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Toolbox for Safety Improvements for Urban Arterials

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A TOOLBOX FOR SELECTING SAFETY IMPROVEMENT PROJECTS

A toolbox for selecting safety improvement projects at urban intersections is presented in this section with the object of providing a set of guidelines for MDOT in implementing its highway safety program. This toolbox indeed represents a synthesis of the research presented in the earlier chapters of this report.

Traffic accidents claim the lives of more than 40,000 people in the U.S. every year. Michigan is the eleventh highest state in roadway fatalities in the U.S., with more than 1,200 fatalities per year. The state trunk line in Southeast Michigan is characterized by high congestion and a large number of crashes compared to other regions.

The state of Michigan covers 122,000 miles of highways that generate approximately 101.8 billion vehicle miles of travel annually. In the year 2004, there were 373,028 highway crashes in Michigan, which include fatalities, injuries and property damages. Highway crashes in the state have been declining over the years, thanks to the hazard mitigation efforts undertaken by MDOT in cooperation with local and regional agencies. In spite of this decline, the economic loss in the state resulting from highway crashes is estimated to exceed $9.5 billion annually.

A review of state-wide crash data by roadway functional classification shows that arterials and collectors are associated with a large number of fatal crashes. For example, 64% of the 1,055 fatal crashes in the state occurred at arterials and collectors in 2004. By contrast, only 10% of these crashes occurred at freeways and expressways, even though these are among the most heavily traveled facilities in the state. These figures reveal that highway facilities with better design features are likely to be safer compared to other roadways.

Traffic crashes occur at various roadway locations. An analysis of the crash data by location shows that approximately 75% of all fatal crashes in the state occur at intersections. Also, 48% of all crashes typically occur at signalized intersections. The total number of crashes in the southeast Michigan region for the year 2004 is more than 150,000, a large fraction of which occurred at intersections. The region has more than 25,000 intersections on its state trunk lines. Further analysis of the crash data showed that:

- approximately 1,167 intersections experienced more than 10 accidents during the last three-year period.
- 463 of these 1,167 intersections experienced more than 30 accidents during the same period.
- Of these 463 intersections, more than 300 experienced accident severities exceeding 0.25, where severity is defined as the ratio of injury accidents to total accidents.

Clearly, any action plan targeted to reduce losses due to highway crashes should focus on intersections, signalized or stop-controlled.

The process described in this section is "driven" by crash data, and is built upon the premise that intersections that experience a large number of crashes that inflict high levels of injuries are hazardous. The authors realize that this process may not necessarily "capture" all hazardous sites in the study area. Accidents, by their very nature, are random events, and there may be sites that are hazardous, and yet have not experienced a large number of accidents (1, 2). The authors hence recommend that accident records over a sustained period, a minimum of three years, be considered in selecting hazardous sites. The following steps are considered critical in selecting safety improvement projects.

1. Identification of Hazardous Sites
2. Review of Accident Reports
3. Development of Condition and Collision Diagram
4. Identification of Probable Causes and Development of Countermeasures
5. Determination of CRF's
6. Development of Mutually Exclusive Alternatives
7. Statistical Evaluation
8. Economic Analysis of Mutually Exclusive Alternatives
9. Project Identification

Identification of Hazardous Locations

In Chapter 2 of this report, a brief review of two broad categories of techniques for selecting high accident locations was presented:

- Conventional techniques
- Emerging techniques

Note, all of these techniques are dependent upon accident data in a macroscopic (aggregate) sense, and are based upon the assumption of a high correlation between accidents and hazards. Under conventional techniques, a set of procedures ranging from one dimensional Frequency Method to two dimensional Rate-Frequency and other methods were discussed. While each of these methods has its specific advantages/disadvantages, the selection of a particular method for a given program depends primarily upon the availability of data. For example, all rate-based techniques (Accident Rate, Rate Frequency, Hazard Index Method, and Rate Quality Control), require exposure or volume data on all streets comprising the intersection (3). Thus, a rate-based technique cannot be used in situations where such comprehensive volume data is not available.

Among the emerging techniques, the Empirical Bayes (EB) Method appears to have high promise because of its ability to address the regression-to-the-mean effect, a factor that is considered a serious disadvantage to the conventional techniques (4). However, EB techniques are still under development, and require the development of site-specific Safety Program Functions (SPF), that must be properly calibrated with local data. Further, the development SPF's requires the availability of exposure data. Little research is reported in the literature on the transferability of SPF's from one region to another.

In the case studies presented earlier in this report, the authors used a two dimensional Frequency Severity Method, based upon availability of data and other project constraints. While one dimensional techniques based upon Frequency and Severity have been used in the past, their integration into a two-dimensional matrix will ensure that sites with high frequency and/or high accident severity are captured in the analysis. Further, for the study area, it was found that the incidence of high frequency and high severity at a given site is a rare event. The use of the two-dimensional technique proposed by the authors is designed to ensure that sites with high frequency and/or high severity are identified (5). The use of the EB technique, although promising, was not considered feasible because of a need to develop SPF's that require a substantial database for calibration and validation.

In Chapter 3, the authors demonstrate how the initially identified 463 intersections (with a frequency of 10 accidents/year) were narrowed down to 36 critical sites, with 28 sites based upon frequency, and 8 based upon severity (Table 1). The procedure presented can be used to identify different levels of critical sites, depending upon the specific study needs. Tables 2 and 3 are suggested formats for databases that can be created from crash and exposure data, and that can be used to identify critical sites following the conventional techniques. The suggested two-dimensional Frequency-Severity Method is a part of the conventional techniques, even though its actual use is rare.

Review of Crash Records

The database contained in the Safety Management System (SMS) of MDOT's Transportation Management System (TMS) contains detailed information on all reported accidents, as recorded on site. This information should be initially reviewed for consistency and then be used for developing collision diagrams. Collision diagrams, in conjunction with condition diagrams are useful in identifying possible patterns, and for developing countermeasures, as discussed below. Table 4 is shown as a sample of database format based upon a review of crash data.

Ideally, all accident records at a given site should be reviewed. For the Detroit metro area, the highest number of accidents reported at a given site over the 3 year period (2001-2004), is approximately 370, requiring as many UD-10 reports to be reviewed for that site. If this is not possible because of project constraints, the authors suggest that all fatal and injury accidents be reviewed, and PDO crashes be reviewed on a sampling basis (a minimum of 20% sample is recommended).

Table 1: Selected 36 Intersections

Site Number	Selection Type	TRKNAME	XRDNAME	TOT	INJ	FAT	SEV
1	Based on Frequency	M59 HALL RD	SCHOENHERR RD	292	57	1	0.199
2		M59 HALL RD	HAYES RD	202	41	0	0.203
3		M3 GRATIOT	PROMENADE ST	221	43	0	0.195
4		M59 HIGHLAND	AIRPORT RD	213	41	0	0.192
5		M97	METRO PKWY	184	60	0	0.326
6		M3 GRATIOT	MASONIC DR	159	54	0	0.34
7		US24	TEN MILE RD	150	49	0	0.327
8		M59 HALL RD	GCRFIELD RD	176	39	0	0.222
9		M59 HIGHLAND	CRESCENT LAKE RD	172	39	0	0.227
10		M8 DAVISON	W DAVIS/N I75	166	39	0	0.235
11		M153 FORD RD	WAYNE RD	166	41	0	0.247
12		US24	GODDARD RD	159	38	0	0.239
13		US24	VAN BORN RD	159	33	0	0.208
14		US24	FRANKLIN RD	154	38	0	0.247
15		M39 SOUTHFLD	DIX TOLEDO HWY	151	36	0	0.238
16		M97	15 MILE RD	138	43	0	0.312
17		M153 FORD RD	N MERCURY DR	133	39	1	0.301
18		US24	FRANKLN,CIVIC CNTR	145	38	0	0.262
19		M53 VAN DYKE	7 MILE RD	137	36	1	0.27
20		M102 8 MILE	DEQUINDRE AVE	136	38	0	0.279
21		US24	I96 SERVICE DRIVES	147	31	0	0.211
22		M59 HIGHLAND	WILLIAMS LAKE RD	140	30	0	0.214
23		M1 WOODWARD	S WOODWARD AVE	140	30	0	0.214
24		M150	HAMLIN RD	140	32	0	0.229
25		M153 FORD RD	INKSTER RD	139	34	0	0.245
26		M24	HARMON ST	138	32	0	0.232
27		M3 GRATIOT	12 MILE RD	137	33	0	0.241
28		US24	MAPLE RD	134	27	0	0.201
29	Based on Severity	US12 MICH	JOHN DALY RD	40	17	1	0.45
30		M29 23 MILE	SEATON RD	34	15	1	0.471
31		M97 HOOVER	GREINER AVE	32	15	0	0.469
32		M59 HIGHLAND	WHITTIER ST	32	14	0	0.438
33		M59 HIGHLAND	TEGGERDINE RD	76	32	0	0.421
34		M153 FORD RD	ARTESIAN,AUTO CLUB	38	15	1	0.421
35		M3 GRATIOT	MARTIN ST	95	39	0	0.411
36		US24	KING RD	62	25	0	0.403

Table 2: Domain of Crash Locations

General Information		**Site Information**	
Analyst	______	Area Type	______
Agency	______	Location Type (s)	______
Date Performed	______	Jurisdiction	______
Analysis Period	______	Analysis Year	______

