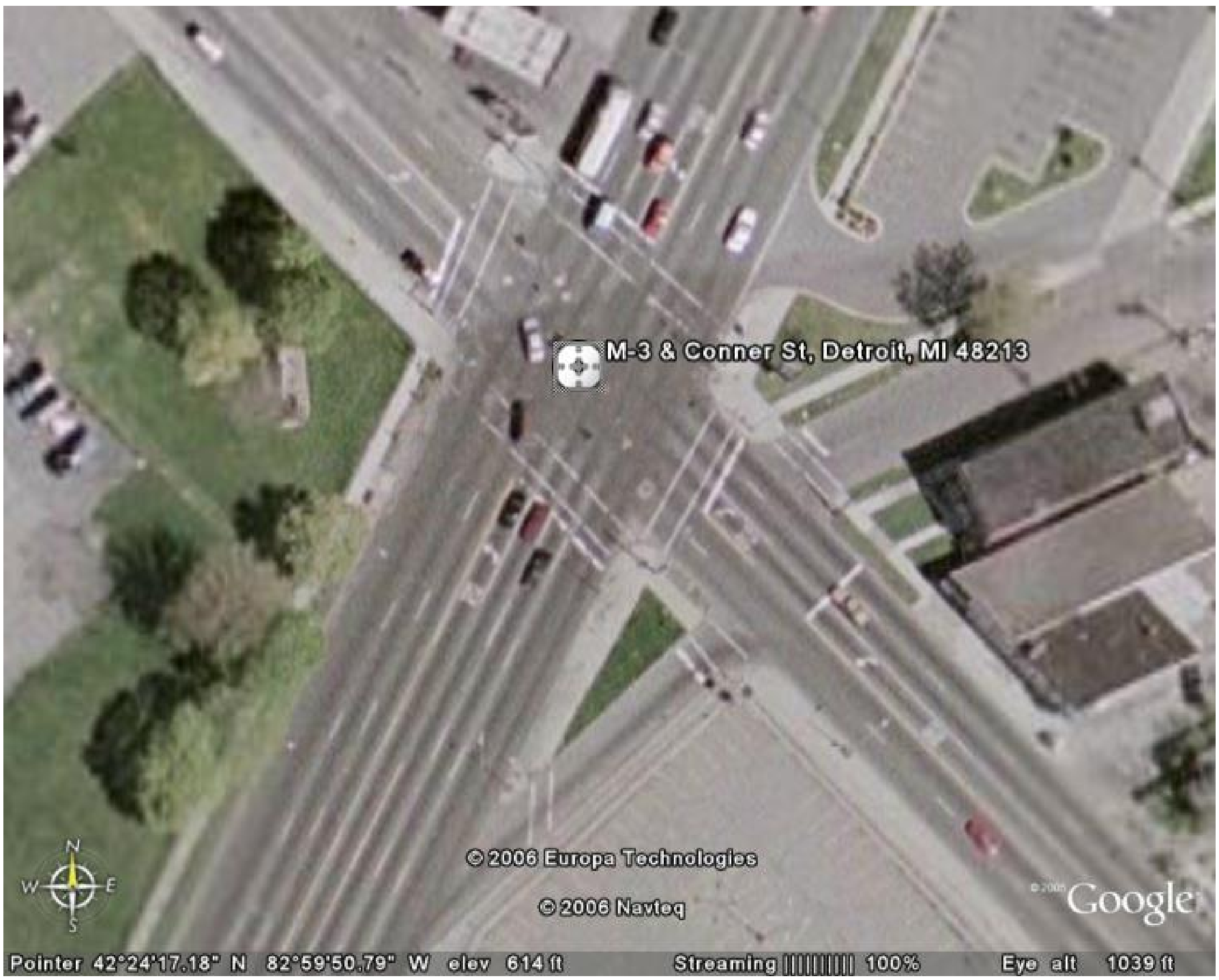


Figure 5.19: Aerial View of the Intersection

Figure 5.20: Photograph of Study Area-1

Figure 5.21: Photograph of Study Area-2

5.2.3.1 Data Collection and Analysis

Data collection procedure involved plotting of condition diagram, traffic volume, collection of signal timing data, UD-10 screening for analyzing the predominant crash pattern.

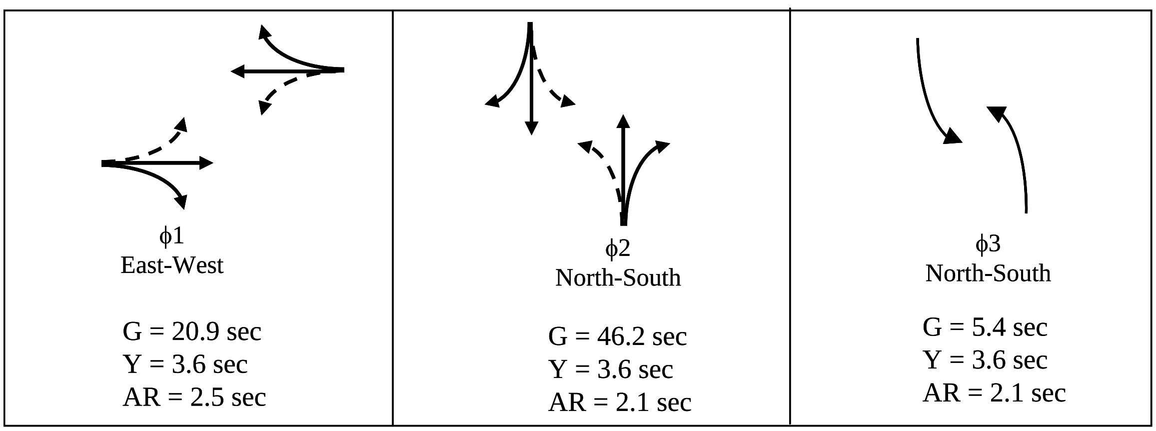
Traffic Volume

Traffic volume counts were made for 15-minute intervals for 4 times for all approaches. The collected traffic was converted to daily traffic from the off peak period by assuming two percent of traffic volume. The peak hourly data was computed from the estimated daily traffic volume (8%) shown below.

Northbound			Southbound			Eastbound			Westbound		
LT	**TH**	**RT**	**LT**	**TH**	**RT**	**LT**	**TH**	**RT**	**LT**	**TH**	**RT**
296	2164	40	188	1334	28	92	400	304	80	504	24

Signal Timing

Signal timing data were collected with a stopwatch and are shown below.



UD-10 Analysis

A total 221 crashes including 43 injury crashes were reported during last three years (2002-2004).Salient features from the collision diagram report (Figure 5.21-A) and actual UD-10 observations are;

1. Predominant crash patterns: Rear end on M-3 Gratiot and Angle crashes for a lot of driveway activities.
2. Traffic increases as Promenade Street also joins just twenty feet away from the intersection
3. Rear end crashes due to poor visibility of the signals and high v/c ratio
4. More angle crashes resulting from vehicles on M-3 Gratiot having to cover long distance to cross the intersection and less all red interval .

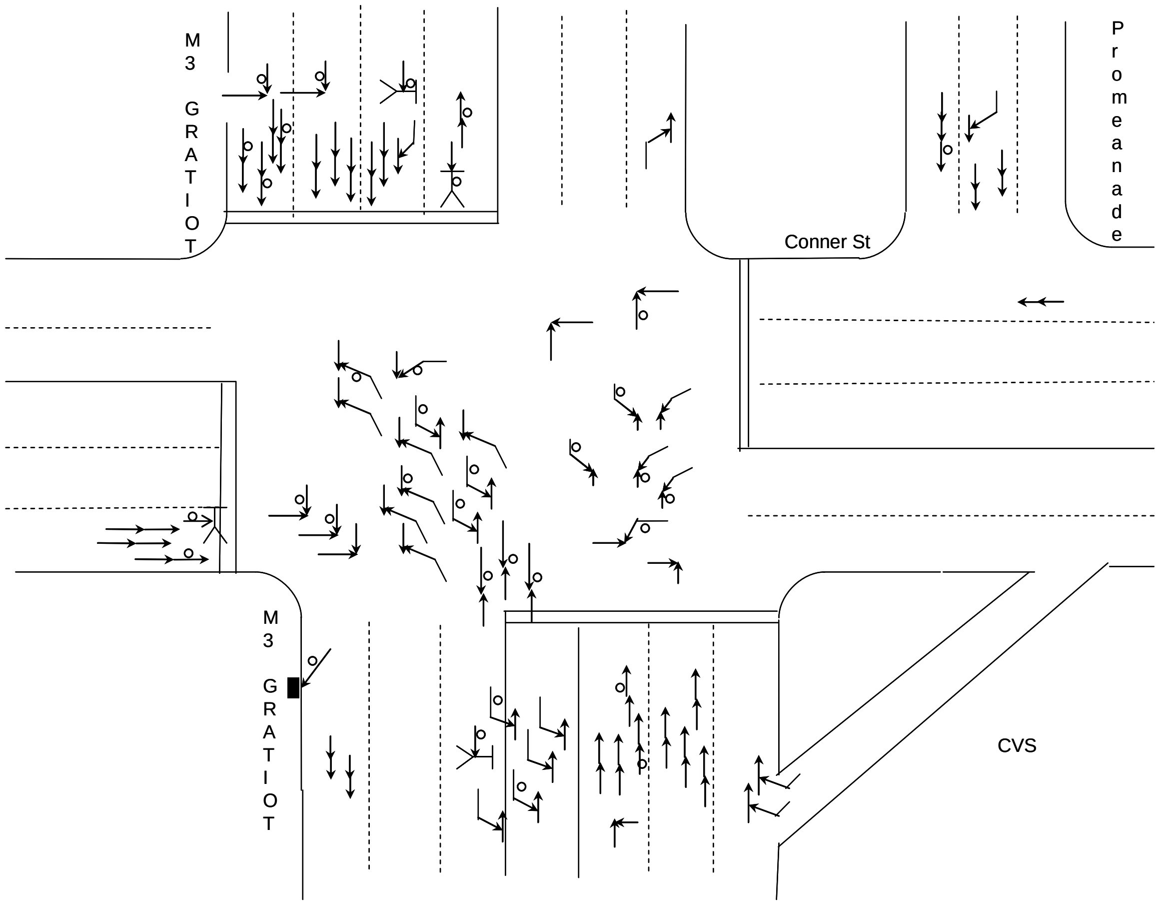


Fig 5.21-A: Collision Diagram

Existing Level of Service

Using traffic volume and signal timing data, the current Level of Service was determined as "D" using Highway Capacity Software. Each approach LOS is shown in Table 5.24.

Table 5.24: Existing LOS at M-3 Gratiot and Conner St.

	EB	WB	NB	SB
Delay (sec)	64.2	50.8	35	24.5
LOS	E	D	C	C
Intersection LOS	D			

Probable Causes and Suggested Countermeasures

A set of probable causes of the crashes, based upon review of the UD-10 reports and site visits along with the suggested countermeasures are presented in Table 5.25.

Table 5.25: Probable Causes and Suggested Countermeasures

Probable Causes	**Suggested Countermeasures**
1. No LT phasing on Conner Ave 2. Poor Progression on Gratiot 3. Higher RT volume on Conner without exclusive RT lane 4. Intersection Geometry problems due to parking lot and Promenade Street 5. Poor pavement condition and pavement markings 6. Permissive LT phase for Conner	1. Separate Phase and heads for EW Left Turn 2. Separate Right Turn Lane for EW movement 3. Attain Progression 4. Installation of Roundabout 5.Roadway Signs 6.pavement markings

5.2.3.2 Proposed Improvements and Analysis

Three alternatives are proposed to address the safety hazards and presented in Table 5.31. Results of the analysis are presented in Table 5.26 to 5.38 and Figure 5.22 to 5.27.

Table 5.26: Proposed Alternatives for Case Study-3

Improvement Alternatives	Type of Alternatives	CRF
Alternative -1	3. Pavement markings, resurfacing, with periodic operation and maintenance 4. Proper Signs for Improving Road User Awareness 5. Change in signal time to improve the LOS and reduction of angle crashes.	CRF1= 20% CRF2=15% CRF3=8% Combined CRF =37.44%
Alternative – 2	1.Separate Phase and heads for EW Left Turn 2. Separate Right Turn Lane for EW movement 3. Attain Progression 4. Pavement Marking 5. Proper Signs for Improving Road User Awareness	CRF1= 25% CRF2=20% CRF3=12.5% CRF4=15% CRF5=20% Combined CRF =64.3%
Alternative -3	1. Installation of Roundabouts including with periodic operation and maintenance	CRF = 80% (Injury) CRF = 60% (PDO)

Table 5.27: Summary of Poisson test Results for Alternative-1 for the First Year

Inputs	Severity Level of Crash		
	Injury	PDO	Total
Crashes Before improvements (3 years)	41	161	202
Crashes without improvements - 2007,(Annual)	15.4	60.4	75.7
CRF for combined improvements	37.4	37.4	37.4
Estimated reduction in number of crashes	5.8	22.6	28.4
Crashes After improvement	9.6	37.8	47.4
Significance	No @ 95% LOC	Yes @ 95% LOC	Yes @ 95% LOC
Savings in cost due to improvements ($/year)	**286,058**	**167,252**	**453,311**

Table 5.28: Summary of Poisson test Results for Alternative-2 for the First Year

Inputs	Severity Level of Crash		
	Injury	PDO	Total
Crashes Before improvements (3 years)	41	161	66
Crashes without improvements (1 year)-2007	15.4	60.4	75.7
CRF for combined improvements	64.30	64.30	64.30
Estimated reduction in number of crashes	9.9	38.8	48.7
Crashes After improvement	5.5	21.6	27.0
Significance	Yes @ 95% LOC	Yes @ 95% LOC	Yes @ 995 LOC
Savings in cost due to improvements ($/year)	**491,281**	**287,242**	**778,523**

Table5.29: Summary of Poisson test Results for Alternative-3 for the First Year

Inputs	Severity Level of Crash		
	Injury	PDO	Total
Crashes Before improvements (3 years)	41	161	66
Crashes without improvements - 2007,(Annual)	15.4	60.4	75.7
CRF for combined improvements	80.00	60.00	40.00
Estimated reduction in number of crashes	12.3	36.2	30.3
Crashes After improvement	3.1	24.1	45.4
Significance	Yes @ 95% LOC	Yes @ 95% LOC	Yes @ 95% LOC
Savings in cost due to improvements ($/year)	**611,236**	**268,033**	**879,269**