Input Data

Site Number	Control Type	CS Name	Crash Frequency	Fatality	Injury	PDO	SEV
	(A). Signalized Intersections						
	1						
	2						
	.						
	.						
	k						
	(B). Stop Signs						
	1						
	2						
	.						
	.						
	k						
	(C) Mid-Blocks						
	1						
	2						
	.						
	.						
	k						
	(D) Freeway						
	1						
	2						
	.						
	.						
	k						

Priority Selection

Priority	Crash Frequency	Fatality	Injury	Comments
Priority-1				
Priority-2				
Priority-3				
Priority-4				

Table 3: Identification of Hazardous Locations (Ref, 5)

IDENTIFICATION OF HAZARDOUS LOCATIONS								
1	2	3	4	5	6	7	8	9
Site Number	AADT	Accident Frequency	Accident Rate	Frequency Rate	Rate Quality Control	EPDO	RSI	Severity
1								
2								
.								
.								
N								
CRITICAL VALUE								
Xc								
Comments								

Table 4: Database Developed Based upon Review of Crash Reports

IDENTIFICATION OF HAZARDOUS LOCATIONS																							
1	2	3	4	5		6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Site Number	Crash Frequency						Surface Type For Majority of Crashes				Crash Type												
	Fatality	Injury-A	Injury-B	Injury-C	PDO	Total	Icy	Wet	Dry	Other	Rear-End	Right-Angle	LTHO	SS-SD	SS-OD	Head On	Fixed Object	Pedestrian	Backed Into	Parked Vehicle	Driveway Related	Other	Total
1																							
2																							
3																							
4																							
5																							
6																							
7																							
8																							
9																							
10																							
.																							
.																							
k																							
TOTAL																							

Development of Condition and Collision Diagram

A condition diagram is designed to depict the geometric (number of lanes, configurations, etc.), operational (signals, other traffic control devices, etc.), and locational features (fixed objects, utility poles) of the intersection. A collision diagram, on the other hand, provides a visual representations of the types of accidents, their exact locations, all plotted on the locational geometry. A collision diagram depicting all accidents by type (severity, PDO), along with the condition diagram usually leads to the identification of probable causes, and the development of countermeasures. Figures 1 and 2 show typical condition and collision diagrams that should be developed for safety improvement programs.

Predominant Crash Patterns and Countermeasures

Predominant crash patterns are those, which comprise a very high percentage of total crashes. These can be identified from the collision diagrams. Some of the predominant crashes identified for the intersections studied in this research are:

- Rear End Crashes
- Angle Crashes
- Left Turn Head on Crashes
- Sideswipe – Same Direction Crashes
- Driveway related Crashes

Once predominant crash patterns are identified, these should be related to the geometric and operational features of the intersection. This process of relating crash patterns to operational and geometric features should lead to the identification of probable causes and countermeasures. Countermeasures should be selected based upon information available in the literature. Countermeasures can be designed either to prevent crashes or to reduce severity of crashes. Table 5 shows a typical data format relating predominant crash patterns to probable causes and countermeasures.

Determination of Crash Reduction Factors (CRF)

Crash Reduction/Modification Factors (CRF/CMF) are used in safety improvement projects to predict expected reductions in the number of accidents (all, injury, PDO) resulting from the installation of engineering countermeasure. Before and after study methods and cross-sectional method have been used to develop CRF's, the former one being most widely used. Literature review clearly shows that states use various sources of information in developing CRF's. Some states evaluate their safety improvement projects to estimate reduction in accidents, while others utilize 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 location. A complete discussion of the development of CRF's/CMF's has been presented in Chapter 2 of this report.