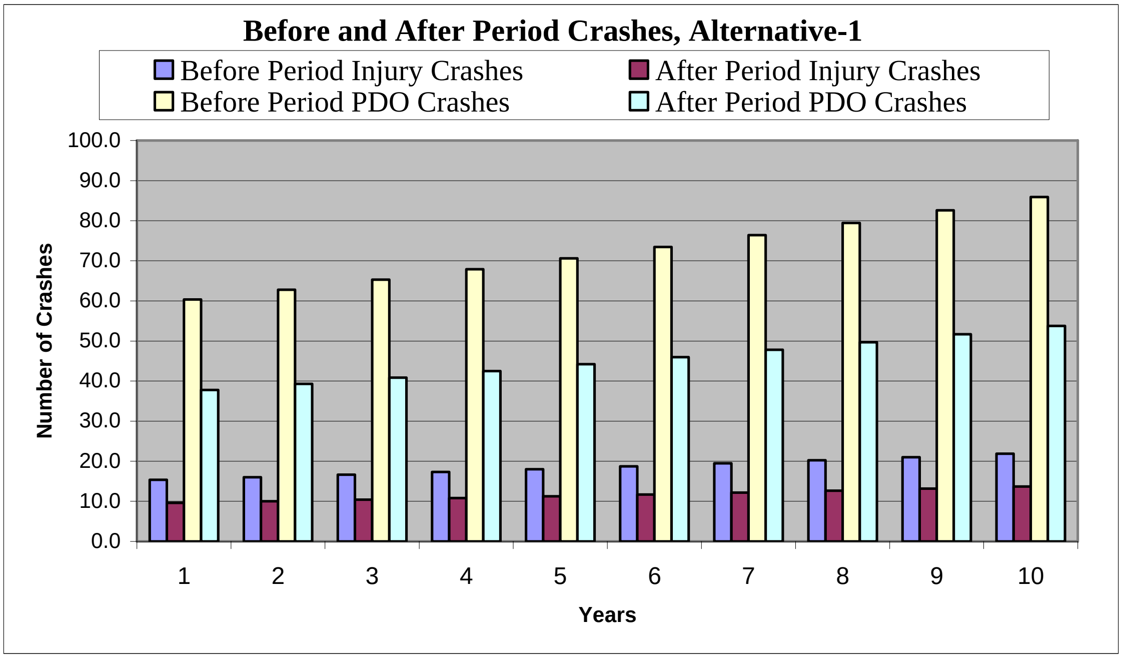


Fig 5.22: Before and After Period Crashes for Alternative-1

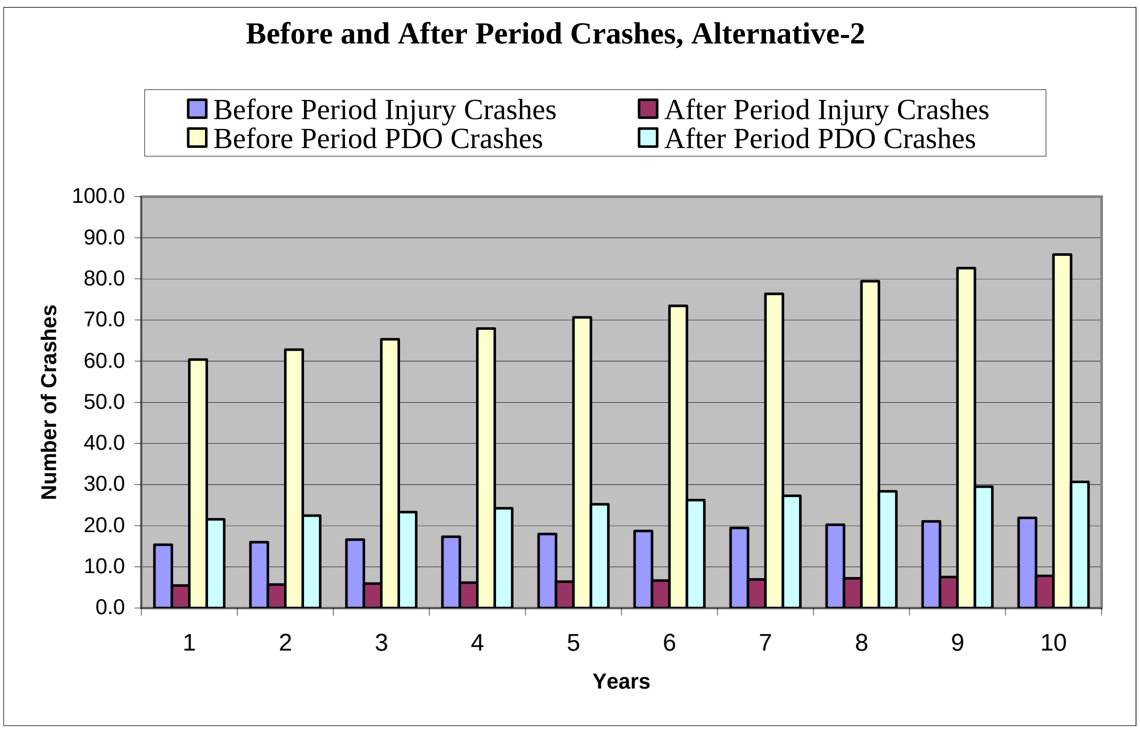


Fig 5.23: Before and After Period Crashes for Alternative-2

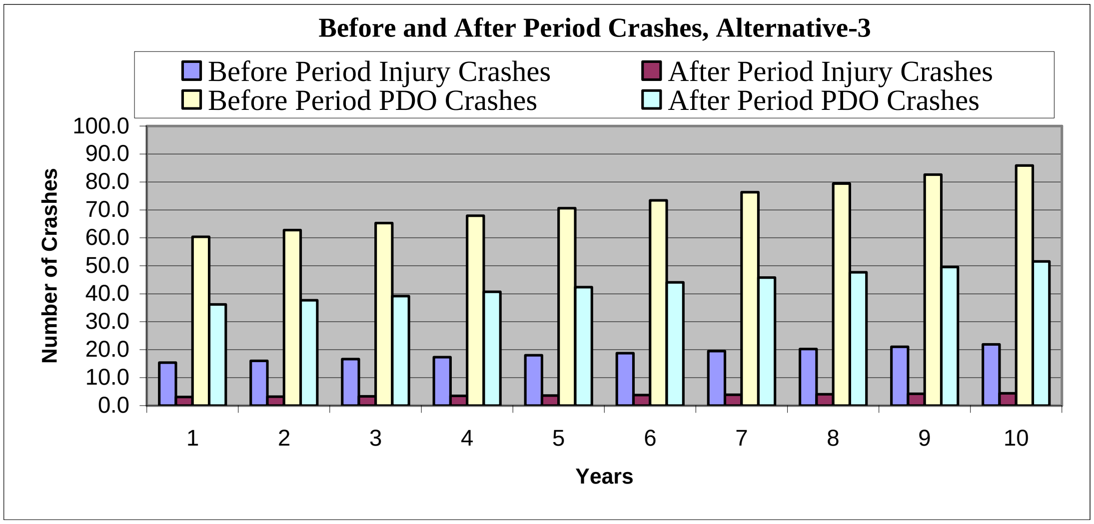


Fig 5.24: Before and After Period Crashes for Alternative-3

Table 5.30: Cost Components for all Alternatives

Cost Component	Alternative-1	Alternative-2	Alternative-3
Initial Planning Cost	$100,000	$80,000	$130,000
Pavement Markings	$20,000		
Proper Signs	$20,000		
Phasing and Signal Timing Improvement Cost	$1,500		
Regular Operation and Maintenance Cost	$15,000	$15,000	$15,000
Periodic Operation and Maintenance Cost	$75,000	$75,000	$75,000
Pavement Marking Cost		$20,000	
Addition of Lane		$400,000	
Signal Head for Left Turn		$1,000	
Progression, Phasing and Signal Timing Improvement Cost		$30,000	
Delay Cost During Construction		$3,154	$12,195
Estimated Project Development Cost			$130,000
Estimated Construction Cost			$500,000
Advance Intersection Signs and Markings			$20,000
Phasing and Signal Timing Improvement Cost			$1,500

Table 5.31: Savings in Travel Time due to Improvement Alternative-1 for the First Year

Direction of Travel	Peak Hour Traffic in veh/hr	Delay Before Improvement in sec/veh	Delay After Improvement in sec/veh	Change in Delay in hr/veh	Change in Vehicle Travel Time in veh-hrs	Change in Passenger Time in person-hrs	Dollars Amount Saved in $/year
NB	2500	35	33.1	0.000528	686	823	**6,587**
SB	1524	24.5	23.2	0.000361	286	343	**2,747**
EB	796	64.2	41.6	0.006278	2,598	3,118	**24,946**
WB	608	50.8	39.2	0.003222	1,019	1,222	**9,780**

Table 5.32: Savings in Travel Time due to Improvement Alternative-2 for the First Year

Direction of Travel	Peak Hour Traffic in veh/hr	Delay Before Improvement in sec/veh	Delay After Improvement in sec/veh	Change in Delay in hr/veh	Change in Vehicle Travel Time in veh-hrs	Change in Passenger Time in person-hrs	Dollars Amount Saved in $/year
NB	2500	35	26.5	0.002361	3,069	3,683	**29,467**
SB	1524	24.5	19.8	0.001306	1,035	1,242	**9,932**
EB	796	64.2	45.7	0.005139	2,127	2,553	**20,420**
WB	608	50.8	32.1	0.005194	1,642	1,971	**15,766**

Table 5.33: Savings in Travel Time due to Improvement Alternative-3 for the First Year

Direction of Travel	Peak Hour Traffic in veh/hr	Delay Before Improvement in sec/veh	Delay After Improvement in sec/veh	Change in Delay in hr/veh	Change in Vehicle Travel Time in veh-hrs	Change in Passenger Time in person-hrs	Dollars Amount Saved in $/year
NB	2500	35	13	0.006111	7,944	9,533	**76,267**
SB	1524	24.5	7.8	0.004639	3,676	4,411	**35,292**
EB	796	64.2	43.9	0.005639	2,334	2,801	**22,407**
WB	608	50.8	8.3	0.011806	3,732	4,479	**35,831**

Table 5.34: Savings in VOC due to Improvement Alternative-1 for the First Year

Direction of Travel	Peak Hour Traffic in veh/hr	Delay Before Improvement in sec/veh	Delay After Improvement in sec/veh	Change in Delay in hr/veh	Cost of Delay in terms of Fuel gal/hr of delay	Savings in Fuel Consumption gallons	Cost of Fuel in $/gal	Dollar Saved in $/year
NB	2500	35	33.1	0.000528	0.5	343.0556	2.25	**772**
SB	1524	24.5	23.2	0.000361	0.5	143.0867	2.25	**322**
EB	796	64.2	41.6	0.006278	0.5	1299.249	2.25	**2,923**
WB	608	50.8	39.2	0.003222	0.5	509.3689	2.25	**1,146**

Table 5.35: Savings in Fuel Consumption due to Improvement Alternative-2 for the First Year

Direction of Travel	Peak Hour Traffic in veh/hr	Delay Before Improvement in sec/veh	Delay After Improvement in sec/veh	Change in Delay in hr/veh	Cost of Delay in terms of Fuel gal/hr of delay	Savings in Fuel Consumption gallons	Cost of Fuel in $/gal	Dollar Saved in $/year
NB	2500	35	26.5	0.002361	0.5	1534.722	2.25	**3,453**
SB	1524	24.5	19.8	0.001306	0.5	517.3133	2.25	**1,164**
EB	796	64.2	45.7	0.005139	0.5	1063.544	2.25	**2,393**
WB	608	50.8	32.1	0.005194	0.5	821.1378	2.25	**1,848**

Table 5.36: Savings in Fuel Consumption due to Improvement Alternative-3 for the First Year

Direction of Travel	Peak Hour Traffic in veh/hr	Delay Before Improvement in sec/veh	Delay After Improvement in sec/veh	Change in Delay in hr/veh	Cost of Delay in terms of Fuel gal/hr of delay	Savings in Fuel Consumption gallons	Cost of Fuel in $/gal	Dollar Saved in $/year
NB	2500	35	13	0.006111	0.5	3972.222	2.25	**8,938**
SB	1524	24.5	7.8	0.004639	0.5	1838.113	2.25	**4,136**
EB	796	64.2	43.9	0.005639	0.5	1167.024	2.25	**2,626**
WB	608	50.8	8.3	0.011806	0.5	1866.222	2.25	**4,199**

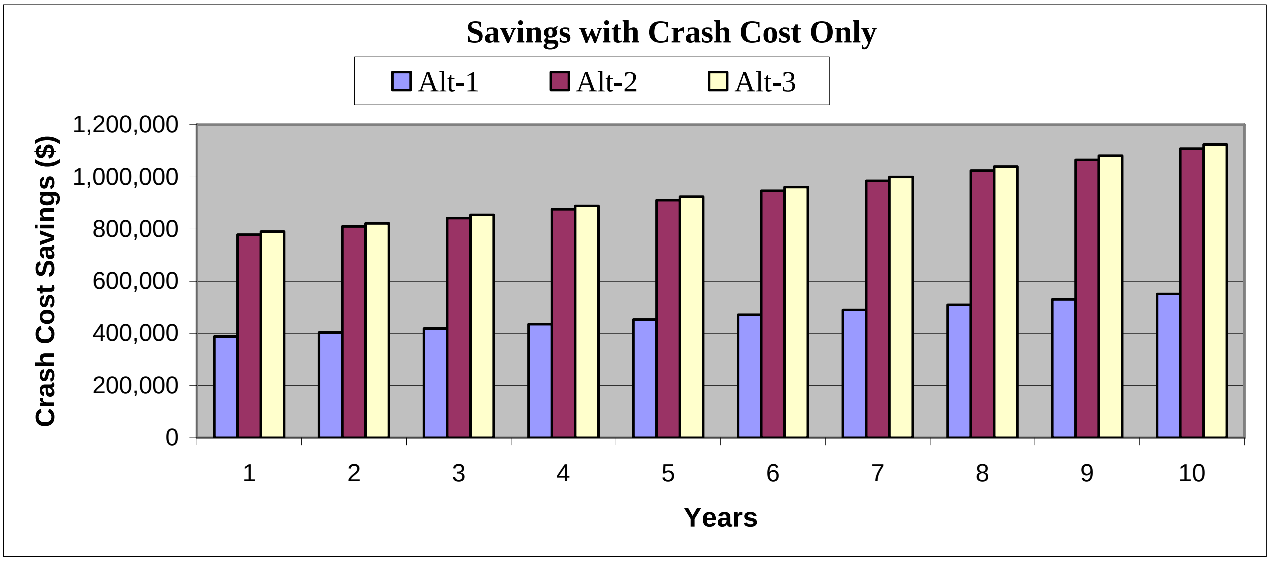


Fig 5.25: Savings with Crash Cost Only

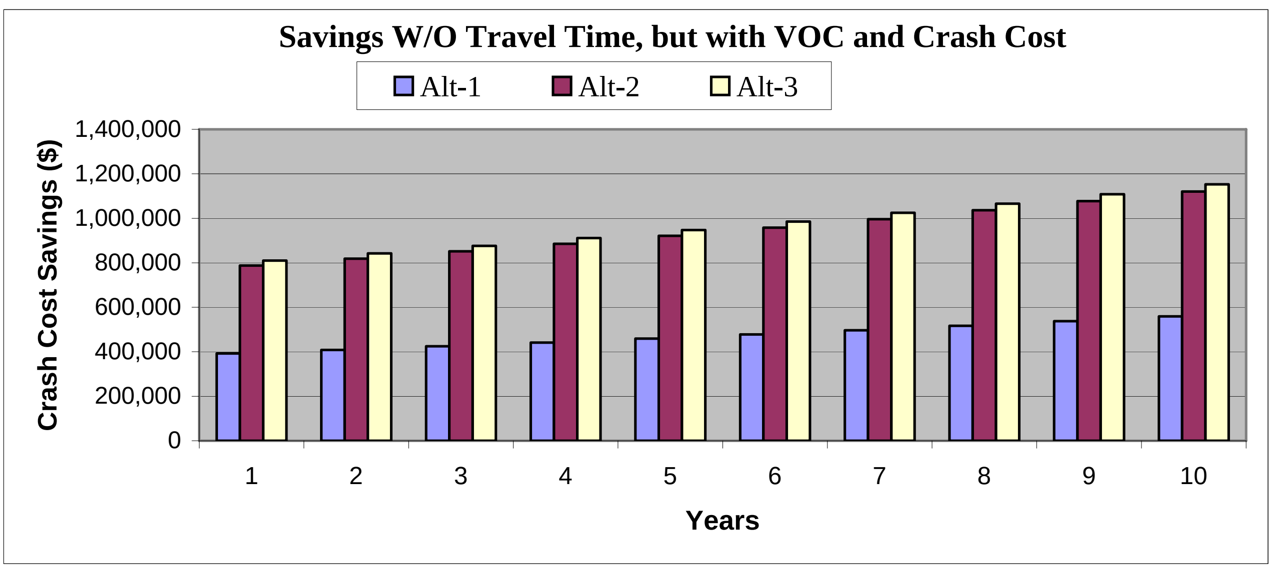


Fig 5.26: Savings with Crash Cost and Vehicle Operating Cost

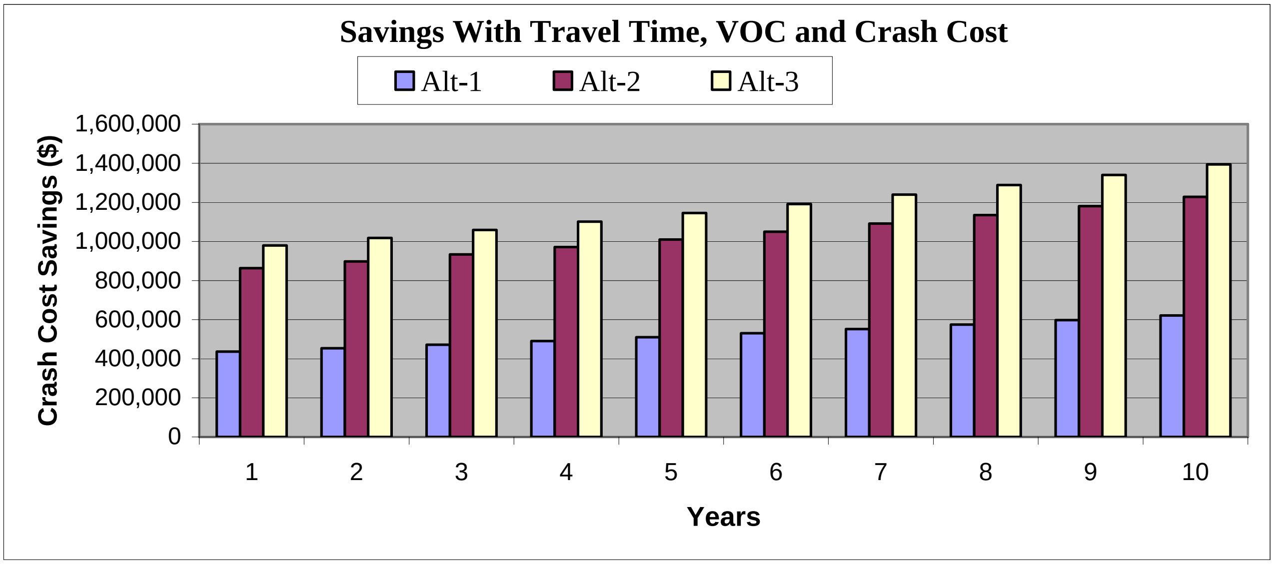


Fig 5.27: Savings with Crash Cost, Vehicle Operating Cost and Travel Time

Table 5.37: Summary of Economic and Sensitivity Analysis Results

Variation		Alternative -1			Alternative -2			Alternative -3		
		Only Crash Cost Savings	Crash and VOC Savings	Crash, VOC and TT Savings	Only Crash Cost Savings	Crash and VOC Savings	Crash, VOC and TT Savings	Only Crash Cost Savings	Crash and VOC Savings	Crash, VOC and TT Savings
B/C Ratio	Original Value	10.7	10.9	12.1	.27	8.17	8.58	7.02	7.23	8.7
	Total Cost (10%)	10.20	10.40	11.60	5.12	5.17	5.70		6.71	8.10
	Total Benefit (-10%)	9.70	9.80	10.90	4.97	5.02	5.50		6.48	7.84
	Combination	9.20	9.30	10.40	4.60	4.66	5.10		6.04	7.30
IRR	Original Value	231%	234%	264%	115%	118%	142.72%	115%	118%	143%
	Total Cost (10%)	207%	210%	237%	77%	78%	86%	104%	107%	130%
	Total Benefit (-10%)	205%	208%	234%	77%	78%	85%	103%	126%	128%
	Combination	184%	186%	210%	70%	70%	77%	93%	96%	116%
NPV	Original Value	$2,770,583	$2,812,824	$3,173,275	$5,570,670.47	5,733,458	7,122,583	$5,570,670	$5,733,458	$7,122,583
	Total Cost (10%)	$2,730,669	$2,772,910	$3,133,361	$5,150,094	$5,222,562	$5,840,931	$5,481,492	$5,644,280	$7,033,405
	Total Benefit (-10%)	$2,270,596	$2,491,627	$2,816,033	$4,624,002	$4,689,224	$5,245,755	$4,924,425	$5,070,935	$6,321,147
	Combination	$2,413,696	$2,451,713	$2,776,119	$4,513,177	$4,578,398	$5,134,930	$4,835,247	$4,981,756	$6,231,968
TOR (Yrs)	Original Value	0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-1
	Total Cost (10%)	0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-1
	Total Benefit (-10%)	0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-1
	Combination	0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-1