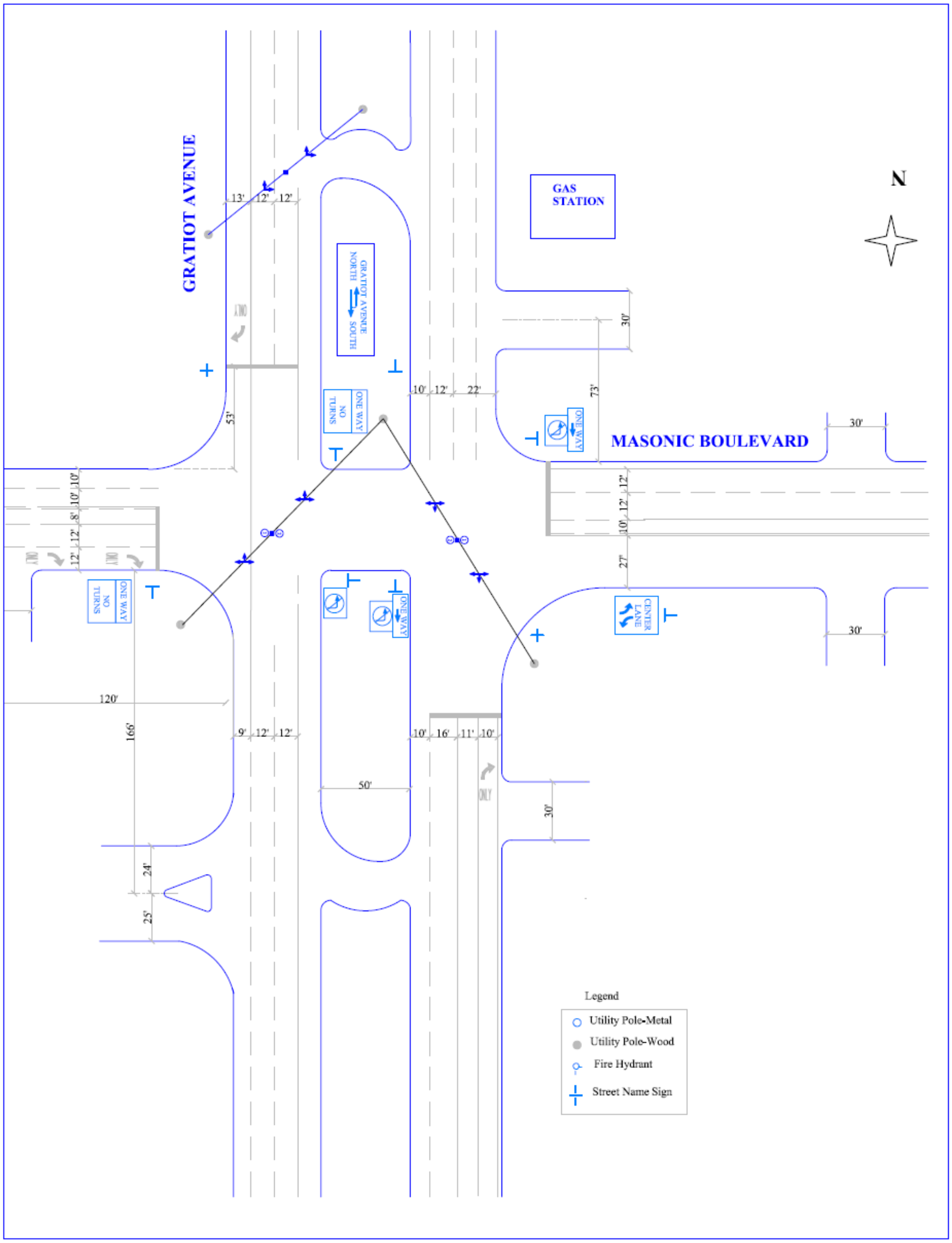

Figure 1: A Sample Condition Diagram

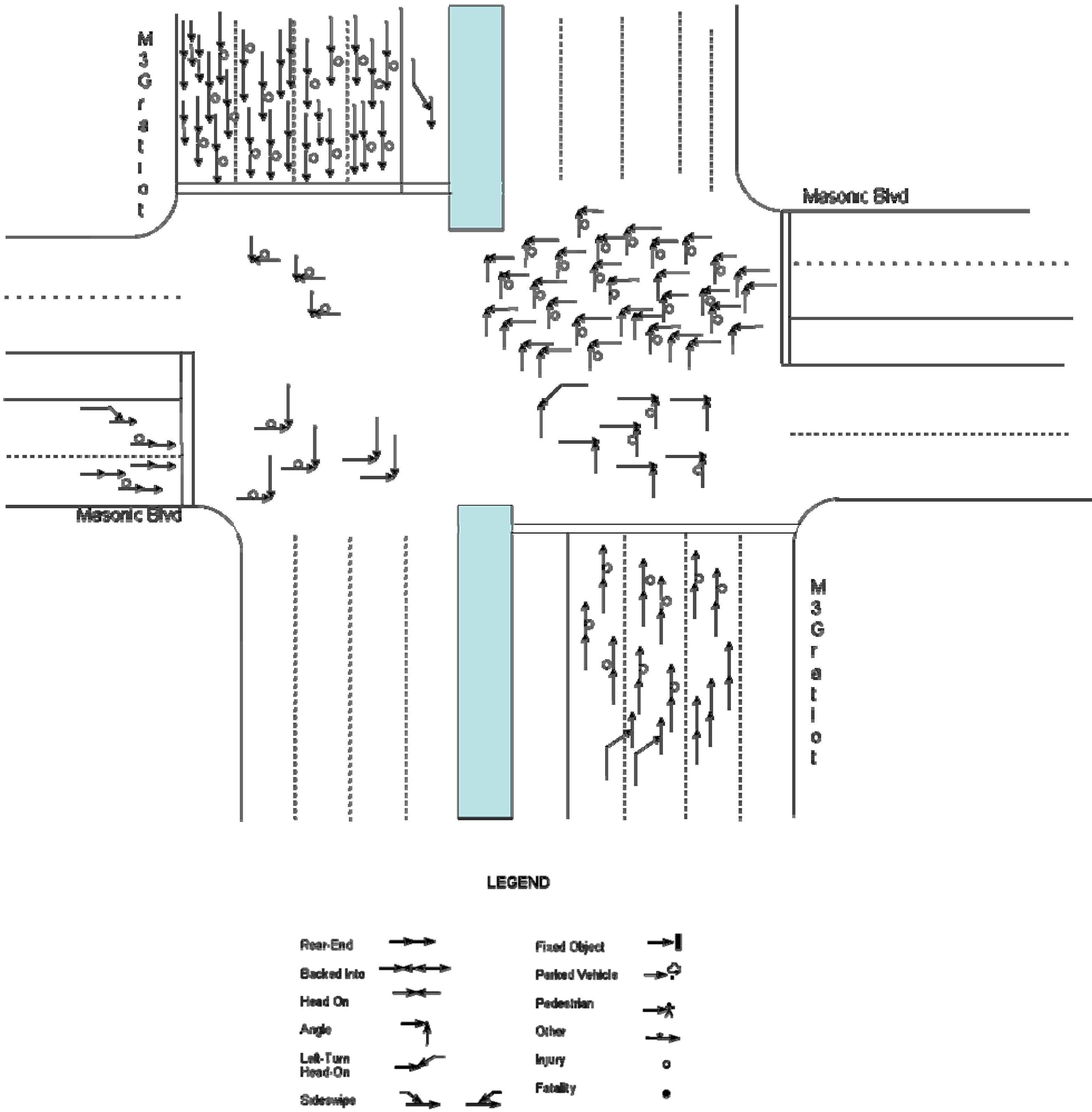

Figure 2: Sample Collision Diagram

Table 5: Predominant Crash Patterns, Probable Causes and Countermeasures

PRDOMINANT CRASH PATTERNS, PROBABLE CAUSES AND COUNTERMEASURES								
	Predominant Crash Patterns							
Site Number	P-1		P-2		P-3		Countermeasures	
		i		i		i	i	
		ii		ii		ii	ii	
	Probable Causes	iii	Probable Causes	iii	Probable Causes	iii	iii	
		iv		iv		iv	iv	
1		v		v		v	v	
		i		i		i	i	
		ii		ii		ii	ii	
	Probable Causes	iii	Probable Causes	iii	Probable Causes	iii	iii	
		iv		iv		iv	iv	
2		v		v		v	v	
. .								
		i		i		i	i	
		ii		ii		ii	ii	
	Probable Causes	iii	Probable Causes	iii	Probable Causes	iii	iii	
		iv		iv		iv	iv	
k		v		v		v	v	
Comments								

Based upon the review of literature presented above, a comprehensive list of type of countermeasures and respective reduction factors in percentage has been prepared. Appendix A (Tables A.1 to A.71) summarizes CRF's from various sources according to type of safety improvements, which has been divided in the following eight major categories:

- Channelization Improvements
- Construction/Reconstruction Improvements
- Illumination Improvements
- ITS Related Improvements
- Pavement Improvements
- Pedestrian Safety Improvements
- Realignment
- Regulation Improvements
- Roadway And Traffic Sign Improvements
- Roadway Delineation And Pavement Marking Improvements
- Separating Devices
- Traffic Signal Improvements

The authors suggest the CRF database presented in Appendix A be used in safety evaluation, and the list be updated periodically by MDOT. Further, in the case when CRF's for the same/similar countermeasure are available from different sources, a conservative approach should be taken. This would imply selecting the lowest CRF, or the mean of the available data. If the data shows the presence of 'outliers' these may be discarded at the discretion of the user, as the 'outliers' may have a tendency to 'distort' the mean. The use of CRF for single countermeasure or multiple countermeasures has been demonstrated in Chapter 5. Table 6 shows a typical representation of CRF data for countermeasures selected for different sites.

Determination of Mutually Exclusive Alternatives

Many times it may be possible to identify a number of mutually exclusive alternatives, each alternative consisting of a set of countermeasures. It is generally recommended that all viable alternatives should be considered, and the selection of the optimal project should be based upon consideration of all project costs and benefits. Further, the project that costs the least is not necessarily the best one, and the one that costs the most should not necessarily be eliminated. Once the framework of costs and benefits are established, all costs and benefits associated with a given alternative within the defined framework should be considered. The project that provides the highest benefit to the tax-payer should be the one selected for implementation.

Additionally, the project benefits (measured in terms of savings in accident costs) should be statistically significant, compared to the current levels of accidents at the project site. Thus two independent evaluations (statistical and economic) are involved in the final project selections. These are discussed in the next section. Before these two evaluations are completed, one must identify a set of viable alternatives, each alternative consisting of a single or multiple countermeasures. Table 7 shows a suggested format for compiling information on mutually exclusive alternatives

Table 6: Crash Reduction Factors for Proposed Countermeasures

CRASH REDUCTION FACTOR				
Site Number	Proposed Countermeasures		CRF Associated with Countermeasures	
1	C-1	:	CRF-1	
	C-2	:	CRF-2	
	C-3	:	CRF-3	
	C-4	:	CRF-4	
2	C-1	:	CRF-1	
	C-2	:	CRF-2	
	C-3	:	CRF-3	
	C-4	:	CRF-4	
3	C-1	:	CRF-1	
	C-2	:	CRF-2	
	C-3	:	CRF-3	
	C-4	:	CRF-4	
.			.	
.			.	
.			.	
.			.	
.			.	
.			.	
.			.	
.			.	
.			.	
.			.	
k	C-1	:	CRF-1	
	C-2	:	CRF-2	
	C-3	:	CRF-3	
	C-4	:	CRF-4	
Comments				

Table 7: Data Format for Compiling Crash Reduction factors for the Mutually Exclusive Alternatives

Site Number	Alternatives	CRF		Combined CRF
		CRF-1 =		
		CRF-2 =		
	A-1	CRF-3 =		
		.		
		CRF-k =		
		CRF-1 =		
		CRF-2 =		
1	A-2	CRF-3 =		
		.		
		CRF-k =		
		CRF-1 =		
		CRF-2 =		
	A-3	CRF-3 =		
		.		
		CRF-k =		
.				
.				
.				
		CRF-1 =		
		CRF-2 =		
	A-1	CRF-3 =		
		.		
		CRF-k =		
		CRF-1 =		
		CRF-2 =		
N	A-2	CRF-3 =		
		.		
		CRF-k =		
		CRF-1 =		
		CRF-2 =		
	A-3	CRF-3 =		
		.		
		CRF-k =		

Formulae Used for Combined CRF = ______________________________

Comments ______________________________

____

Conduct Statistical Test of Significance

The purpose of this test is to ensure that the projected reduction in crashes derived through the use of CRF's after the implementation of the countermeasures identified is statistically significant at a specified level. In other words, this test is likely to attest that the predicted reduction is not caused by random error, and that it is indeed attributable to the countermeasure or the set of countermeasures contained in each alternative.

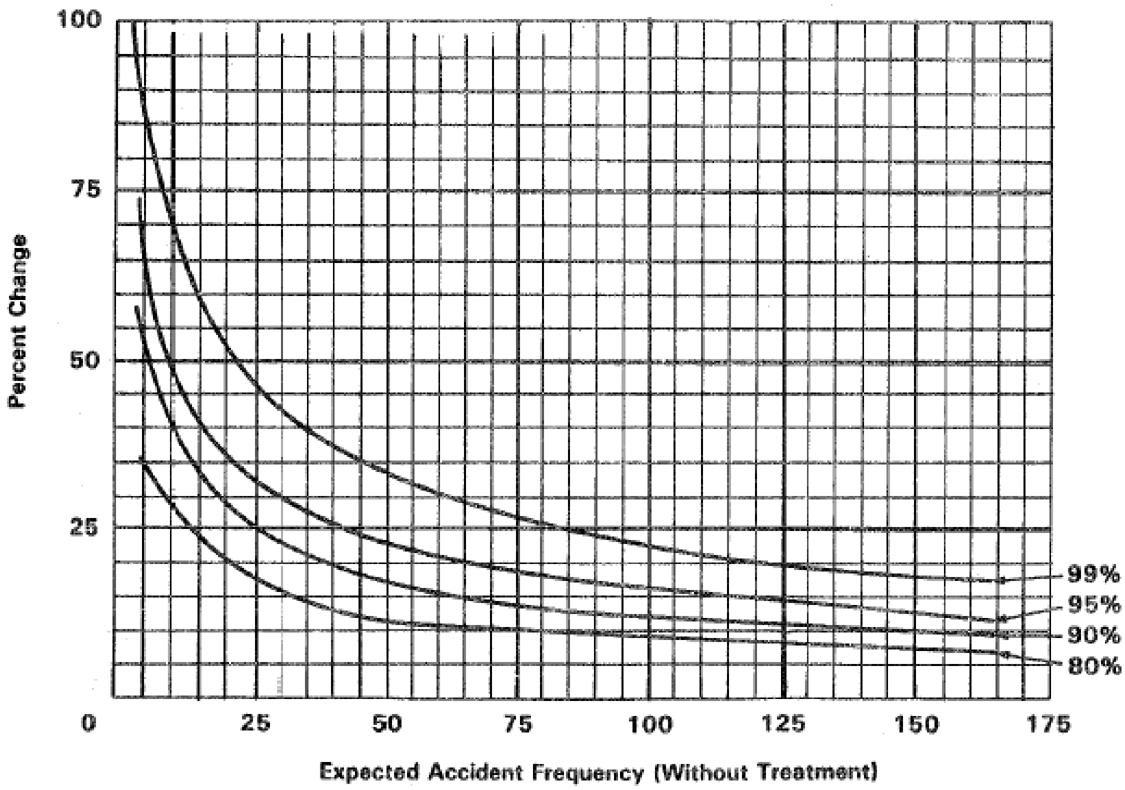

Figure 3: Poisson Curves for Crash Evaluation (Ref: 3)