Table 5.38: Incremental Results

Variation Type	Alternative Comparison	B/C Ratio	IRR	NPV	TOR (Years)	Decision in Favor of	Final Decision
Only Crash Savings	A-2 to A-1	8	25797%	$3,020,982	0-1	A-2	A-2
	A-3 to A-2	0.71	-1%	-$37,477	>10	A-2	
Crash and VOC Savings	A-2 to A-1	8.07	309%	$3,107,463	0-1	A-2	A-3
	A-3 to A-2	1.39	15%	$61,392	0-1	A-3	
Crash, VOC and TT Savings	A-2 to A-1	8.72	112%	$3,117,160	0-1	A-2	A-3
	A-3 to A-2	7.29	94%	$832,148	0-1	A-3	

5.2.3.3. Conclusion for Case Study-3

The MOE's are presented in Table 5.37 and 5.38. The results indicate that all the alternatives are highly cost effective. This is because the alternatives are small scale improvement where the benefits accrued are much higher than the investment. The sensitivity analysis shows that the MOE's are sensitive to changes in cost and benefit data. The Incremental analysis (Table 5.38) shows that A-3 is the best alternative and should be considered as the forerunner among the three.

5.2.4.1. Case Study 4

The fourth study site is the intersection at M-59 Highland and Crescent Lake Road, located in Macomb County with an ADT more than 70,000 vehicles per day using this intersection. .Some of the operating features of the intersection are:

1. The east bound and west bound is 4 lanes with one exclusive lane for each left turn.
2. The north bound and south bound is 3 lanes with one exclusive lane left turn lane.
3. Crescent lake Road has steep slope on both approaches causes signal visibility problem.
4. The Intersection is operated by SCAT System

The aerial picture of the intersection is shown in Figure 5.28.Figure 5.29 and 5.30 show some of the pictures of the intersection during the time of data collection.

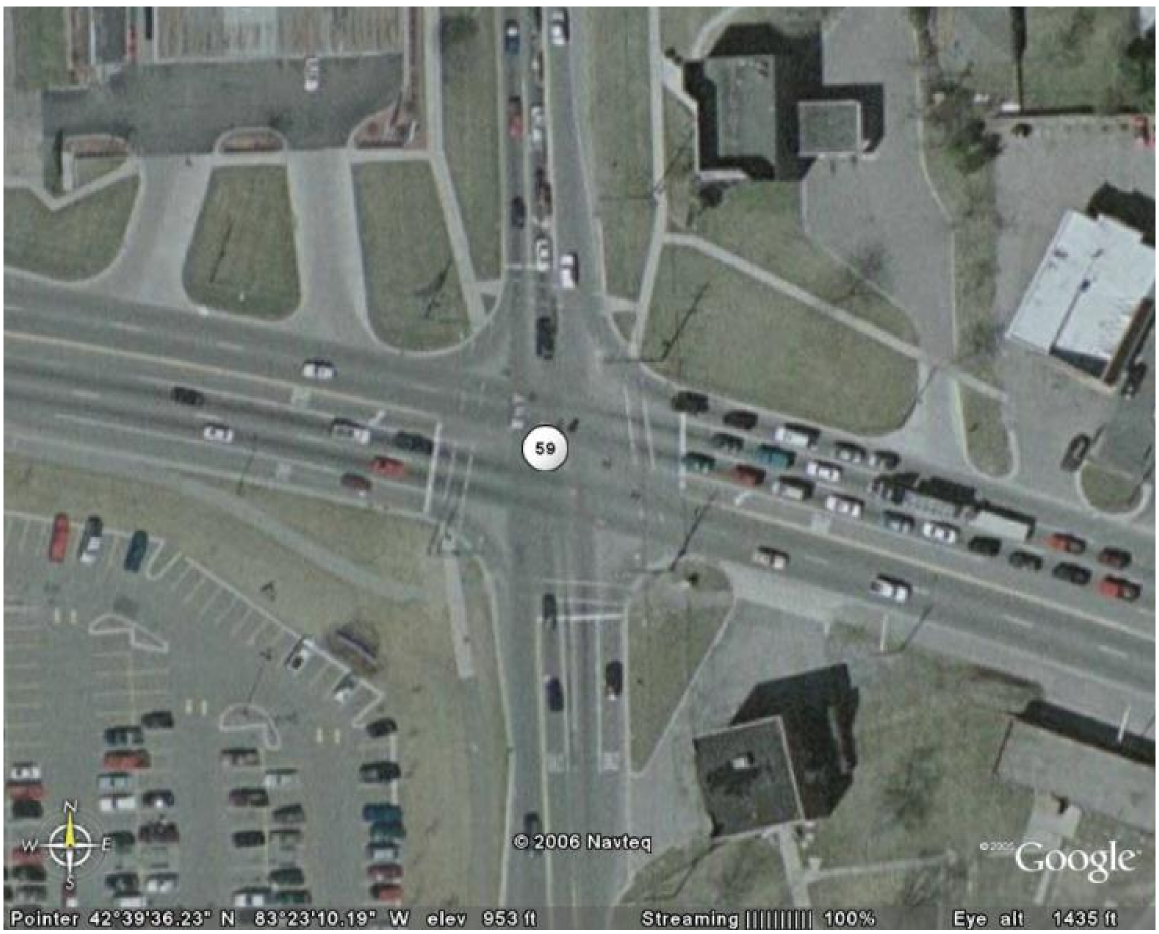


Fig 5.28: Aerial Photograph of the study area

Figure 5.29: Photograph of Study Area-1

Figure 5.30: Photograph of Study Area-2

5.2.4.1. Data Collection and Analysis

Data collection procedure involved plotting of condition diagram, traffic volume, collection of signal timing data, UD-10 screening for analyzing the predominant crash pattern.

Traffic Volume

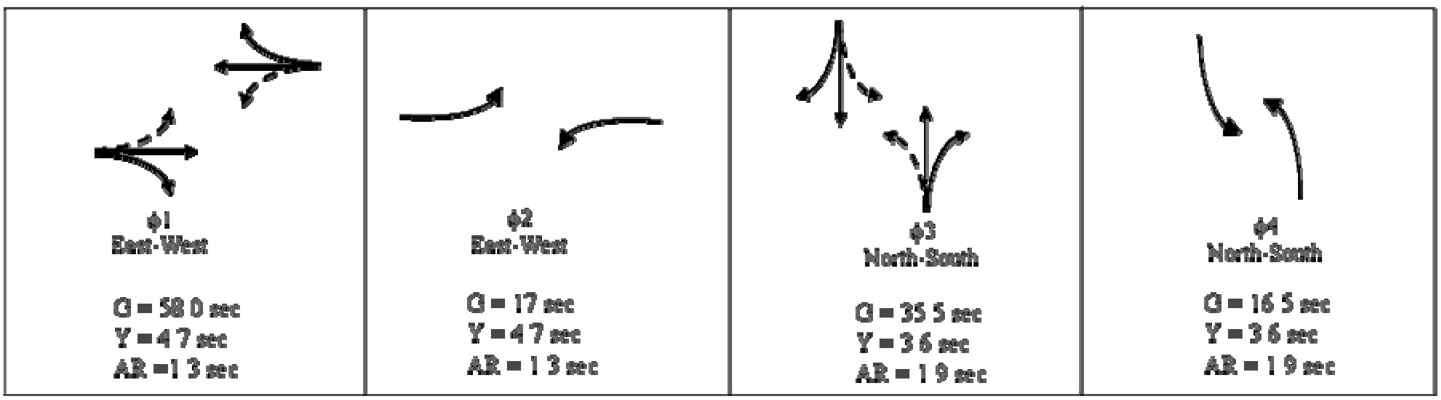
Traffic volume counts were made for 15-minute intervals for 4 times for all approaches. The collected traffic was converted to daily traffic from the off peak period by assuming two percent of traffic volume. The peak hourly data was computed from the estimated daily traffic volume (8%) shown below.

Signal Timing

Signal timing data were collected with a stopwatch and are shown below.

.

Northbound			Southbound			Eastbound			Westbound		
LT	**TH**	**RT**	**LT**	**TH**	**RT**	**LT**	**TH**	**RT**	**LT**	**TH**	**RT**
206	401	140	601	322	182	285	1603	6	109	1609	346



Using traffic volume and signal timing data, the current Level of Service was determined as “D” using Highway Capacity Software. Each approach LOS is shown in Table 5.39..

Table 5.39: Existing LOS at M-59 and Crescent Lake Rd.

	EB	WB	NB	SB
Delay (sec)	163.3	94.1	81.8	410.6
LOS	F	F	F	F
Intersection LOS	F			

UD-10 Analysis

A total 140 crashes including 30 injury crashes were reported during last three years (2002-2004).Salient features from the collision diagram report (Figure 5.30-A) and actual UD-10 observations are;

1. Predominant crash patterns: Rear End and Angle Crashes
2. Heavy Traffic Volume on M-59 and Signal invisibility causes rear end crashes
3. Insufficient Clearance Interval results Angle Crashes within the intersection
4. Steep Curve on Crescent Lake Rd also responsible for Rear End crashes.

5. Improper lane marking creates confusion for traffic movement

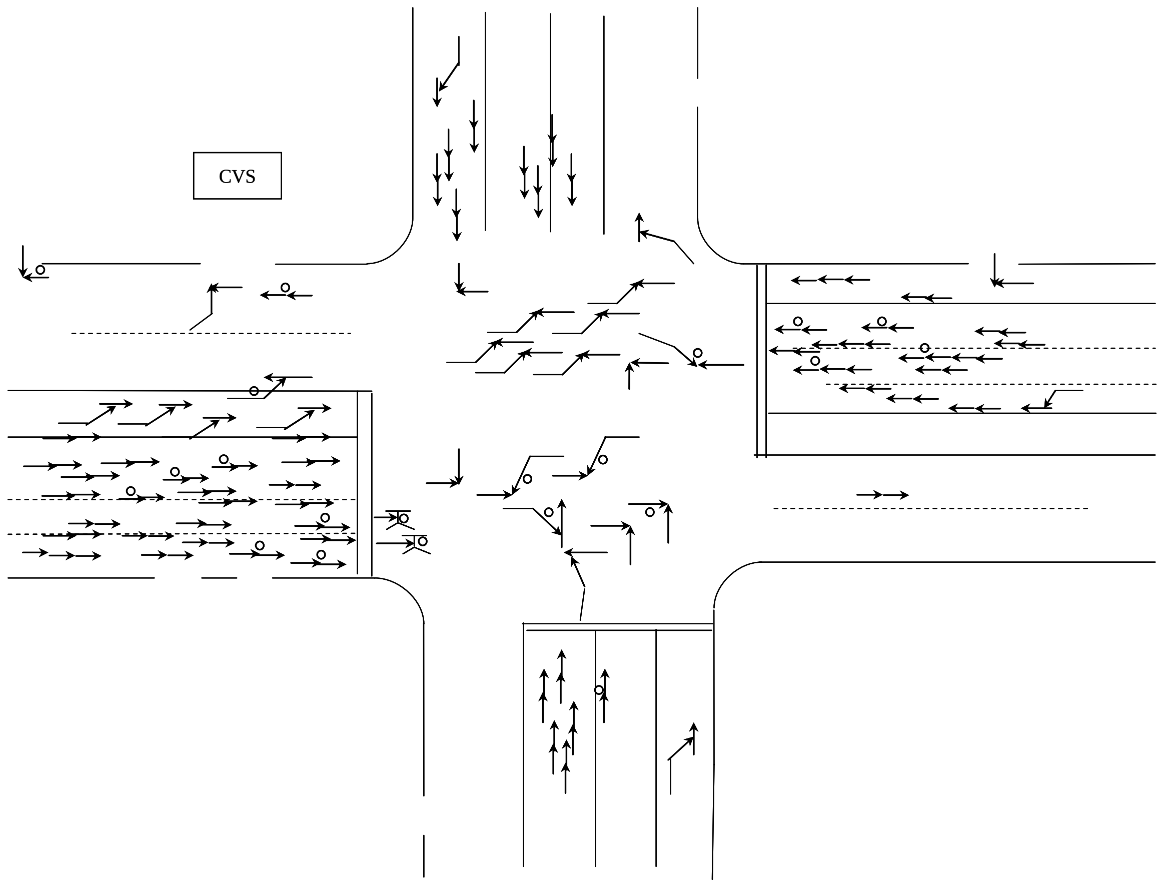


Fig 5.30-A: Collision Diagram

Probable Causes and Countermeasures

A set of probable causes of the crashes, based upon review of the UD-10 reports and site visits along with the suggested countermeasures are presented in Table 5.40.

Table 5.40: Probable Causes and Suggested Countermeasures

Probable Causes	Suggested Countermeasures
1. Horizontal curves on M59 before and after intersection 2. Vertical curve (down) on NB Crescent LK Rd (speed high) 3. vertical curve on SB Crescent LK Rd (visibility problem) 4. long queues on SB Crescent LK 5. Poor progression on M59 (SCAT) 6. Short All Red Interval for M59	1. Flatter slopes on Crescent Lake Road 2. More signal heads on Crescent Lake Road for long queue vehicles and poor visibility due to steeper slopes 3.Add lane on NB Crescent Lake Road due to heavy traffic 4. Advance signal warnings on both roads due to horizontal and vertical curve 5. Allocate more All Red Interval for M-59 for M59

5.2.4.1 Proposed Alternative and Analysis

Three alternatives are proposed to address the safety hazards and presented in Table 5.31. Results of the analysis are presented in Table 5.41 to 5.51 and Figure 5.32 to 5.36.

Table 5.41: Proposed Alternatives for Case Study-4

Improvement Alternatives	Type of Alternatives	CRF
Alternative -1	1. Modify signal timings 2. Periodic operation and maintenance	CRF1= 8%
Alternative – 2	1. Flatter slopes on Crescent Lake Rd 2. Advance warning signs on M59 3. Modify signal timing 4. Add lane on SB approach	CRF1= 40% CRF2=30% CRF3=20% CRF4=8% Combined CRF =69.08%
Alternative -3	1. Add lane on SB approach 2. Flatter slopes on NB Crescent Lake Road 3. Install advance signal warning signs on M59 4. Modify signal timings 5. Add SB left turn lane	CRF1= 20% CRF2=30% CRF3=40% CRF4=8% CRF5 = 25% Combined CRF =76.81%

Table 5.42: Summary of Poisson test Results for Alternative-1 for the First Year

Inputs	Severity Level of Crash		
	Injury	PDO	Total
Crashes Before improvements (3 years 2002-2004)	39.0	133.0	172
Crashes without improvements (1 year - 2007)	14.6	49.9	64.5
CRF for combined improvements	8.0	8.0	8.0
Estimated reduction in number of crashes	1.2	4.0	5.2
Crashes After improvement	13.5	45.9	59.3
Significance	NO	NO	NO
Savings in cost due to improvements ($/year)			

Table 5.43: Summary of Poisson test Results for Alternative-2 for the First Year

Inputs	Severity Level of Crash		
	Injury	PDO	Total
Crashes Before improvements (3 years 2002-2004)	39.0	133.0	172
Crashes without improvements - 2007,(Annual)	14.6	49.9	64.5
CRF for combined improvements	69.0	69.0	69.0
Estimated reduction in number of crashes	10.1	34.4	44.5
Crashes After improvement	4.5	15.5	20.0
Significance	Yes @ 95% LOC	Yes @ 95% LOC	Yes @ 95% LOC
Savings in cost due to improvements ($/year)	**501,474**	**254,631**	**756,105**

Table 5.44: Summary of Poisson test Results for Alternative-3 for the First Year

Inputs	Severity Level of Crash		
	Injury	PDO	Total
Crashes Before improvements (3 years 2002-2004)	39.0	133.0	172
Crashes without improvements - 2007,(Annual)	14.6	49.9	64.5
CRF for combined improvements	76.8	76.8	76.8
Estimated reduction in number of crashes	11.2	38.3	49.5
Crashes After improvement	3.4	11.6	15.0
Significance	Yes @ 95% LOC	Yes @ 95% LOC	Yes @ 95% LOC
Savings in cost due to improvements ($/year)	**558,236**	**283,452**	**841,688**

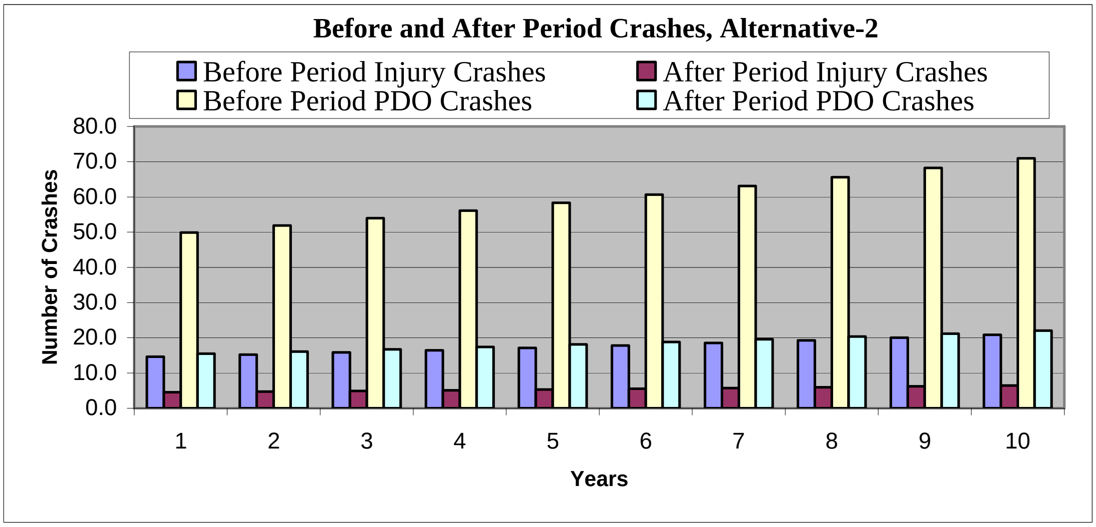


Figure 5.32: Comparison of Before and After Period Crashes due to Improvement Alternative-2

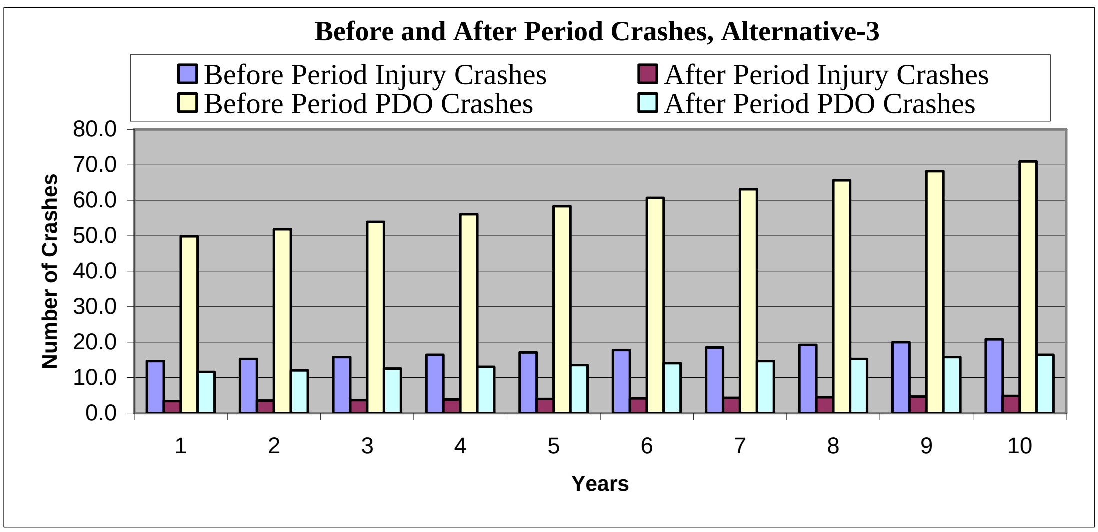


Figure 5.33: Comparison of Before and After Period Crashes due to Improvement Alternative-3

Table 5.45: Cost Components of all Alternatives

Cost Component	Alternative-1	Alternative-2	Alternative-3
Initial Design & Planning Cost		$30,000	$40,000
Modify Signal Timings and Clearance Interval	$1,500		
Regular Operation and Maintenance Cost	$15,000	$15,000	$15,000
Periodic Operation and Maintenance Cost	$75,000	$75,000	$75,000
Advance Intersection Warning Sign and Signal		$14,000	$14,000
Add a Right Turn Lane		$200,000	
Flattening Slopes		$200,000	$200,000
Modify Signal Timings and Clearance Interval		$1,500	$1,500
Delay Cost due to Construction		$104,166	$138,888
Add Left Turn Lane			$200,000
Add a Right Turn Lane			$200,000

Table 5.46: Savings in Travel Time due to Improvement Alternative-2 for the First Year

Direction of Travel	Peak Hour Traffic in veh/hr	Delay Before Improvement in sec/veh	Delay After Improvement in sec/veh	Change in Delay in hr/veh	Change in Vehicle Travel Time in veh-hrs	Change in Passenger Time in person-hrs	Dollars Amount Saved in $/year
NB	747	81.8	77.1	0.001306	507	609	**4,868**
SB	1,105	410.6	81.1	0.091528	52,592	63,110	**504,882**
EB	1,894	163.3	59.3	0.028889	28,452	34,143	**273,140**
WB	1,864	94.1	54.4	0.011028	10,689	12,827	**102,614**

Table 5.47: Savings in Travel Time due to Improvement Alternative-3 for the First Year

Direction of Travel	Peak Hour Traffic in veh/hr	Delay Before Improvement in sec/veh	Delay After Improvement in sec/veh	Change in Delay in hr/veh	Change in Vehicle Travel Time in veh-hrs	Change in Passenger Time in person-hrs	Dollars Amount Saved in $/year
NB	747	81.8	47.9	0.009417	3,658	4,389	**35,115**
SB	1,105	410.6	46.9	0.101028	58,051	69,661	**557,285**
EB	1,894	163.3	51.7	0.031	30,531	36,638	**293,100**
WB	1,864	94.1	46.5	0.013222	12,816	15,379	**123,034**

Table 5.48: Savings in VOC due to Improvement Alternative-2 for the First Year

Direction of Travel	Peak Hour Traffic veh/hr	Delay Before Improvement sec/veh	Delay After Improvement sec/veh	Change in Delay hr/veh	Cost of Delay in terms of Fuel gal/hr of delay	Savings in Fuel Consumption gallons	Cost of Fuel $/gal	Dollar Saved $/year
NB	747	81.8	77.1	0.0013	0.5	254	2.25	571
SB	1,105	410.6	81.1	0.0915	0.5	26296	2.25	59166
EB	1,894	163.3	59.3	0.0289	0.5	14226	2.25	32009
WB	1,864	94.1	54.4	0.0110	0.5	5345	2.25	12025

Table 5.49: Savings in VOC due to Improvement Alternative-3 for the First Year

Direction of Travel	Peak Hour Traffic veh/hr	Delay Before Improvement sec/veh	Delay After Improvement sec/veh	Change in Delay hr/veh	Cost of Delay in terms of Fuel gal/hr of delay	Savings in Fuel Consumption gallons	Cost of Fuel $/gal	Dollar Saved $/year
NB	747	81.8	47.9	0.0094	0.5	1829	2.25	4115
SB	1,105	410.6	46.9	0.1010	0.5	29025	2.25	65307
EB	1,894	163.3	51.7	0.0310	0.5	15266	2.25	34348
WB	1,864	94.1	46.5	0.0132	0.5	6408	2.25	14418

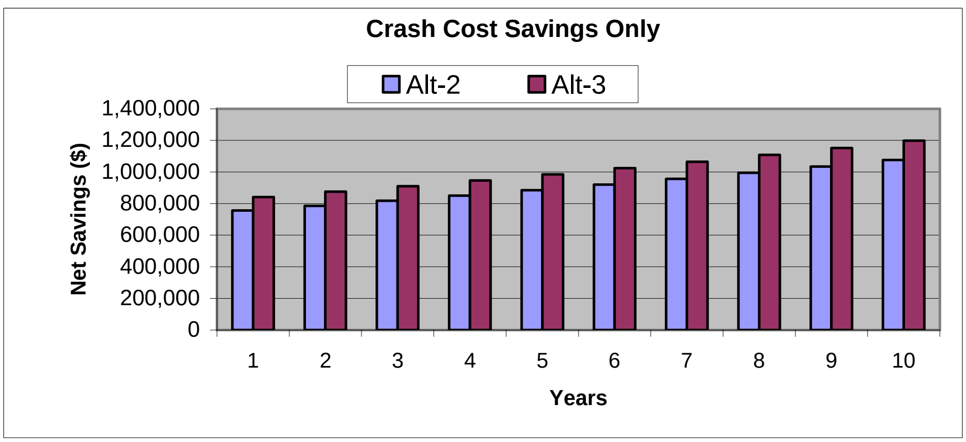


Figure 5.34: Net Savings in crash cost due to improvements for all alternatives for the first year

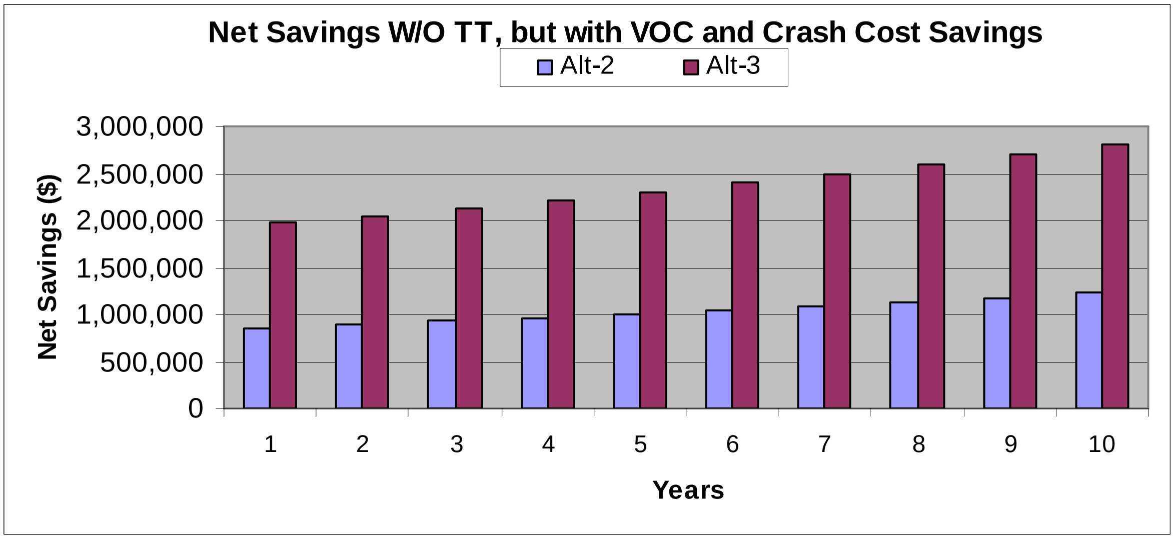


Figure 5.35: Net Savings in crash cost and VOC due to improvements for all alternatives for the first year

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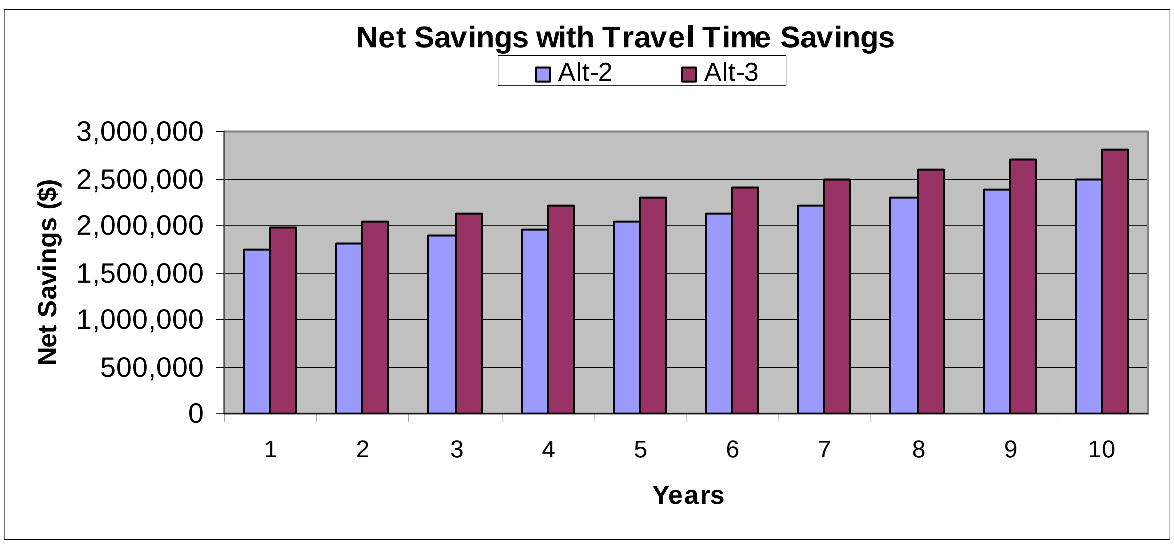


Figure 5.36: Net Savings in crash cost, VOC and TT due to improvements for all alternatives for the first year

Table 5.50: Summary of Economic and Sensitivity Analysis

Variation		Alternative -2 Only Crash Cost Savings	Alternative -2 Crash and VOC Savings	Alternative -2 Crash, VOC and TT Savings	Alternative -3 Only Crash Cost Savings	Alternative -3 Crash and VOC Savings	Alternative -3 Crash, VOC and TT Savings
B/C Ratio	Original Value	7.69	8.75	14.76	6.38	7.29	14.93
	Total Cost(10%)	7.19	8.18	16.60	5.93	6.76	13.85
	Total Benefit(-10%)	6.92	7.87	15.98	5.75	6.55	13.43
	Combination	6.47	7.36	14.94	5.34	6.08	12.47
IRR	Original Value	131.09%	149.59%	308.63%	100.62%	221.77%	236.08%
	Total Cost(10%)	119%	136%	280%	91%	104%	214%
	Total Benefit(-10%)	118%	134%	277%	90%	103%	212%
	Combination	107%	122%	251%	82%	93%	193%
NPV	Original Value	$5,401,568	$6,250,522	$13,494,925	5,847,271	14,098,194	15,065,099
	Total Cost(10%)	$5,323,147	$6,172,101	$13,416,505	$5,743,405	$6,710,310	$14,961,233
	Total Benefit(-10%)	$4,782,991	$5,547,049	$12,067,012	$5,158,678	$6,028,893	$13,454,723
	Combination	$4,704,570	$5,468,628	$11,988,591	$5,054,812	$5,925,026	$13,350,857
TOR (Yrs)	Original Value	0-1	0-1	0-1	0-1	0-1	0-1
	Total Cost(10%)	0-1	0-1	0-1	0-1	0-1	0-1
	Total Benefit(-10%)	0-1	0-1	0-1	0-1	0-1	0-1
	Combination	0-1	0-1	0-1	0-1	0-1	0-1

Table 5.51: Incremental Analysis Summary

Variation Type	Alternative Comparison	B/C Ratio	IRR	NPV	TOR (Years)	Final Decision
Only Crash Savings	A-3 to A-2	2.55	33%	$445,703	0-1	A-3
Crash and VOC Savings	A-3 to A-2	2.98	86%	$1,570,174	0-1	A-3
Crash, VOC and TT Savings	A-3 to A-2	6.64	86%	$1,570,174	0-1	A-3

5.24.3. Conclusions from case Study-4

The MOE's are presented in Table 5.50 and 5.51. The results indicate that all the alternatives are highly cost effective. This is because the alternatives are small scale improvement where the benefits accrued are much higher than the investment. The sensitivity analysis shows that the MOE's are sensitive to changes in cost and benefit data. The Incremental analysis (Table 5.51) shows that A-3 is the best alternative and should be considered as the forerunner among the three

5.2.5. Case Study-5

The fifth study site is the intersection at M-97 (Groesbeck Highway) and Metro Parkway, located in Macomb County with over 80,000 vehicles per day using this intersection. Both M-97 and Metro Parkway are six lane facilities. Metro Parkway is divided by a median. Other operating features of the intersection are:

1. No left turn is allowed on the intersection with Michigan left turns on Metro Parkway .
2. Near and Far Signal Heads are in operation for Groesbeck Highway
3. Multiple Driveway Access Points on Groesbeck Highway
4. A pedestrian over bridge exists on the North Bound of the intersection.