The above test is accomplished by the use of Poisson curves shown in Figure 6.2, for various levels of confidence. The authors recommend the use of a 90% level of confidence. If, for example, the expected accident frequency without the treatment is 50 per year, then at a 90% level, there must be a minimum 17.5% reduction in accidents/year, in order for the countermeasure(s) to be statistically significant in reducing crashes. Further, the above statement can be asserted with a 90% confidence, implying that there is a 10% chance that the above conclusion can be erroneous. Note that if the expected frequency without any treatment is 75, it will take approximately 13.5% reduction in crashes for a similar statistical conclusion to be derived. As Figure 3 shows, with higher frequencies without treatment, the required percentage of reduction is smaller initially, but ultimately "flattens" out, as the frequency increases. Further, higher levels of confidence are associated with higher percentage changes in crashes. For example, in the cases 50 crashes/year without treatment, it will take a 32.5% reduction for the improvement to be significant at 99% level of confidence, implying that there is only 1% chance that this above conclusion is erroneous.

Lastly, the Poisson analysis discussed above can be conducted either at the crash level, or at the injury level (fatality, injury and PDO). Sample tables for conducting Poisson analysis are presented in Table 8. When dealing with a set of mutually exclusive alternatives, those alternatives that do not qualify the statistical test should be eliminated from further analysis. Only those alternatives, that qualify, should be considered for economic analysis, as discussed in the next step. These are termed as viable alternatives.

Economic Evaluation of Mutually Exclusive Alternatives

Economic analysis is a critical component of a comprehensive project or program evaluation methodology used to select safety improvement projects. It allows highway agencies to identify, quantify, and value the economic benefits and costs of the project over the life of the project. The five economic analysis techniques, that are used by different states, B/C Ratio, IRR, C/E, NPV and TOR have been discussed in detail in Chapter 2.

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 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.

Hence, this toolbox only presents the procedures to be followed in applying the TOR technique in the evaluation of highway safety projects.

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 challenging task for the agency. Since a budget is not specified in the study, the incremental cost analysis technique is recommended in selecting the best alternatives from a mutually exclusive set.

Lastly, as illustrated in Chapter 5, the benefits associated with the safety projects, do not only include the savings in accidents or reductions in severity, but also may include operational benefits including savings in travel time, road user costs, etc. MDOT has, in the past, used a conservative approach in benefit assessment, and has only considered safety benefits, the contention being that a safety project selected should be justified on the basis of safety alone, and other operational benefits, if any, are not to be used in justifying the projects. Hence, the guidelines presented here are based upon the consideration of safety benefits only. A total of twenty case studies on economic analysis have been presented in Chapter 5. Of these, five case studies include the application of all five techniques, using both safety and operational benefits. The remainder fifteen case studies show the application of TOR technique using safety benefits only.

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

(A/F) = Sinking Fund Factor
(A/P) = Captial Recovery Factor
EUAB = Equivalent Uniform Annual Benefit ($/year)
EUAC = Equivalent Uniform Annual Cost ($/year)
CC = Initial Cost (assumed to be incurred one year prior to operation)
i = Interest rate used (%, annual)
MARR = Minimum Attractive Rate (%, annual)
NPW = Net Present Worth = PWOB – PWOC ($)
t = Project life (years)
n = Pay off period (PP)(years)
n_i = Year when periodic expenditures are incurred ($n_i < t$)
(P/A) = Present Worth Factor (Uniform Series)
(P/F) = Present Worth Factor (Single Payment)
(PP) = Pay off Period (years)
PWOB = Present Worth of Benefit ($)
PWOC = Present Worth of Cost ($)
S = Salvage Value ($)
R_{om} = Recurring operating and Mtc. Cost (annual)
P_{om} = Periodic Operating and Mtc. Cost
B = Annualized Project Benefits (savings in crashes)
g = Traffic growth rate in %

The TOR technique is used when "the time taken by the project to pay for itself" is the desired answer. The algorithm used is based upon the premise that the pay-off period is the period at which the Net Present Worth (NPW) of the project (being the difference between the Present Worth of Cost and the Present Worth of Benefit) is zero at a specific interest rate. Alternatively, the pay-off period is the period at which the Net Annual Worth (NAW), being the difference the EUAB and the EUAC is zero. Using the latter definition, the algorithm is:

NAW = 0
EUAB = EUAC

$$R_{om} + P_{om}\left[\left(\frac{P}{F}\right)_{n=1} + \left(\frac{P}{F}\right)_{n=2} \ldots\ldots + \left(\frac{P}{F}\right)_{n=n}\right] \times \left(\frac{A}{P}\right)_{n=?} + CC\left(\frac{F}{P}\right)_{n=1}\left(\frac{A}{P}\right)_{n=?} - S\left(\frac{A}{F}\right)_{n=t}$$

$$= B\left(\frac{P}{A}\right)_{g} \times \left(\frac{A}{P}\right)_{n=?}$$

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.

The above equation can be solved either manually or through the use of the Excel software. The manual process entails a trial and error approach where the number of years is changed systematically, until a solution to the above equation is reached. Many a time, the 'convergence' of the final solution may take a number of iterations. Hence, the solution using the Excel software is recommended.

When dealing with mutually exclusive alternatives using the TOR technique, the procedure to be followed can be outlined as follows:

- Identify all candidate alternatives in increasing order of investment cost.
- Compute the Pay off Period of each alternative by itself (termed as $TOR_{absolute}$)
- Eliminate from further consideration these alternatives, whose $TOR_{absolute}$ is more than the service life. For those alternatives, the safety benefits are not high enough to pay for their cost within the project life, and hence become a "liability" to the tax-payer beyond the service life.
- Realign the remaining alternatives (termed viable alternatives) in increasing order of their investment cost.
- Use the "Defender Challenge" technique, where the incremental cost, associated with increasingly higher-cost projects are to be evaluated 'pair-wise,' relative to the incremental benefits generated. For each comparison pair, the Pay-off Period, needed to pay for the incremental cost by way of the incremental benefits generated (termed as the $TOR_{marginal}$) is to be computed. The higher investment cost project is justified if the PP marginal is less than the service life. Otherwise, the higher-investment project is to be eliminated.
- This process is to be continued until the last alternative (i.e. the highest-cost investment) is analyzed.
- Select the alternative with the highest investment cost for which
    - $(TOR)_{absolute}$ < Service life
    - $(TOR)_{marginal}$ < Service

Table 6.9 and 6.10 show the proposed data collection formats for the suggested methodology.

Table 6.8: Poisson Evaluation and Savings in Crash Cost

POISSON EVALUATION AND SAVINGS IN CRASH COST																				
1		**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
		Fatality						**Injury**						**PDO**						Total Savings
Site Number	Alternative	Before Period Crashes (B)	After Period Crashes (A)	(B-A)	% Change (B-A)/B	Significance (Poisson Curves)	Savings in Crash Cost (Source: NSC)	Before Period Crashes (B)	After Period Crashes (A)	(B-A)	% Change (B-A)/B	Significance (Poisson Curves)	Savings in Crash Cost (Source: NSC)	Before Period Crashes (B)	After Period Crashes (A)	(B-A)	% Change (B-A)/B	Significance (Poisson Curves)	Savings in Crash Cost (Source: NSC)	(4)*(7) + (10)*(13) + (16)*19
1	A-1																			
	A-2																			
	A-3																			
	.																			
	A-k																			
2	A-1																			
	A-2																			
	A-3																			
	.																			
	A-k																			
.																				
.																				
k																				
Total																				

Comments

Significance Setup Criteria for Poisson Test__________

Crash Cost for Fatality, (NSC)__________

Crash Cost for Injury, (NSC)__________

Crash Cost for PDO, (NSC)__________

Table 6.9: Economic Analysis Database

INFORMATION FOR ECONOMIC ANALYSIS	
Site Number ____________	Base Year ____________
Alternative Number ____________	Analysis Period ____________
Analysis Year ____________	Vest Charge ____________

ECONOMIC ANALYSIS SPREADSHEET							
1	2	3	4	5	6	7	8
Year	**Cost Component**				**Benefit Components**		**Net Benefits**
	Planning and Design Cost	Initial Investment Cost	Periodic Cost	Total Cost	Crash Cost Savings	Salvage Value	Crash Cost Savings Only (6)+(7)-(5)

MOE	
TOR	

Comments ____

____

Table 6.10: Incremental Analysis

Incremental Analysis					
Site Number	Alternative Number	TOR_{abs}	TOR_{mar}	Service Life	Conclusion
1	A-1				
	A-2				
	A-3				
	.				
	A-k				
2	A-1				
	A-2				
	A-3				
	.				
	A-k				
.					
.					
N	A-1				
	A-2				
	A-3				
	.				
	A-k				
Comments					

Project Implementation

The last step in the safety improvement program is the implementation of projects at different sites, as discussed in the earlier steps. For the economic analysis procedure, it has been assumed that the project implementation will take approximately one year. It is extremely important that actual crash data be collected for a sustained period, a minimum of three years, following the project implementation with three broad objectives:

- To assess if there has been an actual reduction in the number and severity of crashes resulting from the project and if the amount of reduction is statistically significant based upon the Poisson procedure discussed earlier
- To assess how closely the actual reduction in crashes, if any, matches the expected reduction based upon the use of the CRF values used in the analysis.
- To generate a new set of countermeasures and specific CRF values, if possible.

Reference:

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2. “Highway Safety Evaluation: A procedural guide”, FHWA-TS-81-219. National Highway Institute, Federal Highway Administration, Prepared by Goodell-Grivas Inc. November, 1981.
3. “Highway Safety Improvement Program (HSIP)” User’s Manual. FHWA-TS-81-218. National Highway Institute, Federal Highway Administration, Prepared by Goodell-Grivas Inc. January 1981.
4. World Road Association “Road Safety Manual”, Recommendation from PIARC, 2003
5. Khasnabis, S., Safi, C. and Mishra, S. “ Safety Improvements for Urban Arterials”, Draft report prepared for Michigan Department of Transportation by Wayne State University, September, 2006.

APPENDIX-A

SAFETY IMPROVEMENT PROJECTS AND RESPECTIVE CRASH REDUCTION FACTORS

Table A. 1: Crash Reduction Factors For Adding Acceleration / Deceleration Lane

CRASH TYPE	CRASH REDUCTION FACTORS (%)								
	REF-1	REF-10	REF-15	REF-17	REF-20	REF-21	REF-25	REF-26	REF-31
HEAD ON									
REAR END									
RIGHT ANGLE	75								
RUN OFF ROAD									
SIDE SWIPE	75								
PEDESTRIAN									
PDO									
INJURY									
FATALITY									
ALL	75	25	10	10	10	10	10	10	10

Table A. 2: Crash Reduction Factors For Adding All-Red Interval

CRASH TYPE	CRASH REDUCTION FACTORS (%)					
	REF-11	REF-15	REF-17	REF-20	REF-25	REF-30
HEAD ON						
REAR END	1-30			30		
RIGHT ANGLE						
RUN OFF ROAD						
SIDE SWIPE						
RIGHT TURN						
PDO						
INJURY						
FATALITY						
ALL	4-31	15	15MI	15	30	15

Table A. 3: Crash Reduction Factors For Adding Centerline Markings

CRASH TYPE	CRASH REDUCTION FACTORS (%)					
	REF-15	REF-17	REF-20	REF-26	REF-30	REF-31
HEAD ON						
REAR END						
RIGHT ANGLE						
RUN OFF ROAD						
SIDE SWIPE						
RIGHT TURN						
PDO						
INJURY						
FATALITY						
ALL	35	30	35	30	35	65

Table A. 4: Crash Reduction Factors For Adding Edge Line Markings

CRASH TYPE	CRASH REDUCTION FACTORS (%)								
	REF-3	REF-10	REF-15	REF-17	REF-20	REF-23	REF-24	REF-26	REF-31
HEAD ON						50	45		
REAR END									
RIGHT ANGLE									
RUN OFF ROAD						50	45		
PEDESTRIAN	30		30		30				
RIGHT TURN						59	66		
PDO									
INJURY					8				
FATALITY					15				
ALL	30	4	15	15	15	38	44	15	25

Table A. 5: Crash Reduction Factors For Adding Exclusive Left-Turn Phase (Protected)

CRASH TYPE	CRASH REDUCTION FACTORS (%)										
	REF-3	REF-11	REF-15	REF-17	REF-20	REF-21	REF-23	REF-24	REF-25	REF-31	REF-30
HEAD ON							35	27			
REAR END							56	54			
RIGHT ANGLE	80										
RUN OFF ROAD											
SIDE SWIPE	35	63-70	70	85	70		46	41	70		
PEDESTRIAN							35	27			
PDO											
INJURY											
FATALITY											
ALL	15	23-48	25	25	25	30	36	30	25	25	25

Table A. 6: Crash Reduction Factors For Adding Lane General

CRASH TYPE	CRASH REDUCTION FACTORS (%)													
	REF-3	REF-13	REF-10	REF-20	REF-21	REF-23	REF-24	REF-17	REF-15	REF-12	REF-25	REF-31	REF-18	REF-19
HEAD ON	53			53		44							97	38
REAR END	32			32		52	42						53	53
RIGHT ANGLE						45	35						15	46
RUN OFF ROAD	44			44									26	50
SIDE SWIPE									50			24	71	67
PEDESTRIAN														
PDO				27										
INJURY				23										
FATALITY				39										
ALL	25	25	10	25	20	31	20	30	25	24-42	25	41		

Table A. 7: Crash Reduction Factors For Adding Reflectorized Raised Pavement Markings

CRASH TYPE	CRASH REDUCTION FACTORS (%)						
	REF-3	REF-10	REF-20	REF-32	REF-15	REF-17	REF-11
HEAD ON							
REAR END							
RIGHT ANGLE	13		20				
RUN OFF ROAD							
SIDE SWIPE							
RIGHT TURN	10						
PDO	12		20				
INJURY							
FATALITY							
ALL	11	4	10	16	10	5	6-13

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Table A. 8: Crash Reduction Factors For Adding Right Turn Lane

CRASH TYPE	CRASH REDUCTION FACTORS (%)						
	REF-15	REF-20	REF-21	REF-26	REF-12	REF-17	REF-5
HEAD ON							
REAR END						65	
RIGHT ANGLE				50			
RUN OFF ROAD							
SIDE SWIPE						20	
RIGHT TURN	50	50				56	
PDO							
INJURY							
FATALITY							
ALL	25	25	25	25	14-27		30

Table A. 9: Crash Reduction Factors For Advance Warning Signs And Flashing Beacon

CRASH TYPE	CRASH REDUCTION FACTORS (%)							
	REF-18	REF-19	REF-20	REF-15	REF-31	REF-26	REF-23	REF-27
HEAD ON	67							
REAR END		16						
RIGHT ANGLE	73	62						
RUN OFF ROAD	40	54						
SIDE SWIPE	33	83						
LEFT TURN	67	79						
PDO								
INJURY								50
FATALITY								
ALL			35	35	50	35	26	

Table A. 10: Crash Reduction Factors For Attaining Progression

CRASH TYPE	CRASH REDUCTION FACTORS (%)				
	REF-15	REF-30	REF-31	REF-25	REF-11
HEAD ON					
REAR END					25-38
RIGHT ANGLE					
RUN OFF ROAD					
SIDE SWIPE					
LEFT TURN					
PDO					
INJURY					
FATALITY					
ALL	15	10	10	15	15-17

Table A. 11: Crash Reduction Factors For Change In Signal Operation, From Pre-Timed To Traffic Actuated

CRASH TYPE	CRASH REDUCTION FACTORS (%)						
	REF-23	REF-24	REF-25	REF-30	REF-17	REF-15	REF-31
HEAD ON	26	53					
REAR END	32	41					
RIGHT ANGLE	26	53					
RUN OFF ROAD							
SIDE SWIPE	30						
LEFT TURN							
PDO	60	81					
INJURY							
FATALITY							
ALL	28	39	20	20	20	22	22

Table A. 12: Crash Reduction Factors For Change To All-Way Stop Sign From Two-Way Stop Sign

CRASH TYPE	CRASH REDUCTION FACTORS (%)								
	REF-5	REF-15	REF-20	REF-21	REF-17	REF-11	REF-31	REF-23	REF-30
HEAD ON			13						
REAR END			72			84			
RIGHT ANGLE									
RUN OFF ROAD									
SIDE SWIPE			20						
LEFT TURN			39						
PDO									
INJURY									
FATALITY									
ALL	50	55	55	53	50	53-74	20	73	50

Table A. 13: CRASH REDUCTION FACTORS FOR CHANNELIZATION INTERSECTION

CRASH TYPE	CRASH REDUCTION FACTORS (%)									
	REF-10	REF-17	REF-20	REF-21	REF-26	REF-23	REF-24	REF-25	REF-18	REF-19
HEAD ON									25	50
REAR END						30	53			
RIGHT ANGLE						58	48			
RUN OFF ROAD										
SIDE SWIPE									28	
LEFT TURN			45							
PDO										
INJURY										
FATALITY										
ALL	17	25	25	27	25	37	35	25		

Table A. 14: Crash Reduction Factors For Construct Interchange

CRASH TYPE	CRASH REDUCTION FACTORS (%)				
	REF-1	REF-15	REF-17	REF-20	REF-31
HEAD ON					
REAR END					
RIGHT ANGLE					
RUN OFF ROAD					
SIDE SWIPE					
PEDESTRIAN					
PDO					
INJURY					
FATALITY					
ALL	60	55	40	55	55

Table A. 15.Crash Reduction Factors For Flatten Side-Slope (General)

CRASH TYPE	CRASH REDUCTION FACTORS (%)						
	REF-13	REF-15	REF-21	REF-23	REF-24	REF-26	REF-17
HEAD ON							
REAR END							
RIGHT ANGLE							
RUN OFF ROAD							
SIDESWIPE							
LEFT TURN				62	62		
PDO							
INJURY							
FATALITY							
ALL	25	30	32	45	43	30	15