An aerial photograph of the intersection is presented in Fig 5.37. Figure 5.38 and 5.39 show some of the pictures of the intersection during the time of data collection.

Figure 5.37: Aerial Picture of the Intersection

Fig 5.38: Photograph-1 of the Study Area

Fig 5.39: Photograph-2 of the Study Area

5.2.5.1 Data Collection and Analysis

Data collection procedure involved plotting of condition diagram, traffic volume, collection of signal timing data, UD-10 screening for analyzing the predominant crash pattern.

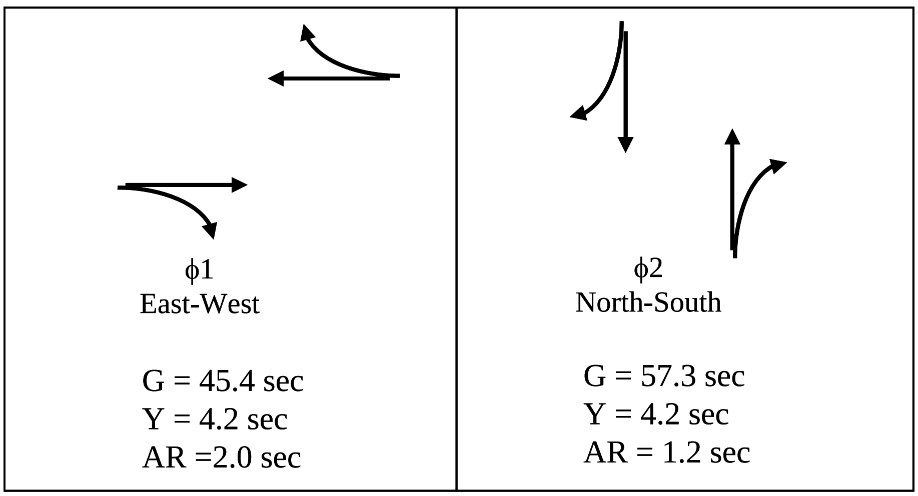
Traffic Volume

Traffic volume counts were made for 15-minute intervals for 4 times for all approaches. The collected traffic was converted to daily traffic from the off peak period by assuming two percent of traffic volume. The peak hourly data was computed from the estimated daily traffic volume (8%) shown below.

Signal Timing

Signal timing data were collected with a stopwatch and are shown below.

Northbound		**Southbound**		**Eastbound**		**Westbound**	
TH	**RT**	**TH**	**RT**	**TH**	**RT**	**TH**	**RT**
819	287	811	349	1277	264	1183	171



UD-10 Analysis

A total 184 crashes including 60 injury crashes were reported during last three years (2002-2004).Salient features from the collision diagram report (Figure 5.40) and actual UD-10 observations are;

1. Predominant crash patterns: Angle Crash due to driveway activities on Groesbeck Highway
2. Insufficient Clearance Interval results Angle Crashes within the intersection
3. Improper lane marking creates confusion for traffic movement

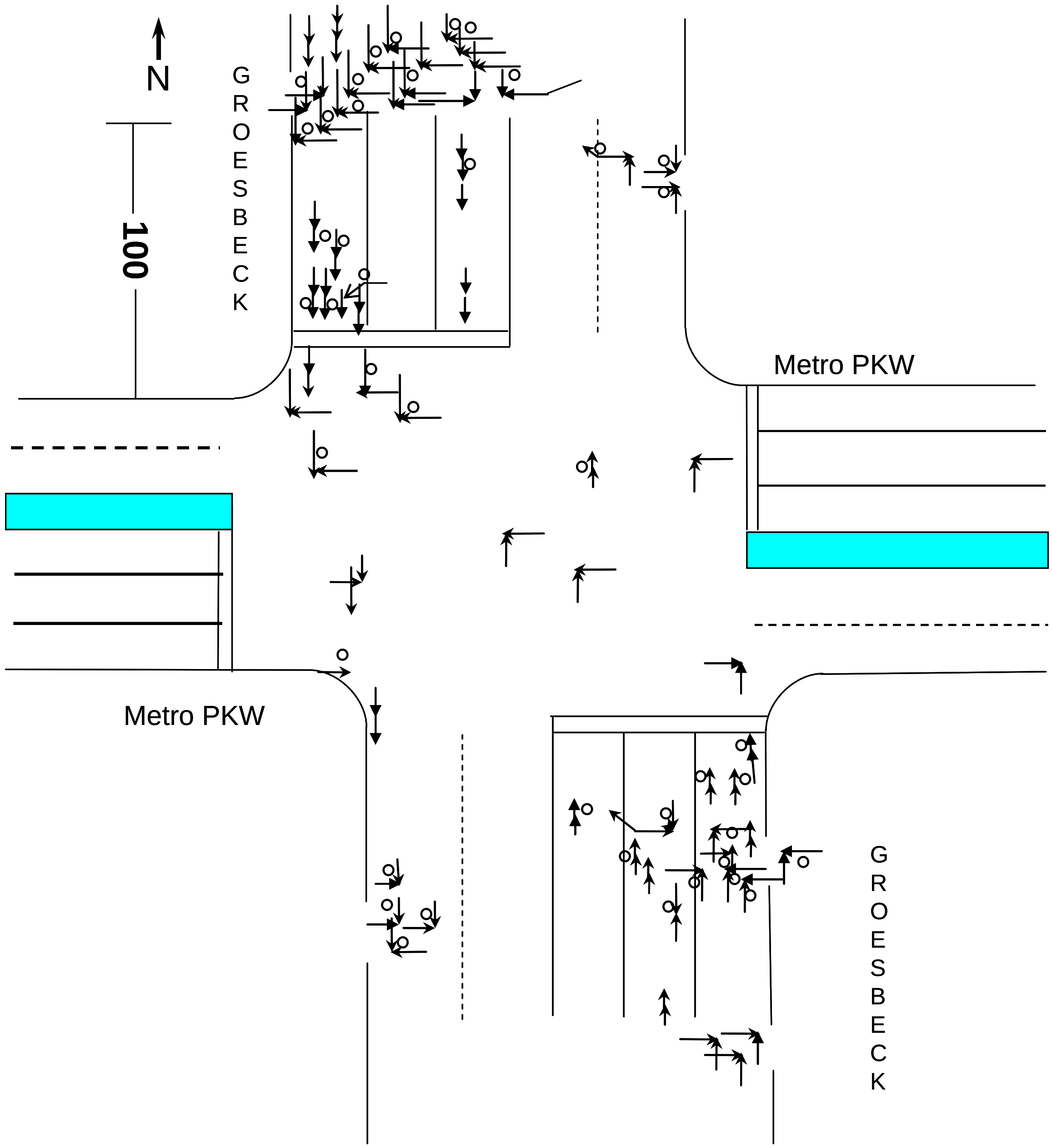


Figure 5.40: Collision Diagram of M-97 (Groesbeck Highway) and Metro Parkway

Existing Level of Service

Using traffic volume and signal timing data, the current Level of Service was determined as "F" using Highway Capacity Software. Each approach LOS is shown in Table 5.52.

Table 5.52: Existing LOS at M-97 and Metro Parkway

Direction	EB	WB	NB	SB
Delay (sec)	140.8	110.9	31.7	33
LOS	F	F	C	C
Intersection LOS	F			

Probable Causes and Countermeasures

A set of probable causes of the crashes, based upon review of the UD-10 reports and site visits along with the suggested countermeasures are presented in Table 5.53

Table 5.53: Probable Causes and Suggested Countermeasures

Probable Causes	**Suggested Countermeasures**
1.No curbs on both Streets 2.Too many driveway activities 3.Insufficient Lane Directions 4.Heavy traffic on driveway around intersection 5.Heavy right turn traffic from M97 to Metro 6. Poor pavement condition	1. Curbs on Metro Parkway(Both Directions) 2. Median on driveway for avoiding conflict 3.Sign as Right Turn Only 4. Divide M97 with raised median (prohibit left turns) 5. Close down multiple driveways and construct a new driveway with signalized operation to the M97 6. Improve Pavement condition

5.2.5.2. Proposed Alternative and Analysis

Three alternatives are proposed to address the safety hazards and presented in Table 5.31. Results of the analysis are presented in Table 5.54 to 5.65 and Figure 5.41 to 5.47.

Table 5.54: Proposed Alternatives for Case Study-5

Improvement Alternatives	Type Of Alternatives	CRF
Alternative -1	1. Install Proper Signs 2. Improve Signal Timings	CRF1= 20% CRF2=8% Combined CRF =26.4%
Alternative – 2	1. Curbs On Metro Parkway 2. Separate Entry And Exit Gates By Raised Median At Driveways 3. Divide M97 With Raised Median Near Intersection (Prohibit Left Turns) 4. Install Proper Signs 5. Improve Signal Timings	CRF1= 10% CRF2=10% CRF3=40% CRF4=20% CRF5=8% Combined CRF =64.23%
Alternative -3	1. Curbs On Metro Parkway (Both Directions) 2. Install Proper Signs 3. Divide M97 With Raised Median (Prohibit Left Turns) 4. Close Down Multiple Driveways And Construct A New Driveway With Signalized Operation To The M97 5. Improve Pavement Condition 6. Improve Signal Timings	CRF1= 10% CRF2=20% CRF3=40% CRF4=10% CRF5=25% CRF6= 8% Combined CRF =73.17%
Alternative -3	1. Install Roundabout 2. Improve Pavement Condition 3.Close Down Multiple Driveways And Construct New Opening Away From Roundabout 4.Install Proper Warning Signs	CRF1= 60% CRF2=25% CRF3=10% CRF4=10% CRF5 = 25% Combined CRF =81.77%

Table 5.55: Summary of Poisson test Results for Alternative-1 for the First Year

Inputs	Severity Level of Crash		
	Injury	PDO	Total
Crashes Before improvements (3 years 2002-2004)	60.0	124.0	184
Crashes without improvements - 2007,(Annual)	22.5	46.5	69.0
CRF for combined improvements	26.4	26.4	26.4
Estimated reduction in number of crashes	4.5	9.3	13.8
Crashes After improvement	18.0	37.2	55.2
Significance	No @ 95% LOC	No @ 95% LOC	Yes @ 95% LOC
Savings in cost due to improvements ($/year)	**223,623**	**68,812**	**292,435**

Table 5.56: Summary of Poisson test Results for Alternative-2 for the First Year

Inputs	Severity Level of Crash		
	Injury	PDO	Total
Crashes Before improvements (3 years 2002-2004)	60.0	124.0	184
Crashes without improvements - 2007,(Annual)	22.5	46.5	69.0
CRF for combined improvements	64.23	64.23	64.23
Estimated reduction in number of crashes	13.7	28.4	42.2
Crashes After improvement	8.8	18.1	26.8
Significance	Yes @ 95% LOC	Yes @ 95% LOC	Yes @ 95% LOC
Savings in cost due to improvements ($/year)	**683,168**	**210,220**	**893,388**

Table 5.57: Summary of Poisson test Results for Alternative-3 for the First Year

Inputs	Severity Level of Crash		
	Injury	PDO	Total
Crashes Before improvements (3 years 2002-2004)	60.0	124.0	184
Crashes without improvements - 2007,(Annual)	22.5	46.5	69.0
CRF for combined improvements	73.17	73.17	73.17
Estimated reduction in number of crashes	15.9	32.9	48.8
Crashes After improvement	6.6	13.6	20.1
Significance	YES @ 99% LOC	YES @ 99% LOC	YES @ 99% LOC
Savings in cost due to improvements ($/year)	**791,625**	**243,593**	**1,035,219**

Table 5.58: Summary of Poisson test Results for Alternative-4 for the First Year

Inputs	Severity Level of Crash		
	Injury	PDO	Total
Crashes Before improvements (3 years)	39	56	66
Crashes without improvements - 2007,(Annual)	22.5	46.5	75.7
CRF for combined improvements	81.77	81.77	81.77
Estimated reduction in number of crashes	18.4	38.0	61.9
Crashes After improvement	4.1	8.5	13.8
Significance	YES @ 95% LOC	YES @ 99% LOC	YES @ 99% LOC
Savings in cost due to improvements ($/year)	**914,393**	**281,371**	**1,195,764**

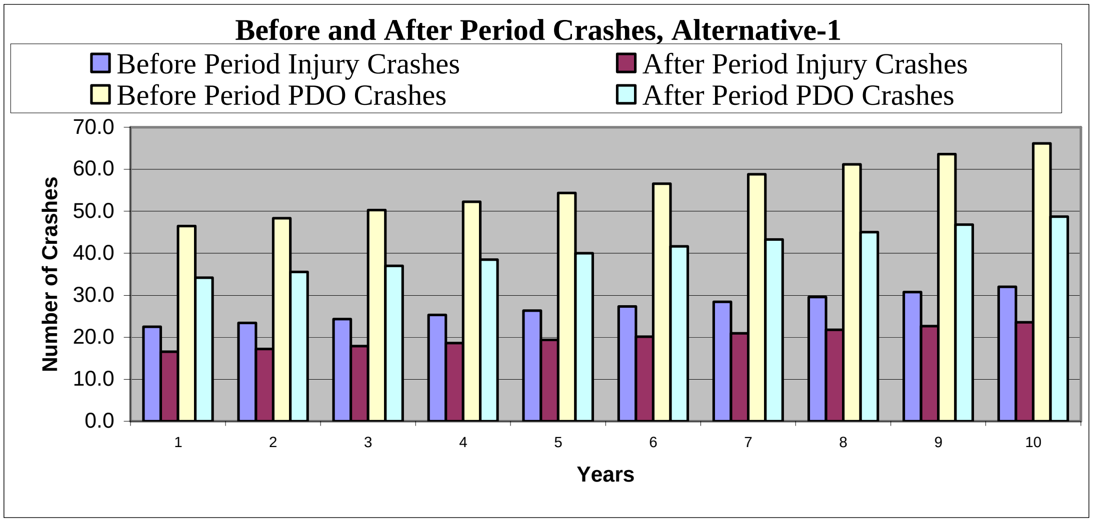


Figure 5.41: Comparison of Before and After Period Crashes due to Improvement Alternative-1

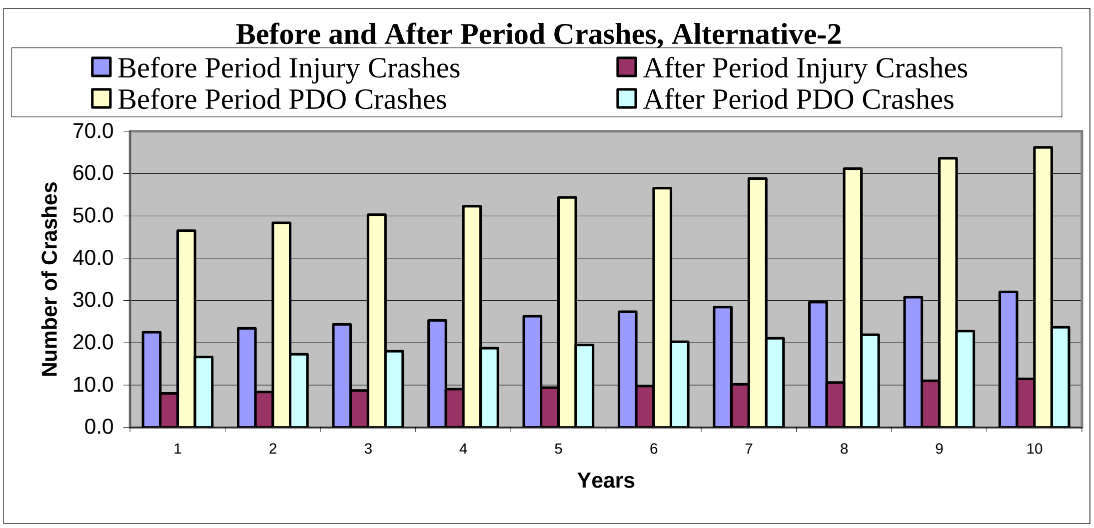


Figure 5.42: Comparison of Before and After Period Crashes due to Improvement Alternative-2