Table A. 16: Crash Reduction Factors For Flatter Grade (Vertical Curve)

CRASH TYPE	CRASH REDUCTION FACTORS (%)			
	REF-3	REF-21	REF-31	REF-26
HEAD ON				
REAR END				
RIGHT ANGLE				
RUN OFF ROAD	30			
SIDE SWIPE				
LEFT TURN				
PDO	20			
INJURY	15			
FATALITY	30			
ALL	40	32	46	30

Table A. 17. Crash Reduction Factors For Horozonal Alignment Changes (General)

CRASH TYPE	CRASH REDUCTION FACTORS (%)			
	REF-13	REF-23	REF-24	REF-33
HEAD ON		64	67	
REAR END		24	73	
FIXED OBJECT		87	68	
RUN OFF ROAD				
SIDE SWIPE				
LEFT TURN				
PDO				87
INJURY				87
FATALITY				87
ALL	35	41	59	

Table A. 18: Crash Reduction Factors For Improvement Horizontal And Vertical Curve

CRASH TYPE	CRASH REDUCTION FACTORS (%)						
	REF-5	REF-13	REF-15	REF-20	REF-17	REF-23	REF-30
HEAD ON							
REAR END							
FIXED OBJECT							
RUN OFF ROAD							
SIDE SWIPE							
LEFT TURN							
PDO							
INJURY							
FATALITY							
ALL	50	73	50	50	50	21	50

Table A. 19: Crash Reduction Factors For Improvement Of Signal Timing (General)

CRASH TYPE	CRASH REDUCTION FACTORS (%)						
	REF-15	REF-20	REF-17	REF-23	REF-25	REF-300	REF-11
HEAD ON							
REAR END							
RIGHT ANGLE							
RUN OFF ROAD							
SIDE SWIPE							
PEDESTRIAN							
PDO							
INJURY							
FATALITY							
ALL	10	10	10	19	10	10	10-15

Table A. 20: Crash Reduction Factors For Improvement Of Vertical Alignment (General)

CRASH TYPE	CRASH REDUCTION FACTORS (%)			
	REF-17	REF-15	REF-30	REF-33
HEAD ON				
REAR END				
FIXED OBJECT				
RUN OFF ROAD				
SIDE SWIPE				
LEFT TURN				
PDO				87
INJURY				87
FATALITY				83
ALL	45	40	40	

Table A. 21: Crash Reduction Factors For Improvement Of Yellow Change Interval

CRASH TYPE	CRASH REDUCTION FACTORS (%)					
	REF-15	REF-20	REF-17	REF-30	REF-25	REF-12
HEAD ON						
REAR END	30	30			30	4-31
RIGHT ANGLE						
RUN OFF ROAD						
SIDE SWIPE						
RIGHT TURN						
PDO						
INJURY						
FATALITY						
ALL	15	15	15	15	15	

Table A. 22: Crash Reduction Factors For Improving Pavement Condition

CRASH TYPE	CRASH REDUCTION FACTORS (%)									
	REF-13	REF-5	REF-15	REF-20	REF-23	REF-24	REF-17	REF-30	REF-25	REF-11
WET PAVEMENT			60	60	54	64	55			42-75
OVER TURN					35	54				
RIGHT ANGLE										
RUN OFF ROAD					40	41				
SIDE SWIPE										
FIXED OBJECT					19	30				
PDO										
INJURY										
FATALITY										
ALL	14	10	25	25	21	37	15	25	14	

Table A. 23. Crash Reduction Factors For Improving Sight Distance

CRASH TYPE	CRASH REDUCTION FACTORS (%)											
	REF-15	REF-20	REF-13	REF-17	REF-1	REF-23	REF-30	REF-31	REF-5	REF-2	REF-18	REF-19
HEAD ON										10		
REAR END		21								21		70
RIGHT ANGLE												
RUN OFF ROAD											100	100
SIDE SWIPE		10			75							
LEFT TURN		13								13		
PDO		10			75						100	
INJURY												
FATALITY												
ALL	30	30	35	30	75	31	45	32	20	7		

Table A. 24: Crash Reduction Factors For Increase In Lane Width

CRASH TYPE	CRASH REDUCTION FACTORS (%)										
	REF-3	REF-33	REF-17	REF-31	REF-20	REF-23	REF-5	REF-15	REF-21	REF-30	REF-25
HEAD ON	70		5								
REAR END											
RIGHT ANGLE											
RUN OFF ROAD	49										
SIDE SWIPE	52		5								
LEFT TURN						69					
PDO		50									25
INJURY		50									15
FATALITY		50									40
ALL	56			12	25	17	20	20	32	15	28

Table A. 25: Crash Reduction Factors For Increase Turn Lane Length

CRASH TYPE	CRASH REDUCTION FACTORS (%)						
	REF-15	REF-20	REF-21	REF-23	REF-26	REF-24	REF-11
HEAD ON							
REAR END							
RIGHT ANGLE							
RUN OFF ROAD							
SIDE SWIPE							
LEFT TURN							
PDO							
INJURY							
FATALITY							
ALL	15	15	40	40	15	24	15-30

Table A. 26: Crash Reduction Factors For Increase Turning Radius

CRASH TYPE	CRASH REDUCTION FACTORS (%)						
	REF-15	REF-20	REF-21	REF-17	REF-30	REF-25	REF-12
HEAD ON							
REAR END				15			
RIGHT ANGLE							
RUN OFF ROAD							
SIDE SWIPE				15			
PEDESTRIAN							
PDO							
INJURY							
FATALITY							
ALL	15	15	10	15	15	15	15-21

Table A. 27: Crash Reduction Factors For Installation Of 12-Inch Lenses

CRASH TYPE	CRASH REDUCTION FACTORS (%)					
	REF-15	REF-20	REF-26	REF-17	REF-30	REF-11
HEAD ON						
REAR END						48
RIGHT ANGLE						
RUN OFF ROAD						
SIDE SWIPE						
LEFT TURN						
PDO						
INJURY						
FATALITY						
ALL	10	10	10	10	10	10-12

Table A. 28: Crash Reduction Factors For Installation Of Guardrail At Bridge

CRASH TYPE	CRASH REDUCTION FACTORS (%)					
	REF-21	REF-23	REF-24	REF-13	REF-3	REF-20
HEAD ON						
REAR END		32	37			
RIGHT ANGLE						
RUN OFF ROAD						
SIDE SWIPE						
PEDESTRIAN						
PDO						
INJURY						45
FATALITY						90
ALL	44	20	22	24	11	

Table A. 29: Crash Reduction Factors For Install Median Barrier (General)

CRASH TYPE	CRASH REDUCTION FACTORS (%)									
	REF-3	REF-5	REF-20	REF-23	REF-24	REF-26	REF-15	REF-11	REF-30	REF-31
HEAD ON										
REAR END										
RIGHT ANGLE				54	58					
RUN OFF ROAD	35		35							
SIDE SWIPE										
PEDESTRIAN								68		
PDO										
INJURY			65							
FATALITY			40							
ALL	36	20	5	19	19	15	25	25	25	25

Table A. 30: Crash Reduction Factors For Installation Of Optically Programmed Signal Lenses

CRASH TYPE	CRASH REDUCTION FACTORS (%)			
	REF-15	REF-20	REF-25	REF-11
HEAD ON		10		
REAR END		10		
RIGHT ANGLE		10		
RUN OFF ROAD				
SIDE SWIPE				
LEFT TURN				
PDO		20		
INJURY				
FATALITY				
ALL	15	15	20	15-18

Table A. 31: Crash Reduction Factors For Installation Of Rumble Strips

CRASH TYPE	CRASH REDUCTION FACTORS (%)							
	REF-3	REF-15	REF-20	REF-21	REF-18	REF-19	REF-1	REF-5
HEAD ON	80				75	100		
REAR END					50			
RIGHT ANGLE					54	47		
RUN OFF ROAD	54					50	50	50
SIDESWIPE					100			
LEFT TURN					33	60		
PDO								
INJURY								
FATALITY								
ALL	53	25	25	18				

Table A. 32: Crash Reduction Factors For Installation Of School Zone Signs

CRASH TYPE	CRASH REDUCTION FACTORS (%)				
	REF-15	REF-26	REF-20	REF-21	REF-31
HEAD ON					
REAR END					
RIGHT ANGLE					
RUN OFF ROAD					
SIDE SWIPE					
RIGHT TURN					
PDO					
INJURY					
FATALITY					
ALL	15	15	15	20	20

Table A. 33: Crash Reduction Factors For Installation Of Signal (General)

CRASH TYPE	CRASH REDUCTION FACTORS (%)													
	REF-5	REF-13	REF-10	REF-15	REF-20	REF-26	REF-23	REF-24	REF-17	REF-30	REF-25	REF-11	REF-18	REF-19
HEAD ON													97	38
REAR END							20	22						
RIGHT ANGLE				65	65	65	43	74			65		60	42
RUN OFF ROAD							20	22						
SIDE SWIPE														
LEFT TURN														
PDO											23	36		
INJURY											23	29)		
FATALITY														
ALL	15	20	13	25	25	20	20	38	20	20	22	45)		

Table A. 34: Crash Reduction Factors For Installation Of Stop Ahead Sign

CRASH TYPE	CRASH REDUCTION FACTORS (%)					
	REF-23	REF-17	REF-15	REF-25	REF-31	REF-30
HEAD ON						
REAR END						
RIGHT ANGLE						
RUN OFF ROAD						
SIDE SWIPE						
RIGHT TURN						
PDO						
INJURY						
FATALITY						
ALL	15	30	30	300	20	30

Table A. 35: Crash Reduction Factors For Installation Of Two-Way Left-Turn Lane In Median

CRASH TYPE	CRASH REDUCTION FACTORS (%)													
	REF-5	REF-15	REF-20	REF-26	REF-21	REF-3	REF-23	REF-17	REF-11	REF-30	REF-31	REF-25	REF-18	REF-19
HEAD ON														
REAR END			36			36							32	32
RIGHT ANGLE								20					31	23
RUN OFF ROAD														
SIDE SWIPE													32	37
LEFT TURN			33			33							17	38
PDO			35											
INJURY			20											
FATALITY														
ALL	25	30	35	25	34	30	24	30	30-40	35	40	30		

Table A. 36: Crash Reduction Factors For Installation Of Variable Message Sign

CRASH TYPE	CRASH REDUCTION FACTORS (%)					
	REF-15	REF-20	REF-26	REF-17	REF-30	REF-31
HEAD ON						
REAR END						
RIGHT ANGLE						
RUN OFF ROAD						
SIDESWIPE						
LEFT TURN						
PDO						
INJURY						
FATALITY						
ALL	15	15	15	15	15	20

Table A. 37: Crash Reduction Factors For Installation Of Visors Or Back-Plates

CRASH TYPE	CRASH REDUCTION FACTORS (%)				
	REF-15	REF-30	REF-11	REF-20	REF-25
HEAD ON					
REAR END	20		7-93	20	20
RIGHT ANGLE					
RUN OFF ROAD					
SIDE SWIPE					
LEFT TURN					
PDO					
INJURY					
FATALITY					
ALL	20	20	2-24		

Table A. 38: Crash Reduction Factors For Installation Of Warning Signs In Advance Of Curves

CRASH TYPE	CRASH REDUCTION FACTORS (%)							
	REF-20	REF-21	REF-13	REF-17	REF-23	REF-15	REF-31	REF-30
HEAD ON								
REAR END								
RIGHT ANGLE								
RUN OFF ROAD								
SIDE SWIPE								
RIGHT TURN	30					30		
PDO	29							
INJURY	20							
FATALITY	55							
ALL	30	23	29	30	54	30	20	30

Table A. 39: Crash Reduction Factors For Installation Of Yield Sign

CRASH TYPE	CRASH REDUCTION FACTORS (%)				
	REF-20	REF-1	REF-23	REF-17	REF-2
HEAD ON					
REAR END					43
RIGHT ANGLE					
RUN OFF ROAD					
SIDE SWIPE					
LEFT TURN					
PDO					
INJURY					
FATALITY					
ALL	45	25	23	50	

Table A. 40: Crash Reduction Factors For Installation Of Proper Signs

CRASH TYPE	CRASH REDUCTION FACTORS (%)					
	REF-3	REF-5	REF-10	REF-23	REF-24	REF-26
HEAD ON						
REAR END						
RIGHT ANGLE						
RUN OFF ROAD	100					
SIDE SWIPE						
LEFT TURN				24	34	
PDO						
INJURY						
FATALITY						
ALL	10	5	15	13	28	20

Table A. 41: Crash Reduction Factors For Installation Of Improvement Roadway Lighting

CRASH TYPE	CRASH REDUCTION FACTORS (%)						
	REF-13	REF-15	REF-20	REF-17	REF-11	REF-26	REF-1
HEAD ON							
REAR END							
RIGHT ANGLE							
RUN OFF ROAD							
SIDESWIPE							
NIGHT TIME CRASHES		45	45	50	42-50	45	20
PDO							
INJURY							
FATALITY							
ALL	20	25	25	25	25-50		

Table A. 42: Crash Reduction Factors For Installation Of Raised Median Near Intersection

CRASH TYPE	CRASH REDUCTION FACTORS (%)											
	REF-3	REF-5	REF-21	REF-20	REF-23	REF-26	REF-15	REF-11	REF-30	REF-31	REF-1	REF-24
HEAD ON											75	
REAR END												
RIGHT ANGLE					54							58
RUN OFF ROAD	35			35								
SIDE SWIPE												
LEFT TURN												
PDO												
INJURY				40								
FATALITY				65								
ALL	36	20	25	5	19	15	25	25	25	25		19

Table A. 43: Crash Reduction Factors For Installation Of Red Light Running Cameras And Its Warnings Signs

CRASH TYPE	CRASH REDUCTION FACTORS (%)			
	REF-22	REF-31	REF-33	REF-12
HEAD ON				
REAR END				
RIGHT ANGLE	16			
RUN OFF ROAD				
SIDE SWIPE				
LEFT TURN				
PDO				
INJURY	16	29	20-33	
FATALITY				
ALL	9	32	24-33	20-30

Table A. 44: Crash Reduction Factors For Installation Of Actuated Signal Control

CRASH TYPE	CRASH REDUCTION FACTORS (%)						
	REF-23	REF-24	REF-30	REF-26	REF-17	REF-15	REF-31
HEAD ON	60	81					
REAR END	26	53					
RIGHT ANGLE	32	41					
RUN OFF ROAD							
SIDE SWIPE	26	53					
LEFT TURN	30						
PDO							
INJURY							
FATALITY							
ALL	28	39	20	25	20	22	22

Table A. 45: Crash Reduction Factors For Intersection Lighting

CRASH TYPE	CRASH REDUCTION FACTORS (%)							
	REF-15	REF-5	REF-20	REF-17	REF-24	REF-30	REF-11	REF-31
HEAD ON								
REAR END								
RIGHT ANGLE								
RUN OFF ROAD								
SIDE SWIPE								
NIGHT TIME	50	67	50	55			10-70	75
PDO								
INJURY								
FATALITY								
ALL	30	36	30	25	36	30	19-75	

Table A. 46: Crash Reduction Factors For Left Turn Protected Only From Protected/Permissive

CRASH TYPE	CRASH REDUCTION FACTORS (%)										
	REF-15	REF-20	REF-21	REF-17	REF-25	REF-23	REF-24	REF-31	REF-11	REF-2	REF-30
HEAD ON											
REAR END						35	27				
RIGHT ANGLE						56	54				
RUN OFF ROAD											
SIDE SWIPE											
LEFT TURN	70	70		85	70	46	41		63-70	35	
PDO											
INJURY											
FATALITY											
ALL	25	25	30	25	25	36	30	25	23-48	15	25

Table A. 47: Crash Reduction Factors For Modification In Signal Phasing

CRASH TYPE	CRASH REDUCTION FACTORS (%)					
	REF-15	REF-20	REF-30	REF-18	REF-19	REF-26
HEAD ON				75		
REAR END					17	
RIGHT ANGLE				30	46	
RUN OFF ROAD				62	28	
SIDE SWIPE						
LEFT TURN				55	63	75
PDO						
INJURY						
FATALITY						
ALL	25	25	25			

Table A. 48: Crash Reduction Factors For Modification Of Entrance / Exit Ramp

CRASH TYPE	CRASH REDUCTION FACTORS (%)				
	REF-15	REF-20	REF-17	REF-23	REF-21
HEAD ON					
REAR END					
RIGHT ANGLE					
RUN OFF ROAD					
SIDE SWIPE					
PEDESTRIAN					
PDO					
INJURY					
FATALITY					
ALL	25	25	25	25	40

Table A. 49: Crash Reduction Factors For Offset Opposing Left Turn Lane

CRASH TYPE	CRASH REDUCTION FACTORS (%)		
	REF-15	REF-23	REF-30
HEAD ON			
REAR END			
RIGHT TURN			
RUN OFF ROAD			
SIDE SWIPE			
LEFT TURN			
PDO			
INJURY			
FATALITY			
ALL	25	24	25

Table A. 50: Crash Reduction Factors For Pavement Markings

CRASH TYPE	CRASH REDUCTION FACTORS (%)						
	REF-3	REF-5	REF-20	REF-15	REF-21	REF-26	REF-13
HEAD ON							
REAR END	58						
RIGHT ANGLE							
RUN OFF ROAD	22						
SIDE SWIPE							
LEFT TURN							
PDO							
INJURY							
FATALITY							
ALL	48	5	13	15	20	35	25

Table A. 51: Crash Reduction Factors For Prohibiting Left Turns

CRASH TYPE	CRASH REDUCTION FACTORS (%)					
	REF-25	REF-31	REF-15	REF-17	REF-30	REF-20
HEAD ON						
REAR END						30
RIGHT ANGLE						
RUN OFF ROAD						
SIDE SWIPE						
LEFT TURN						90
PDO						
INJURY						
FATALITY						
ALL	40	40	45	40	45	45

Table A. 52: Crash Reduction Factors For Prohibiting On Street Parking

CRASH TYPE	CRASH REDUCTION FACTORS (%)								
	REF-15	REF-20	REF-10	REF-17	REF-11	REF-23	REF-24	REF-31	REF-25
HEAD ON									
REAR END		10							
RIGHT ANGLE		10							
RUN OFF ROAD									
SIDE SWIPE		30							
FIXED OBJECT		40							
PDO									
INJURY									
FATALITY									
ALL	35	35	8	30	8-90	32	30	32	35