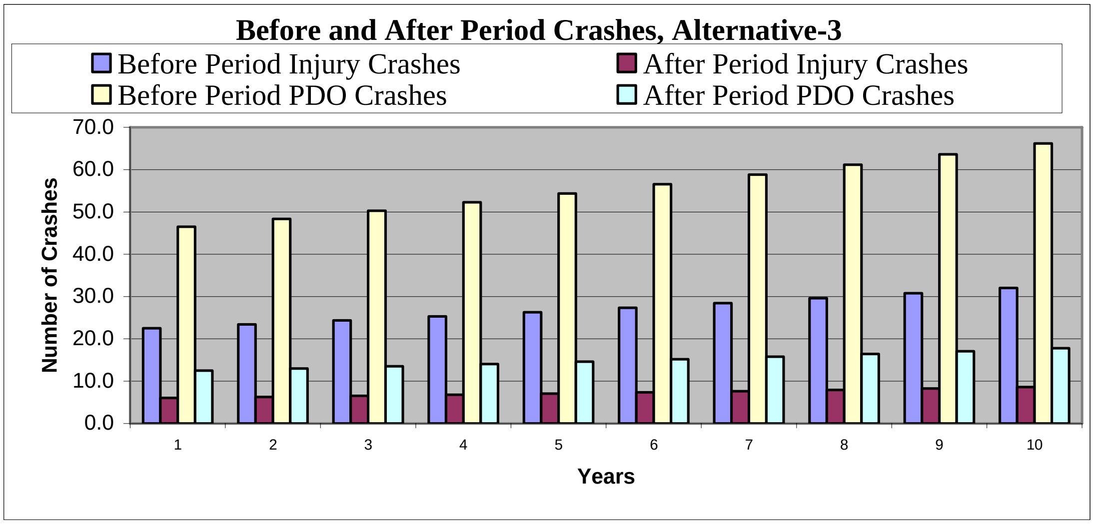


Figure 5.43: Comparison of Before and After Period Crashes due to Improvement Alternative-3

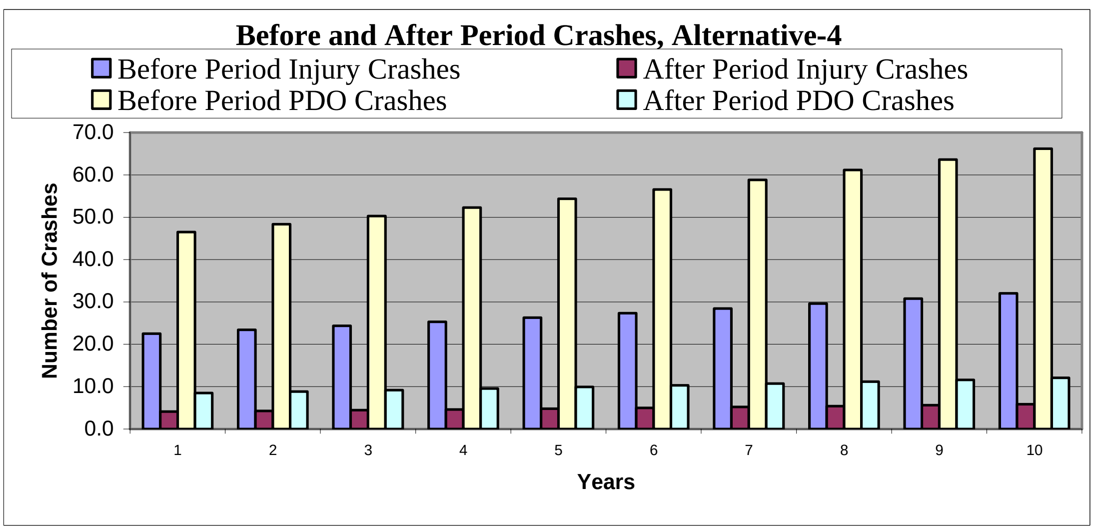


Figure 5.44: Comparison of Before and After Period Crashes due to Improvement Alternative-4

Table 5.59: Cost Components of all Alternatives

Cost Component	Alternative-1	Alternative-2	Alternative-3	Alternative-4
Initial Planning Cost	$10,000			
Install Proper Signs	$4,000			
Regular O&M Cost	$15,000	$15,000	$15,000	
Periodic O&M Cost	$75,000	$75,000	$75,000	
Curbs on Metro Park way		$220,000	$220,000	
Initial Design & Planning Cost		$20,000	$20,000	$50,000
Separate Entry and Exit Lanes with Raised Median (Driveways)		$100,000		
Median to Prohibit Left Turn		$100,000	$100,000	
Install Proper Signs		$4,000		
Close multiple driveways and construct new with signalized operation			$300,000	$300,000
Install Proper Signs and Improve Pavement Condition			$54,000	$54,000
Delay Cost during Construction				$11,586
Roundabout with Curbs On Metro Park way				$500,000

Table 5.60: Savings in Travel Time due to Improvement Alternative-1,2 and 3 for the First Year

Direction of Travel	Peak Hour Traffic in veh/hr	Delay Before Improvement in sec/veh	Delay After Improvement in sec/veh	Change in Delay in hr/veh	Change in Vehicle Travel Time in veh-hrs	Change in Passenger Time in person-hrs	Dollars Amount Saved in $/year
NB	1105	20.1	24.7	-0.00128	-734	-881	**-7,048**
SB	1159	20.5	25.3	-0.00133	-804	-964	**-7,714**
EB	1353	52.1	24.9	0.007556	5,316	6,379	**51,032**
WB	1540	41.8	23	0.005222	4,182	5,018	**40,147**

Table 5.61: Savings in Travel Time due to Improvement Alternative- 4 for the First Year

Direction of Travel	Peak Hour Traffic in veh/hr	Delay Before Improvement in sec/veh	Delay After Improvement in sec/veh	Change in Delay in hr/veh	Change in Vehicle Travel Time in veh-hrs	Change in Passenger Time in person-hrs	Dollars Amount Saved in $/year
NB	1105	20.1	18.4	0.000472	271	326	**2,605**
SB	1159	20.5	14.7	0.001611	971	1,165	**9,321**
EB	1353	52.1	11.7	0.011222	7,896	9,475	**75,797**
WB	1540	41.8	14.1	0.007694	6,162	7,394	**59,152**

Table 5.62: Savings in VOC due to Improvement Alternative-1,2 and 3 for the First Year

Direction of Travel	Peak Hour Traffic in veh/hr	Delay Before Improvement in sec/veh	Delay After Improvement in sec/veh	Change in Delay in hr/veh	Cost of Delay in terms of Fuel gal/hr of delay	Savings in Fuel Consumption gallons	Cost of Fuel in $/gal	Dollar Saved in $/year
NB	1105	20.1	24.7	-0.00128	0.5	-367.1056	2.25	**-826**
SB	1159	20.5	25.3	-0.00133	0.5	-401.7867	2.25	**-904**
EB	1353	52.1	24.9	0.007556	0.5	2657.8933	2.25	**5,980**
WB	1540	41.8	23	0.005222	0.5	2090.9778	2.25	**4,705**

Table 5.63: Savings in VOC due to Improvement Alternative-4 for the First Year

Direction of Travel	Peak Hour Traffic in veh/hr	Delay Before Improvement in sec/veh	Delay After Improvement in sec/veh	Change in Delay in hr/veh	Cost of Delay in terms of Fuel gal/hr of delay	Savings in Fuel Consumption gallons	Cost of Fuel in $/gal	Dollar Saved in $/year
NB	1105	20.1	24.7	0.000472	0.5	135.66944	2.25	**305**
SB	1159	20.5	25.3	0.001611	0.5	485.49222	2.25	**1,092**
EB	1353	52.1	24.9	0.011222	0.5	3947.7533	2.25	**8,882**
WB	1540	41.8	23	0.007694	0.5	3080.8556	2.25	**6,932**

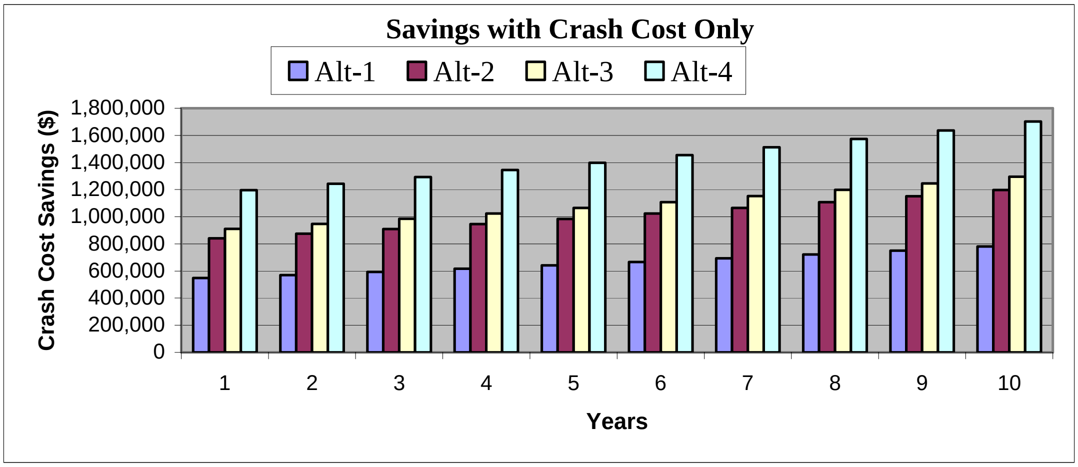


Figure 5.45: Savings due to Crash Reduction for the Service Life

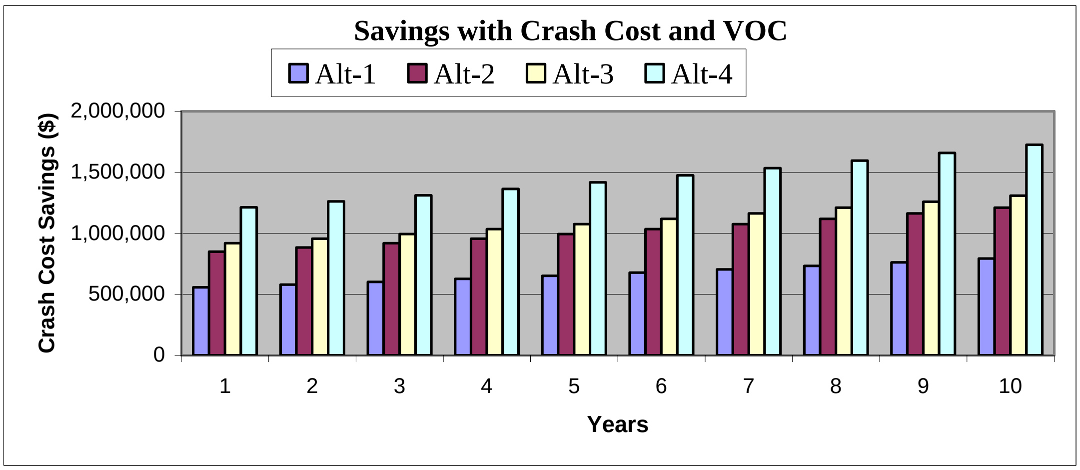


Figure 5.46: Savings due to Crash Reduction, and VOC for the Service Life

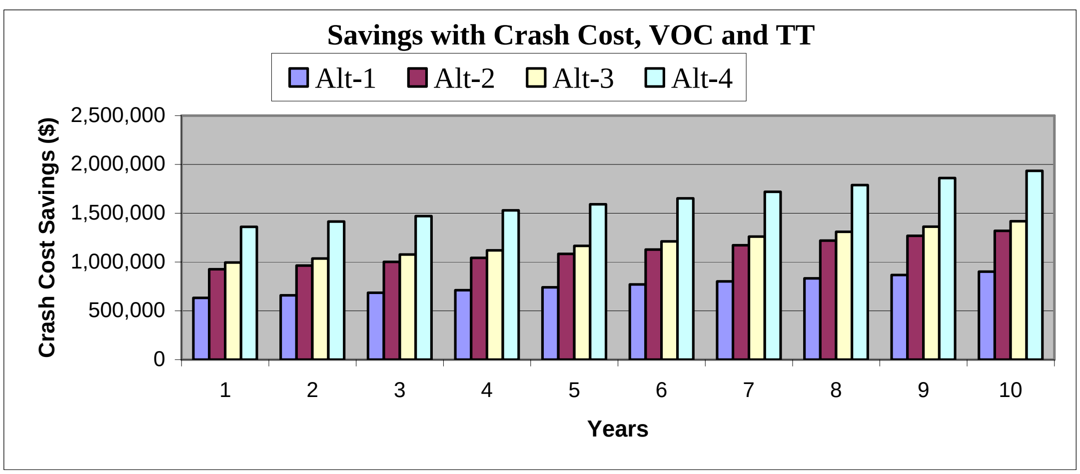


Figure 5.47: Savings due to Crash Reduction, VOC and Travel Time for the Service Life

Table 5.64: Summary of Sensitivity Analysis

Variation		Alternative -1			Alternative -2			Alternative -3			Alternative -4		
		Only Crash Cost Savings	Crash and VOC Savings	Crash, VOC and TT Savings	Only Crash Cost Savings	Crash and VOC Savings	Crash, VOC and TT Savings	Only Crash Cost Savings	Crash and VOC Savings	Crash, VOC and TT Savings	Only Crash Cost Savings	Crash and VOC Savings	Crash, VOC and TT Savings
B/C Ratio	Original Value	17.4	17.7	20.1	9.9	9.99	10.89	7.83	7.91	8.57	9.1	9.23	10.35
	Total Cost (10%)	17.28	17.56	19.96	9.28	9.38	10.22	7.29	7.36	7.97	8.45	8.57	9.61
	Total Benefit (-10%)	15.63	15.89	18.07	8.89	8.99	9.80	7.05	7.12	7.71	8.19	8.31	9.31
	Combination	15.55	15.80	17.97	8.35	8.44	9.20	6.56	6.62	7.18	7.16	7.71	8.64
IRR	Original Value	3295%	3359%	3902%	179%	181%	198%	127%	128%	139%	143%	145%	163%
	Total Cost (10%)	2941%	2999%	3492%	163%	164%	180%	115%	116%	126%	130%	132%	148%
	Total Benefit (-10%)	2905%	2963%	3451%	161%	163%	178%	114%	115%	125%	129%	131%	147%
	Combination	2587%	2639%	3083%	146%	147%	161%	104%	105%	113%	117%	119%	133%
NPV ($)	Original Value	4,207,730	4,280,992	4,906,077	6,197,705	6,270,967	6,896,052	6,527,993	6,601,255	7,226,340	8,746,405	8,887,218	10,088,825
	Total Cost (10%)	4,179,844	4,253,106	4,878,191	6,129,253	6,202,515	6,827,600	6,435,956	6,509,218	7,134,303	8,642,897	8,783,710	9,985,318
	Total Benefit (-10%)	3,500,023	3,825,007	4,387,583	5,509,482	5,575,418	6,137,995	5,783,157	5,849,092	6,411,669	7,768,257	7,894,989	8,976,435
	Combination	3,731,185	3,797,121	4,359,697	5,441,030	5,506,966	6,069,542	5,691,120	5,757,055	6,319,632	7,664,749	7,791,481	8,872,928
TOR (Yrs)	Original Value	0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-1
	Total Cost (10%)	0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-1
	Total Benefit (-10%)	0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-1
	Combination	0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-1

Table 5.65: Incremental Analysis

Variation Type	Alternative Comparison	B/C Ratio	IRR	NPV	TOR (Years)	Decision in Favor of	Final Decision
Only Crash Savings	A-2 to A-1	5.5	72%	$1,989,975	0-1	A-2	A-4
	A-3 to A-2	2.20	28%	$330,288	0-1	A-3	
	A-4 to A-3	18.80	239%	$2,218,411	0-1	A-4	
W/O TT Savings	A-2 to A-1	5.56	73%	$1,889,975	0-1	A-2	A-4
	A-3 to A-2	2.23	29%	$333,289	0-1	A-3	
	A-4 to A-3	19.40	245%	$2,285,963	0-1	A-4	
W TT Savings	A-2 to A-1	5.72	74%	$1,999,876	0-1	A-2	A-4
	A-3 to A-2	2.28	31%	$335,298	0-1	A-3	
	A-4 to A-3	24.03	303%	$2,862,485	0-1	A-4	

5.2.5.3. Conclusion for Case Study-5

The MOE's are presented in Table 5.64 and 5.65. The results indicate that all the alternatives are highly cost effective. This is because the alternatives are small scale improvement where the benefits accrued are much higher than the investment. The sensitivity analysis shows that the MOE's are sensitive to changes in cost and benefit data. The Incremental analysis (Table 5.65) shows that A-4 is the best alternative and should be considered as the forerunner among the four.

5.2 Group B Results

Results for the analyses are presented in Tabular form. Table 5.66 shows crucial information about the intersections, including crash data, the types of predominant crashes, their probable causes based upon an analysis of the UD-10 reports and condition/collision diagram prepared, and a list of the countermeasures. The data presented in Table 5.66 includes information retrieved from various sources mentioned above, and were supplemented with actual visits to the sites, observation of the traffic movements, driver behavior, overview of the roadway furniture, etc.

Table 5.67 shows the results of the economic analysis using the TOR technique. In most cases, data was derived from information available in the literature. Benefit data was estimated using Accident Reduction Factors compiled from various sources (presented in a stand alone separate report as a part of this study) and, converted to dollar equivalents using the latest National Security Council (NSC) figure. For each site, mutually exclusive alternatives are listed in increasing order of investment cost, and the economic viability of the projects are tested using the Defender-Challenger analysis technique, with absolute Time of Return, and Marginal Time of Return as the two MOE's. In order for a project to be considered economically justifiable, both TOR's must be lower than the project life. All projects considered in Group B were assumed to have a project life of 10 years. Thus, the project selection is based upon the criteria that,

1) The TOR of the project, on its own (absolute) must be less than the project life, and
2) The TOR of the project, compared to the next lower-cost alternative (marginal) must be less than the project life, thereby justifying that the additional investment is also justifiable by way of the additional savings in crashes.

Table 5.66: Probable Causes and Countermeasures

Sl No[1]	Intersection	Frequency	Severity	Predominant Crashes[2]	Probable Causes	Countermeasures
1	M-59 Highland (EW) And Schoenherr Rd (NS)	292	0.199	1,2,3	1. Signal Visibility For EW Movement In The Direction Of Sunrise And Sunset 2. Higher Speed On M59 Causes Rear End Crashes 3. Narrow Lanes On Schoenherr Rd Leads To Side Swipe Crashes 4. Michigan Left Is Very Close To Intersection Approach On Schoenherr Rd (50 Ft) 5. Near And Far Signal Heads For M59 May Confuse Drivers	1. Mast Arm Signal Heads With Back Plates To Improve Visibility 2. No Need Of Near And Far Signals On M-59 3. Increase Lane Width On Schoenherr Rd From 10 Ft To 12 Ft. 4. Construct The Michigan Left Away From The Existing On South Bound Of Schoenherr Rd 5. Advance Warning Flashing Bacon At M59
2	M-59 Highland (EW) And Hays Rd (NS)	202	0.203	1.2.3	1. Signal Visibility Problem For EW Movement 2. Only One RT Lane On Westbound Traffic Though Higher Volume may cause rear end crashes 3. Higher Speed On M59 Causes Many Rear End Crashes	1. Mast Arm Signal Heads With Back Plates For Improving Visibility 2.Add RT Lane On West Bound M59 3.More Clearance Interval On Both Roads 4. Lane Guidance System Or Flashing Beacon On M-59
4	M59 Highland(EW) And Airport Road (NS)	213	0.192	2,1,3	1. Poor Progression 2.Steep Vertical Curve On North Bound Airport (Visibility Problem) 3. Short All Red Interval for M59 4. Signal Visibility Due To EW Movement On M59	1. Attain Progression 2. Flatter Grade On North Bound Airport Rd. 3. Allocate More All Red For M59 4. Mast Arm Signal Heads With Back Plates

Note: [1] Sl. No, Refer to Sl No of Table 4.4
[2]1. Rear End Crash, 2.Angle Crash, 3.Left Turn Head on Crash

Cont Table 5.66

Sl No[1]	Intersection	Frequency	Severity	Predominant Crashes[2]	Probable Causes	Countermeasures
7	US 24 (NS) And 10 Mile Rd (EW)	150	0.327	2,1,4	1. Michigan Left is Very Close To Intersection For US24 North Bound Before Intersection 2. Short All Red Interval for Both Streets 3.Higher Speed On US24 4. Poor Pavement Condition 5. Too Many Driveway Activities	1. Relocate Michigan Left On North Bound Approach Of US24 2.Modify Signal Timings 3.Speed Limit Signs 4. Improve Pavement Condition 5.Relocate Some Driveways
8	M-59 Highland (EW) And Garfield Rd (NS)	176	0.222	1,2,3	1. Poor Visibility Of Signals for EW Movement 2. Curve On South Bound Garfield When Approaching To Intersection 3. Short All Red Interval For M59 4. High Right Turning Volume At North Bound Garfield 5. High Speeds On M59 causes rear end crashes	1. Mast Arm Signal With Back Plates 2. Advance Intersection Sign Or Signals 3.Revise Clearance Interval 4. Add One Right Turn Lane At North Bound Garfield 5. Post Speed Limit on M-59
11	M-153 Ford Rd (EW) And Wayne Rd (NS)	166	0.247	1,2,3	1. Poor Progression 2.Insufficient Green Time For LT On Both Roads 3. Driveway Activities 4 Permissive Protective Left Turn For Ford Road 5. Heavy Through And Left Turning Traffic For Ford Road	1.Attain Progression 2. Make Ford LT Protected Only Instead Of P/P 3. Separate Entry/Exit Ways Divided By Median At Some Driveways 4. Install Left Turn T Mounted Signal Head For Ford Rd Left Turning Vehicle 5. Modify Signal Timings For Left Turns , Modify Signal Timings For Left Turns 6. Install Actuated Signal Controller

Note:

[1] Sl. No, Refer to Sl No of Table 4.4

[2]1. Rear End Crash, 2.Angle Crash, 3.Left Turn Head on Crash, 4. Side Swipe

Cont Table5.66

Sl No[1]	Intersection	Frequency	Severity	Predominant Crashes[2]	Probable Causes	Countermeasures
12	US 24 (NS) And Goddard Rd (EW)	159	0.239	2,1,3	1.Heavy Traffic Volume on US-24 2. High Speed on US-24 3. Absence Of Exclusive Right Turn Lane on South Bound US24 4. Heavy Right Turning Volume From Goddard 5. Poor Visibility Of Signals	1. Modify Signal Timings 2. Add Exclusive Right Turn Lane At South Bound US24 3. Install Advance Intersection Warning Flashing Beacon 4. Install Sign Of "No Turn On Red" At Goddard 5. Install Red Light Running Cameras
13	US-24 (NS) And Van Born Rd (EW)	159	0.208	1,3,2	1. Intersection Is Very Close To I-94 Interchange 2. Absence Of Exclusive Right Turn Lane At North Bound US24 3. Heavy Traffic Volume on US-24 4. Poor Visibility Of Signals And Sings 5. Wet Pavement Crashes	1. Provide Intersection Warning Sign/Beacon At Interchange 2.Add Exclusive Right Turn Lane At North Bound US24 3. Perform Spot Speed Study And Reduce Speed Limit 4. Provide Dynamic Message Sings 5.Treatment for Slippery Pavements
19	Vandyke (NS) And 7 Mile Rd (EW)	137	0.27	2,1,4	1. No Lane Markings On Any Approach 2. Too Congested Intersection 3. Heavy Traffic With many Driveways 4. Permissive Left Turn On Vandyke 5. No Left Turn Provision From East Bound 7 Mile 6. Only 2 Lanes On 7 Mile Approaches (No Marking) 7. Parking Is Permitted Near Intersection	1. Install Lane Markings 2.Redesign Phasing (Protected Left Turn For Vandyke) 3. Improve Sight Distance and Relocate Driveways 4. Install Separate Signal Heads For Left Turns and Phasing Redesign 5Add Right Turn Lane On 7 Mile Approaches 6. Prohibit Parking Within 500 Ft From Intersection

Note:
[1] Sl. No, Refer to Sl No of Table 4.4
[2]1. Rear End Crash, 2.Angle Crash, 3.Left Turn Head on Crash, 4. Side Swipe

Cont Table 5.66

Sl No[1]	Intersection	Frequency	Severity	Predominant Crashes[2]	Probable Causes	Countermeasures
22	M-59 Highland (EW) And Williams Lake Rd (NS)	140	0.214	1,3,2	1. Poor Progression 2. Short All Red Interval for both Streets 3. Higher Speeds on M-59 4. Pavement Surface Condition 5. Poor Visibility At Night (Lighting)	1. Attain Progression 2. Modify Signal Timings 3. Perform Spot Speed Study and Provide Appropriate Speed Limit 4. Pavement Condition Improvement 5.Install/Improve Intersection Lighting
25	M-153 Ford Rd (EW) And Inkster Rd (NS)	139	0.245	3,2,1	1. Poor Visibility Of Signals 2. Absence Of Lane Markings 3. Heavy Traffic Volume on Ford Rd 4. Too many Driveway Activities 5. Poor Progression	1. Install Mast Arm Signals With Back Plates 2. Pavement Markings 3.Signal Phasing Redesign (Provide Split Phase) 4. Redesign Driveway Activities 5.Separate Right Turn Lane And 2 Through Lanes At Ford 6.Attain Progression
27	M-3 Gratiot (NS)And 12 Mile Rd (EW)	137	0.241	2,3,1	1. Short All Red Interval for 12 Mile Rd 2. Poor Pavement Condition 3. Poor Sign And Intersection Ahead Information	1. Modify Clearance Interval 2. Improve Pavement Condition 3. Install Pavement Markings 4. Install Proper Signs

Note:
[1] Sl. No, Refer to Sl No of Table 4.4
[2]1. Rear End Crash, 2.Angle Crash, 3.Left Turn Head on Crash

Cont Table 5.66

Sl No[1]	Intersection	Frequency	Severity	Predominant Crashes[2]	Probable Causes	Countermeasures
28	US-24 (NS) And Maple Rd (EW)	134	0.201	1,2,4	1. Michigan Left Is Very Close To Intersection For North Bound US-24 Traffic 2. Short All Red Interval for Both Streets 3. Narrow Lane Width on West Bound Maple Road 4. Steep Vertical Curve On North Bound US24 (Visibility Problem)	1. Relocate Michigan Left 2. Modify Signal Timings 3. Increase Lane Width To 11ft On West Bound Maple 4. Flatten Grades to have proper visibility of the signal
33	M-59 Highland (EW) And Teggerdine Rd (NS)	76	0.421	3,2,1	1. No Pavement Markings On Teggerdine 2. Short All Red Interval for both streets 3. Vertical Curve On South Bound Teggerdine (Visibility Problem) 4. No Separate Signal Head For Left Turns 5. Permissive Left Turn Phase	1. Pavement Markings On Teggerdine 2.Modify Signal Timings 3. Provide Advance Intersection Signs On South Bound Teggerdine 4. Install Signal Head For Left Turns 5. Modify Signal Phasing
35	M-3 Gratiot And Martin Street	95	0.411	1,2,3	1. No Lane Markings On Pavement 2. Michigan Left Is Too Close To Intersection On North Bound And South Bound Gratiot 3. Poor Pavement Condition 4. Short All Red Interval for both Streets 5. Heavy Traffic On Gratiot	1.Pavement Marking On Both Approaches 2.Relocate M-Left 3.Improve Pavement Condition 4. Modify Clearance Interval 5.Add Lane On M-3 Gratiot

Note:

[1] Sl. No, Refer to Sl No of Table 4.4

[2]1. Rear End Crash, 2.Angle Crash, 3.Left Turn Head on Crash, 4. Side Swipe

Table 5.67: Summary of Economic Analysis

Intersection (Sl No.)	ALTERNATIVE-1		ALTERNATIVE-2					ALTERNATIVE-3				
	Improvements	CRF And Significance	Improvements	CRF And Significance	Costs And Benefits	MOE		Improvements	CRF And Significance	Costs And Benefits	MOE	
						TORabs (Years)	TORmar (Years)				TORabs (Years)	TORmar (Years)
M-153 Ford Rd And Wayne Rd (1)	Modify Green Time For Left Turns	CRF= 8% (Savings In Crashes Not Significant)	1. Make Ford LT Protected Only (Phasing Modification) 2. Modify Green Timing For Left Turns 3. Install LT Mounted Signal Head For Ford Left Turns 4. Achieve Progression	CRF1 = 25% CRF2 = 8% CRF 3 = 15% CRF4 = 12.5% Combined CRF= 48.68	**Costs** 1.Construction Cost = $27,700 2.Regular O &M = $15,000 3.Periodic O&M = $75000 @ 1,5,9 Benefits = $540,998 For First Year, Crash Savings I= 8, PDO=22	0-1		1. Install LT Mounted Signal Head For Ford Rd Left Turning Vehicle 2. Make Ford LT Protected Only Instead Of P/P 3. Modify Signal Timings For Left 4. Achieve Progression 5. Separate Entry/Exit Ways Divided By Median At Some Driveways 6. Install Actuated Signal Controller	CRF1 = 15% CRF2 = 25% CRF 3 = 8% CRF4 = 12.5% CRF5 = 10% CRF6 = 25% Combined CRF = 65.35%	**Costs** 1.Construction Cost = $58,700 2.Regular O &M = $15,000 3.Periodic O&M = $75000 @ 1,5,9 Benefits =$726,514 For First Year, Crash Savings I=10 , PDO=31	0-1	Alt-3* 0-1
											TORabs (Years)	TORmar (Years)
M-59 And Airport Rd (2)	1. Modify Signal Timings	CRF= 8% (Savings In Crashes Not Significant)	1. Install Mast Arm Signals With Back Plates 2. Modify Signal Timings 3. Attain Progression	CRF1=20% CRF1-1=20% CRF2=8% CRF3=12.5% Combined CRF=48.48%	**Costs** 1.Construction Cost = $221,500,2.Regular O &M = $15000 3.Periodic O&M = $75000 @ 1,5,9 Benefits = $602,204 For First Year ,Crash Savings I=8 , PDO=31	0-1		1. Attain Progression 2. Flatter Grade On NB Airport Rd. 3. Cut Down Yellow Interval And Allocate More All Red For M59 4. Mast Arm Signal Heads With Back Plates	CRF1=12.5% CRF2=40% CRF3=8% CRF4=20% CRF4-1=20%	**Costs** 1.Construction Cost = $331,500,2.Regular O &M = $15000 3.Periodic O&M = $75000 @ 1,5,9 Benefits = $776488 For First Year, Crash Savings I=11 , PDO=44	0-1	Alt-3* 0-1

Note:

- $ Equivalent for Savings in Crash, I=$49,700 and PDO =$7,400 and * : The Alternative Selected

Cont Table 5.67

Intersection (Sl No.)	ALTERNATIVE-1		ALTERNATIVE-2					ALTERNATIVE-3				
	Improvements	CRF And Significance	Improvements	CRF And Significance	Costs And Benefits	MOE		Improvements	CRF And Significance	Costs And Benefits	MOE	
						TORabs (Years)	TORmar (Years)				TORabs (Years)	TORmar (Years)
M-59 And Garfield Rd (3)	1. Revise Clearance Intervals	CRF= 8% (Savings In Crashes Not Significant)	1. Mast Arms Signals With Back Plates 2. Advance Intersection Signs Or Signals At M59 And SB Garfield	CRF1=20% CRF1-1=20% CRF2=20% Combined CRF=48.8%	**Costs** 1.Construction Cost = $231,000,2.Regular O &M = $15,000 3.Periodic O&M = $75,000 @ 1,5,9 Benefits = $542,383 For First Year , Crash Savings I=7 , PDO=26	0-1		1. Revise Clearance Interval 2. Mast Arm Signal With Back Plates 3. Add One Right Turn Lane At NB Garfield 4. Advance Intersection Sign Or Signals	CRF1=8% CRF2=20% CRF2-1=20% CRF3=20% CRF4=20% Combined CRF=62.31%	**Costs** 1.Construction Cost = $ 442,500,2.Regular O &M = $150,00 3.Periodic O&M = $75,000 @ 1,5,9 Benefits = $689,601 For First Year, Crash Savings I=9 , PDO=31	0-1	Alt-3* 0-1
M-3 Gratiot And 12 Mile Rd (4)	1. Modify Clearance Interval	CRF= 8% (Savings In Crashes Not Significant)	1. Modify Clearance Interval 2. Install Pavement Markings And Proper Signs 3. Improve Pavement Condition	CRF1=8% CRF2=20% CRF3=25% Combined CRF=44.8%	**Costs** 1.Construction Cost =$ 80,500 2.Regular O &M = $15,000 3.Periodic O&M = $75,000 @ 1,5,9 Benefits = $404,781 For First Year, Crash Savings I= 6, PDO=17	0-1	Alt2* 0-1					

Note:

- $ Equivalent for Savings in Crash, I=$49,700 and PDO =$7,400
- * : The Alternative Selected

Cont Table 5.67

Intersection (Sl No.)	ALTERNATIVE-1		ALTERNATIVE-2					ALTERNATIVE-3				
	Improvements	CRF And Significance	Improvements	CRF And Significance	Costs And Benefits	MOE		Improvements	CRF And Significance	Costs And Benefits	MOE	
						TORabs (Years)	TORmar (Years)				TORabs (Years)	TORmar (Years)
M-3 Gratiot And Martin Street (5)	1. Modify Clearance Interval	CRF= 8% (Savings In Crashes Not Significant)	1. Pavement Markings 2. Modify Clearance Interval 3. Add Lane On Each Approaches Of Gratiot	CRF1=15% CRF2=8% CRF3=20% Combined CRF=37.44%	**Costs** 1.Construction Cost = 431500 2.Regular O &M = 15000 3.Periodic O&M = 75000 @ 1,5,9 Benefits = 330279 For First Year, Crash Savings I=6 , PDO=7	0-1		1. Improve Pavement Condition 2. Relocate M-Left 3. Modify Clearance Interval 4. Add Lane O Each Approach Of Gratiot 5. Pavement Markings	CRF1=25% CRF2=25% CRF2-1=8% CRF3=20% CRF4=15% Combined CRF=64.81%	**Costs** 1.Construction Cost = $681,500,2.Regular O &M =$15,000 3.Periodic O&M = $75,000 @ 1,5,9 Benefits = $771,725 For First Year, Crash Savings I=10 , PDO=14	0-1	Alt-3* 0-1
M-59 And Hays Rd (6)	1. Modify Clearance Interval	CRF= 8% (Savings In Crashes Not Significant)	1. Mast Arm Signals With Back Plates 2. Advance Warning Flashing Beacon At M59 3. Modify Clearance Interval	CRF1=20% CRF1-1=20% CRF3=30% CRF4 = 8% Combined CRF=58.78%	**Costs** 1.Construction Cost = $ 235,500 2.Regular O &M = $15,000 3.Periodic O&M = $75,000 @ 1,5,9 Benefits = $711,737 For First Year, Crash Savings I=9 , PDO=36	0-1		1. Mast Arm Signals With Back plates 2.Advance Warning Flashing Beacon 3. Add RT Lane On WB M-59 4.Modify Clearance Interval	CRF1=20% CRF1-1=20% CRF2=30% CRF3=20% CRF4=8% Combined CRF=67.02%	**Costs** 1.Construction Cost = $435,500,2.Regular O &M =$15,000 3.Periodic O&M = $75,000 @ 1,5,9 Benefits =$ 811,543 For First Year, Crash Savings I=11 , PDO=40	0-1	Alt-3* 0-1