Table A. 53: Crash Reduction Factors For Prohibiting Right Turn On Red

CRASH TYPE	CRASH REDUCTION FACTORS (%)			
	REF-15	REF-30	REF-11	REF-20
HEAD ON				
REAR END				30
RIGHT ANGLE				20
RUN OFF ROAD				30
SIDE SWIPE				30
LEFT TURN				
PDO				
INJURY				
FATALITY				
ALL	45	45	20-25	

Table A. 54: Crash Reduction Factors For Protected Permissive Left Turn Phase Addition

CRASH TYPE	CRASH REDUCTION FACTORS (%)				
	REF-15	REF-20	REF-17	REF-11	REF-26
HEAD ON					
REAR END					
RIGHT ANGLE					
RUN OFF ROAD					
SIDESWIPE					
LEFT TURN	40	40	40	40-64	40
PDO					
INJURY					
FATALITY					
ALL	10	10	10	4-10	

Table A. 55: Crash Reduction Factors For Provide Left-Turn Lane (With Signal)

CRASH TYPE	CRASH REDUCTION FACTORS (%)						
	REF-15	REF-20	REF-21	REF-26	REF-24	REF-17	REF-11
HEAD ON							
REAR END					79		
RIGHT TURN	45	50		45	24		
RUN OFF ROAD							
SIDE SWIPE							
LEFT TURN							
PDO							
INJURY							
FATALITY							
ALL	25	25	28	30	19	30	28-42

Table A. 56: Crash Reduction Factors For Provide Left-Turn Lane (Without Signal)

CRASH TYPE	CRASH REDUCTION FACTORS (%)							
	REF-5	REF-15	REF-20	REF-21	REF-26	REF-24	REF-17	REF-11
HEAD ON								
REAR END								
RIGHT TURN								
RUN OFF ROAD								
SIDE SWIPE		50			55	35		
LEFT TURN								
PDO								
INJURY								
FATALITY								
ALL	35	35	35	25	40	45	30	25-41

Table A. 57: Crash Reduction Factors For Realignment (General)

CRASH TYPE	CRASH REDUCTION FACTORS (%)			
	REF-5	REF-17	REF-15	REF-30
HEAD ON				
REAR END				
RIGHT ANGLE				
RUN OFF ROAD				
SIDE SWIPE				
LEFT TURN				
PDO				
INJURY				
FATALITY				
ALL	50	40	40	40

Table A. 58: Crash Reduction Factors For Reconstruction Curve

CRASH TYPE	CRASH REDUCTION FACTORS (%)				
	REF-17	REF-15	REF-11	REF-31	REF-30
HEAD ON					
REAR END					
RIGHT ANGLE					
RUN OFF ROAD					
SIDE SWIPE					
LEFT TURN					
PDO					
INJURY					
FATALITY					
ALL	50	40	40-50	50	45

Table A. 59: Crash Reduction Factors For Reduction In Speed Limit

CRASH TYPE	CRASH REDUCTION FACTORS (%)				
	REF-15	REF-20	REF-21	REF-30	REF-25
HEAD ON					
REAR END					
RIGHT ANGLE					
RUN OFF ROAD					
SIDE SWIPE					
LEFT TURN					
PDO		35			35
INJURY					
FATALITY					
ALL	20	20	36	20	20

Table A. 60: Crash Reduction Factors For Relocating Fixed Objects

CRASH TYPE	CRASH REDUCTION FACTORS (%)				
	REF-15	REF-20	REF-17	REF-26	REF-1
HEAD ON					
REAR END					
RIGHT ANGLE					
RUN OFF ROAD					
SIDESWIPE					
LEFT TURN					
PDO					90
INJURY	25	25	15		
FATALITY	40	40	40		
ALL	25	25	55	25	

Table A. 61: Crash Reduction Factors For Relocating Some Drive Ways

CRASH TYPE	CRASH REDUCTION FACTORS (%)			
	REF-26	REF-17	REF-31	REF-33
HEAD ON				
REAR END				
RIGHT ANGLE				
RUN OFF ROAD				
SIDE SWIPE				
LEFT TURN				
PDO				
INJURY				
FATALITY				
ALL	50	33	45	48

Table A. 62: Crash Reduction Factors For Removing Fixed Objects

CRASH TYPE	CRASH REDUCTION FACTORS (%)										
	REF-3	REF-5	REF-15	REF-20	REF-21	REF-23	REF-24	REF-26	REF-17	REF-25	REF-1
HEAD ON											
REAR END						44	42				
RIGHT ANGLE											
RUN OFF ROAD											
SIDESWIPE											
LEFT TURN									75		100
PDO											
INJURY			30	30					15	20	
FATALITY			50	50					50	66	
ALL	61	20	30	30	30	17	18	25			

Table A. 63: Crash Reduction Factors For Removing Unwarranted Signal

CRASH TYPE	CRASH REDUCTION FACTORS (%)						
	REF-3	REF-15	REF-20	REF-26	REF-25	REF-30	REF-11
HEAD ON							
REAR END							
RIGHT ANGLE							
RUN OFF ROAD							
SIDE SWIPE							
RIGHT TURN	100		90				
PDO							
INJURY							
FATALITY							
ALL	50	50	50	75	50	55	50-53

Table A. 64: Crash Reduction Factors For Roundabout

CRASH TYPE	CRASH REDUCTION FACTORS (%)							
	REF-22	REF-14	REF-2	REF-24	REF-16	REF-8	REF-29	REF-27
HEAD ON								
REAR END								
RIGHT ANGLE								
RUN OFF ROAD								
SIDE SWIPE								
PEDESTRIAN			10					
PDO						29		
INJURY	80		75	75	83	51	56	74
FATALITY			90	90			100	
ALL	40	76		39	64	37	70	35

Table A. 65: Crash Reduction Factors For Signal Progression (General)

CRASH TYPE	CRASH REDUCTION FACTORS (%)				
	REF-15	REF-30	REF-31	REF-25	REF-11
HEAD ON					
REAR END					
RIGHT ANGLE					
RUN OFF ROAD					
SIDE SWIPE					
RIGHT TURN					
PDO					
INJURY					
FATALITY					
ALL	15	10	10	15	15-17

Table A. 66: Crash Reduction Factors For Skid Treatment With Overlay

CRASH TYPE	CRASH REDUCTION FACTORS (%)			
	REF-23	REF-24	REF-18	REF-19
HEAD ON			12	21
REAR END	23	23)	11	31
RIGHT ANGLE	61	43	12	27
RUN OFF ROAD				
SIDE SWIPE			41	34
RIGHT TURN			34	43
PDO	61	43	19	30
INJURY				
FATALITY				
ALL	20	13		

Table A. 67: Crash Reduction Factors For Superelevation Correction

CRASH TYPE	CRASH REDUCTION FACTORS (%)					
	REF-15	REF-26	REF-17	REF-31	REF-30	REF-20
HEAD ON						
REAR END						
FIXED OBJECT						
RUN OFF ROAD						50
SIDE SWIPE						
LEFT TURN						
PDO						
INJURY						
FATALITY						
ALL	40	40	40	65	40	

Table A. 68: Crash Reduction Factors For Upgradation Of Guardrail

CRASH TYPE	CRASH REDUCTION FACTORS (%)							
	REF-3	REF-13	REF-10	REF-15	REF-20	REF-17	REF-23	REF-24
HEAD ON								
REAR END							27	41
RIGHT ANGLE								
RUN OFF ROAD	26				26		32	
SIDE SWIPE								
PEDESTRIAN								
PDO								
INJURY				40	40	35		
FATALITY				65	65	55		
ALL	19	16	4	5	5		9-31	

Table A. 69: Crash Reduction Factors For Upgradation Of Signal

CRASH TYPE	CRASH REDUCTION FACTORS (%)													
	REF-5	REF-13	REF-10	REF-15	REF-20	REF-21	REF-23	REF-24	REF-26	REF-32	REF-17	REF-14	REF-18	REF-19
HEAD ON							52	32					47	61
REAR END							26	41				39-41	22	32
RIGHT ANGLE							37	47)				36-74	29	32
RUN OFF ROAD							26							
SIDE SWIPE							52	32					50	28
LEFT TURN							26	38				12-15	27	21
PDO												47-51		
INJURY														
FATALITY												31-34		
ALL	15	15	11	20	20	22	19	37	20	62	20	43-49		

Table A. 70: Crash Reduction Factors For Upgrade Signals / Mast Arm Signal Installation

CRASH TYPE	CRASH REDUCTION FACTORS (%)											
	REF-11	REF-5	REF-15	REF-20	REF-21	REF-13	REF-26	REF-24	REF-23	REF-14	REF-18	REF-19
HEAD ON								32	57		47	61
REAR END								26	41	39-41	22	32
RIGHT ANGLE								37	47	36-74	29	32
RUN OFF ROAD											37	52
SIDE SWIPE								32	52		50	28
LEFT TURN								26	38	12-15	27	21
PDO										47-51		
INJURY										31-34		
FATALITY												
ALL	28-43	15	20	20	22	36	20	37	19	43-49		

Table A. 71: Crash Reduction Factors For Shoulder Widening

CRASH TYPE	CRASH REDUCTION FACTORS (%)										
	REF-5	REF-13	REF-3	REF-21	REF-17	REF-15	REF-23	REF-30	REF-31	REF-25	REF-33
HEAD ON			75		15						
REAR END											
RIGHT ANGLE											
RUN OFF ROAD			60								
SIDE SWIPE			41		15						
PEDESTRIAN											
PDO										12	50
INJURY										13	50
FATALITY										22	50
ALL	20	8	57	32	20	20	17	15	12	8	

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