Note:

- $ Equivalent for Savings in Crash, I=$49,700 and PDO =$7,400
- * : The Alternative Selected

Cont Table 5.67

Intersection (Sl No.)	ALTERNATIVE-1		ALTERNATIVE-2					ALTERNATIVE-3				
	Improvements	CRF And Significance	Improvements	CRF And Significance	Costs And Benefits	MOE		Improvements	CRF And Significance	Costs And Benefits	MOE	
						TORabs (Years)	TORmar (Years)				TORabs (Years)	TORmar (Years)
M-59 Williams Lake Rd (7)	1. Modify Clearance Interval	CRF= 8% (Savings In Crashes Not Significant)	1. Attain Progression 2. Install/Improve Intersection Lighting 3. Reduce Speed Limit	CRF1=12.5% CRF2=30% CRF3=20% Combined CRF=51.00%	**Costs** 1.Construction Cost = $41,000 2.Regular O &M = $15,000 3.Periodic O&M = $75,000 @ 1,5,9 Benefits = $440,778 For First Year, Crash Savings I= 6, PDO=21	0-1		1. Attain Progression 2. Modify Signal Timings 3. Install/Improve Intersection Lighting 4. Reduce Speed Limit 5. Pavement Condition Improvement	CRF1=12.5% CRF2=8% CRF3=30% CRF4=20% CRF5=25% Combined CRF=64.81%	**Costs** 1.Construction Cost = $102,500,2.Regular O &M = $15,000 3.Periodic O&M = $75,000 @ 1,5,9 Benefits = $572,147 For First Year, Crash Savings I=7 , PDO=28	0-1	Alt-3 0-1
M-153 Ford Rd And Inkster Rd (8)	1. Modify Phasing	CRF= 15% (Savings In Crashes Not Significant)	1. Install Mast Arm Signals With Back Plates 2. Pavement Markings 3. Exclusive Right Turn Lane At Ford	CRF1=20% CRF1-1=20% CRF2=15% CRF3=20%Combined CRF=49.95%	**Costs** 1.Construction Cost =$ 416500 2.Regular O &M = $15,000 3.Periodic O&M = $75,000 @ 1,5,9 Benefits = $462,007 For First Year, Crash Savings I=7 , PDO=19	0-1		1. Signal Phasing Redesign (Provide Split Phase) 2. Separate Right Turn Lane And 2 Through Lanes At Ford 3. Install Mast Arm Signals With Back plates 4. Pavement Markings	CRF1=25% CRF2=30% CRF3=20% CRF3-1=20% CRF4=15% Combined CRF=71.44%	**Costs** 1.Construction Cost = $626,500,2.Regular O &M =$15,000 3.Periodic O&M = $75,000 @ 1,5,9 Benefits =$ 660,776 For First Year, Crash Savings I=9 , PDO=29	0-1	Alt-3* 0-1

Note:

- $ Equivalent for Savings in Crash, I=$49,700 and PDO =$7400
- * : The Alternative Selected

Cont Table 5.67

Intersection (Sl No.)	ALTERNATIVE-1		ALTERNATIVE-2					ALTERNATIVE-3				
	Improvements	CRF And Significance	Improvements	CRF And Significance	Costs And Benefits	MOE		Improvements	CRF And Significance	Costs And Benefits	MOE	
						Torabs (Years)	Tormar (Years)				Torabs (Years)	Tormar (Years)
US-24 And 10 Mile Rd (9)	1.Modify Signal Timings	CRF= 8% (Savings In Crashes Not Significant)	1. Modify Signal Timings 2. Relocate Some Driveways 3. Improve Pavement Condition	CRF1=8% CRF2=10% CRF3=25% Combined CRF=37.9%	**Costs** 1.Construction Cost =$ 81,500 2.Regular O &M = $15,000 3.Periodic O&M =$75,000 @ 1,5,9 Benefits =$452,287 For First Year, Crash Savings I=7 , PDO=15	0-1		1. Modify Signal Timings 2. Relocate M-Left On NB Approach Of US24 3. Relocate Some Driveways 4. Improve Pavement Condition	CRF1=8% CRF2=25% CRF3=10% CRF3-1=25% Combined CRF=53.425%	**Costs** 1.Construction Cost = $281,500,2.Regular O &M =$15,000 3.Periodic O&M = $75,000 @ 1,5,9 Benefits =$ 637,259 For First Year, Crash Savings I=10 , PDO=20	0-1	Alt-3* 0-1
US 24 And Goddard Rd (10)	1. Modify Signal Timing	CRF= 8% (Savings In Crashes Not Significant)	1. Add Exclusive Right Turn Lane At SB US24 2. Install Advance Intersection Warning Sign 3. Modify Signal Timings	CRF1=20% CRF2=30% CRF3=8% Combined CRF=48.48%	**Costs** 1.Construction Cost = $235,500 2.Regular O &M =$15,000 3.Periodic O&M = $75,000 @ 1,5,9 Benefits =$506,279 For First Year, Crash Savings I= 7, PDO=22	0-1		1. Install Red Light Running Cameras With Its Warning Sign 2. Install Advance Intersection Warning Sign 3. Install Sign Of "No Turn On Red" At Goddard 4. Modify Signal Timings 5. Add Exclusive Right Turn Lane At SB US24	CRF1=9% CRF2=30% CRF3=20% CRF4=8% CRF5=20% Combined CRF=62.49%	**Costs** 1.Construction Cost = $335,900,2.Regular O &M =$15,000 3.Periodic O&M = $75,000 @ 1,5,9 Benefits =$652,421 For First Year , Crash Savings I= 9, PDO=28	0-1	Alt-3* 0-1

Note:

- $ Equivalent for Savings in Crash, I=$49,700 and PDO =$7,400
- * : The Alternative Selected

Cont Table 5.67

Intersection (Sl No.)	ALTERNATIVE-1 Improvements	ALTERNATIVE-1 CRF And Significance	ALTERNATIVE-2 Improvements	ALTERNATIVE-2 CRF And Significance	ALTERNATIVE-2 Costs And Benefits	ALTERNATIVE-2 MOE Torabs (Years)	ALTERNATIVE-2 MOE Tormar (Years)	ALTERNATIVE-3 Improvements	ALTERNATIVE-3 CRF And Significance	ALTERNATIVE-3 Costs And Benefits	ALTERNATIVE-3 MOE Torabs (Years)	ALTERNATIVE-3 MOE Tormar (Years)
US 24 And Maple Rd (11)	1. Modify Signal Timings	ARF= 20% (Savings In Crashes Not Significant)	1. Flatten Slopes On NB And SB Telegraph 2. Increase Lane Width On WB Maple To 11 Ft 3. Modify Signal Timings	CRF1=40% CRF2=30% CRF3=8% Combined CRF=61.36%	**Costs** 1.Construction Cost =$ 471,500 2.Regular O &M = $15,000 3.Periodic O&M =$75,000 @ 1,5,9 Benefits =$490,905 For First Year, Crash Savings I=7 , PDO= 24	0-1		1. Relocate M-Left 2.Flatten Slopes On NB And SB Telegraph 3. Increase Lane Width On WB Maple To 11 Ft 4. Modify Signal Timings	CRF1=25% CRF2=40% CRF3=30% CRF4=8% Combined CRF=71.02%	**Costs** 1.Construction Cost = $661,500,2.Regular O &M =$15,000 3.Periodic O&M = $75,000 @ 1,5,9 Benefits =$ 668,189 For First Year, Crash Savings I= 8, PDO=28	0-1	Alt-3* 0-1
US 24 And Van born Rd (12)	1. Spot Speed Study And Check On Speed Limit	CRF= 20% (Savings In Crashes Not Significant)	1. Add Exclusive Right Turn Lane At NB US24 2. Provide Intersection Warning Sign/Beacon At Interchange 3. Spot Speed Study And Revise Speed Limit	CRF1=20% CRF2=30% CRF3=20% Combined CRF=55.2%	**Costs** 1.Construction Cost = $235,000,2.Regular O &M = $15,000 3.Periodic O&M = $75,000 @ 1,5,9 Benefits =$532,443 For First Year , Crash Savings I=7 , PDO= 26	0-1		1. Add Exclusive Right Turn Lane At NB US24 2. Perform Spot Speed Study And Reduce Speed Limit 3. Provide Intersection Warning Sign/Beacon At Interchange 4. Provide Dynamic Message Sings For Slippery Pavements	CRF1=20% CRF2=20% CRF3=30% CRF4=15% Combined CRF=61.92%	**Costs** 1.Construction Cost = $285,000,2.Regular O &M =$15,000 3.Periodic O&M = $75,000 @ 1,5,9 Benefits =$532,443 For First Year , Crash Savings I=8 , PDO= 29	0-1	Alt-3* 0-1

Note:

- $ Equivalent for Savings in Crash, I=$49,700 and PDO =$7,400
- * : The Alternative Selected

Cont Table 5.67

Intersection (Sl No.)	ALTERNATIVE-1		ALTERNATIVE-2					ALTERNATIVE-3				
	Improvements	CRF And Significance	Improvements	CRF And Significance	Costs And Benefits	MOE		Improvements	CRF And Significance	Costs And Benefits	MOE	
						TORabs (Years)	TORmar (Years)				TORabs (Years)	TORmar (Years)
Vandyke And 7 Mile Rd (13)	1. Install Pavement Markings	CRF= 15% (Savings In Crashes Not Significant)	1. Prohibit Parking Within 500 Ft From Intersection 2. Improve Sight Distance 3. Install Pavement Markings	CRF1=30% CRF2=35% CRF3=15% Combined CRF=61.32%	**Costs** 1.Construction Cost =$84,000 2.Regular O &M =$15,000 3.Periodic O&M = $75,000 @ 1,5,9 Benefits =$583,030 For First Year, Crash Savings I= 8, PDO=29	0-1		1. Add Right Turn Lane On 7 Mile 2. Redesign Phasing 3. Install Separate Signal Heads For Left Turns 4. Prohibit Parking 5. Improve Sight Distance 6 Pavement Markings	CRF1=20% CRF2=15% CRF3=10% CRF4=30% CRF5=35% CRF6=15% Combined CRF=76.33%	**Costs** 1.Construction Cost = $296,200,2.Regular O &M = $15,000 3.Periodic O&M = $75,000 @ 1,5,9 Benefits =$597,069 For First Year, Crash Savings I= 10, PDO=36	0-1	Alt-3* 0-1

Note:

- $ Equivalent for Savings in Crash, I=$49,700 and PDO =$7,400
- * : The Alternative Selected

Cont Table 5.67

Intersection (Sl No.)	ALTERNATIVE-1				ALTERNATIVE-2					ALTERNATIVE-3				
	Improvements	CRF And Significance	Costs And Benefits	MOE	Improvements	CRF And Significance	Costs And Benefits	MOE		Improvements	CRF And Significance	Costs And Benefits	MOE	
				TORabs				TORabs (Years)	TORmar (Years)				TORabs (Years)	TORmar (Years)
M-59 And Schoenherr (14)	1. Advance Warning Flashing Beacon On M59	ARF= 30%	**Costs** 1.Construction Cost = $14,000 2.Regular O &M =$15,000 3.Periodic O&M = $75,000 @ 1,5,9 Benefits =$514,227 For First Year, Crash Savings I= 7, PDO=26	0-1	1. Mast Arm Signals With Back Plates 2. Remove Near-Far Signal Heads And Install On One Type 3. Advance Warning Flashing Beacon On M59	CRF1=20% CRF1-1=20% CRF2=20% CRF3=30% Combined CRF=64.16%	**Costs** 1.Construction Cost = $224,000 2.Regular O &M =$ 15,000 3.Periodic O&M = $75,000 @ 1,5,9 Benefits =$109,7123 For First Year, Crash Savings I= 14, PDO=56	0-1	Alt-2	1. Mast Arm Signal Heads With Back Plates To Improve Visibility 2. No Need Of Near And Far Signals On M-59 3. Increase Lane Width On Schoenherr Rd From 10 Ft To 12 Ft. 4. Construct The M-Left Away From The Existing On SB Of Schoenherr Rd 5. Advance Warning Flashing Beacon At M59	CRF1=20% CRF1-1=20% CRF2=20% CRF3=30% CRF4 =25% CRF5= 20% Combined CRF=78.49%	**Costs** 1.Construction Cost = $934, 000, 2.Regular O &M =$ 15,000 3.Periodic O&M = $75,000 @ 1,5,9 Benefits = $1,345,690 For First Year, Crash Savings I=17 , PDO= 69	0-1	Alt-3* 0-1

Note:

- $ Equivalent for Savings in Crash, I=$49,700 and PDO =$7,400
- * : The Alternative Selected

Cont Table 5.67

Intersection (Sl No.)	ALTERNATIVE-1				ALTERNATIVE-2					ALTERNATIVE-3				
	Improvements	CRF And Significance	Costs And Benefits	MOE	Improvements	CRF And Significance	Costs And Benefits	MOE		Improvements	CRF And Significance	Costs And Benefits	MOE	
				TORabs				TORabs (Years)	TORmar (Years)				TORabs (Years)	TORmar (Years)
M-59 And Teggerdine Rd (15)	1. Modify Signal Timings And Phases	CRF1= 8% CRF1-1=25% Combined CRF=31%	**Costs** 1.Construction Cost =$14,000 2.Regular O &M =$15,000 3.Periodic O&M = $75,000 @ 1,5,9 Benefits =$514,227 For First Year, Crash Savings I= 4, PDO=5	0-1	1. Modify Signal Timings And Phases 2. Install Signal Head For Left Turns 3. Provide Pavement Markings On Teggerdine	CRF1=8% CRF1-1=25% CRF2=15% CRF3=15% Combined CRF=50.14%	**Costs** 1.Construction Cost =$172,000 2.Regular O &M =$15,000 3.Periodic O&M = $75,000 @ 1,5,9 Benefits =$360,212 For First Year, Crash Savings I= 6, PDO=8	0-1	Alt-2	1. Modify Signal Timings And Phases 2. Provide Advance Intersection Sign On SB Teggerdine 3. Provide Pavement Markings On Teggerdine 4. Install Signal Heads For Left Turns	CRF1=8% CRF1-1=25% CRF2=30% CRF3=15% CRF4 =15% Combined CRF=65.10%	**Costs** 1.Construction Cost = $174,500,2.Regular O &M = $15,000 3.Periodic O&M = $75,000 @ 1,5,9 Benefits = $467,687 For First Year, Crash Savings I= 8, PDO=10	0-1	Alt-3* 0-1

Note:

- $ Equivalent for Savings in Crash, I=$49,700 and PDO =$7,400
- * : The Alternative Selected

6. SUMMARY

This study was undertaken with the prime objective of developing a toolbox for MDOT to be used as a guidebook for safety improvement programs for urban intersections. Other objectives of this study were to conduct a comprehensive literature review with particular emphasis on Accident Reduction Factors and to demonstrate the use of guidelines through a series of case studies.

This report presented in five chapters provides a detailed account of the project activities. Additionally a separate report, entitled "A Toolbox for A Selecting Safety Improvement Projects" has been developed as a stand-alone document to be used by practiceneers as a guidebook for planning, designing and implementing safety improvement projects for urban intersections. Chapters 1, 2, 3 of this report provide brief introduction of the problem, literature review (on the development of Accident Reduction Factors, Identification of Hazardous Locations and Economic Analysis Techniques) and a brief discussion of the study area. Chapter 4 is on research methodology, where the authors discuss the major steps used in selecting safety projects within the study area including the identification of hazardous sites; collection of data on traffic operation, and crashes, preparation of condition and collision diagrams, identification of predominant crash patterns, probable causes of crashes, countermeasures and economic evaluation of alternatives. Chapter 5 documents twenty case studies in two groups demonstrating the application of procedures developed. For each case study presented, detailed documentation of the analyses conducted are recorded electronically on individual files and can be made available to MDOT if necessary.

The toolbox developed as a separate document represents the synthesis of the entire study and is designed to be used as a stand-alone document that can be used by MDOT in developing a safety program, consisting of a number of safety projects at urban arterials. Even though the case study applications presented in chapter 5 are all related to Detroit Metropolitan area, the toolbox is not necessarily designed for any specific urban area. Rather, the authors believe that it can be used for any urban area in Michigan.

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